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Pedestrian Injury Patterns and Risk in Minibus Collisions in China

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: The minibus, with a nearly flat front, is widely used in China, especially in the underdeveloped regions, and results in large numbers of pedestrian injuries and deaths. The purpose of this study was to determine the injury patterns and risk for pedestrians involved in these crashes.

Material/Methods: We conducted an in-depth investigation of minibus/pedestrian accidents in Chongqing, China, occurring between September 2000 and April 2014. The enrolled pedestrians was classified into 3 groups: young (aged 14–44 years), middle-aged (aged 45–59 years), and elderly (aged over 60 years). Pedestrian injuries were coded according to the Abbreviated Injury Scale (AIS).

Results: A total of 109 pedestrians, with an average age of 55.7±16.2 years, were injured or killed – 30.3% were young, 23.9% were middle-aged, and 45.9% were elderly. Pedestrians hit by a minibus had a high proportion of head, chest, and extremity injuries – 84.4%, 50.5%, and 52.3%, respectively. In addition, impact speeds in excess of 75 km/h all ultimately resulted in fatalities. At an impact speed of 30 km/h, the risk of pedestrian fatality and AIS3+ injury are approximately 12.0% and 37.2%, respectively. At 50 km/h the risks are 65.2% and 96.9%, respectively, and at 70 km/h the risks are 96.3% and 99.9%, respectively.

Conclusions: A higher likelihood of chest injury was associated with being older and impact speed of over 40 km/h in minibus/pedestrian collision. Our data suggest that the injury patterns of pedestrians in minibus collisions differ from that in other vehicle/pedestrian collisions. These findings could contribute to better understanding of the injury patterns and risk of pedestrian in minibus collisions in China, which may play an important role in developing measures to improve traffic safety.

MeSH Keywords: Accidents, Traffic • Risk Assessment • Wounds and Injuries

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Background

The extensive utilization of motor vehicles plays a very important role in the motorization process of developing countries [1]. However, traffic accidents have become one of the most severe problems which threaten public safety [2–4]. According to the latest statistics released by the World Health Organization [5] approximately 1.2 million people lost their lives on roads around the world each year, and more than 20 million had nonfatal injuries. Pedestrians, as the most vulnerable road users, suffered most of the deaths. The issue of pedestrian road safety is more serious in the low- and middle-income countries. Although it has attracted much attention from vehicle engineers and some steps have been taken to protect pedestrians, further efforts are needed to address this issue.

To date, the best solution to pedestrian safety is to take precautions. For this purpose it is valuable to fully characterize the vehicle/pedestrian crashes by means of accident investigation. The injury patterns and risk of adult and child pedestrians, bicyclists, and motorcyclists have been explored in recent years [6–9]. Some studies used logistic regression analysis [10–12]. Although many studies on vehicle/pedestrian accidents were performed, the vehicles were usually hood-fronted (as opposed to flat-fronted) vehicles such as passenger cars, SUVs, and MPVs [13–17]. Few studies have focused on pedestrian injury patterns and risk in minibus collisions.

In China, the minibus is categorized as a passenger car. It has 7–9 seats and is characterized by a box shape and a nearly flat front. With the advantage of low price and preferential government policies, the minibus is becoming more and more popular in recent years. Consequently, the number of accidents involving minibuses has increased significantly. According to the latest report by the Traffic Administration Bureau of Police Ministry [18], nearly 6865 people die and 35 000 people are injured annually in minibus accidents, which account for 10.0% of total deaths and 11.1% of injuries due to traffic accidents in China. Some previous studies that focused on the flat-fronted and box-shaped vehicles found that the injury patterns and injury mechanics differ from bonnet-front vehicle collisions [19–22]. Tanno et al. [23] suggested that flat-fronted vehicles were worse than the bonnet-front vehicles in causing chest injuries. Mizuno and Kajzer [24] demonstrated that pedestrian chest acceleration was higher in single-compartment vehicle collisions. However, these findings are country-specific, and are not exactly comparable to the actual situation in China. There is a little information for minibus/pedestrian accident investigations. Thus, a detailed study is needed to clearly understand the injury patterns and injury risk of pedestrians in minibus/pedestrian crashes.

The objective of this study was to analyze the injury patterns in minibus/pedestrian collisions in China, as well as to determine the pedestrian injury risk. An in-depth investigation of minibus/pedestrian collisions from September 2000 to April 2014 in Chongqing, China was conducted. The effects of person-, vehicle-, and environment-related factors were investigated and analyzed. We believe that our findings would be helpful to develop countermeasures to protect pedestrians in minibus/pedestrian collisions.

Material and Methods

Sampling scheme

Ethics approval for this research was obtained from the Research Ethics Committee of the Third Military Medical University. A team composed of researchers, engineers, and medical experts was formed to investigate the minibus/pedestrian crashes in Chongqing, in the southern part of China. This area is approximately 8.23 million square meters, and is a typical mountainous region. The team cooperated with the police departments and collected onsite minibus/pedestrian accident cases. The person- (injury outcome, age, others), environment- (on-site trace, collision point, end-position, others) and vehicle- (deformed mode, impact speed, others) related factors were collected in detail. The selected cases needed to fulfill the following criteria:

1. The vehicle involved in the pedestrian crash was a minibus.
2. The pedestrians were struck by the front of the minibus (Figure 1).
3. The accident documentation included comprehensive information, such as field sketches, photographs, police reports, and injury outcomes.
4. The pedestrians was older than 14 years of age, consistent with previous works [10,25,26].
5. The pedestrians who were in a sitting or crouching position were excluded and the pedestrians who were run over or involved in a second collision were also excluded.

Impact speed determination

Accurate estimation of impact speed is essential in deducing the pedestrian injury risk in minibus/pedestrian collisions. According to previous studies, the vehicle impact speed was mostly calculated from braking skid distance and distance the pedestrian was thrown [11,27]. If no skid marks or throwing distance was identified, accident reconstructions are helpful for impact speed estimation [15]. In addition, a new method to estimate impact speed based on surveillance videos was adopted in this study. A combination of the aforementioned methods was used for each case to avoid uncertainty. If the impact speed could not be determined, the case was rejected.

Figure 1. Minibus with front nearly perpendicular to the road.

Injury severity coding and statistical analysis

Each injured or killed pedestrian was classified into 1 of 3 groups: group I (young, 14–44 years), group II (middle-aged, 45–59 years), and group III (elderly, over 60 years), according to the most recent WHO guideline. Pedestrian injuries were coded according to the Abbreviated Injury Scale [28], which uses 1, 2, 3, 4, 5, and 6 to denote minor, moderate, serious, severe, critical, and untreated injury, respectively. Special care was taken in chest injuries examination. Pedestrian injury outcomes were divided into 3 groups: fatality, severe injury/non-fatal (MAIS≥3), and slight injury (MAIS<3). In order to clearly confirm the distribution of variables (e.g., accident data, weather, and road type), descriptive statistical analysis was performed. In addition, logistic regression analysis was applied to explore pedestrian injury risk and relative likelihood of having a chest injury versus having no chest injury. It was statistically significant when the p-value was lower than 0.05.

Results

Overall description

In general, 109 minibus/pedestrian crashes that met the selection criterion were chosen and investigated. The sample is consisted of 109 pedestrians (52 males, 57 females) aged 15–87 years with an average of 55.7±16.2 years, and included 57 fatalities (32 males, 25 females). The cumulative distribution of the pedestrian age was presented in Figure 2. The data illustrates that the highest proportion of pedestrians was in Group III (23.9% in Group I and 30.3% in Group II), which accounted for 45.9%. Table 1 shows the description of person-, vehicle-, environment-related factors among these three groups. Of
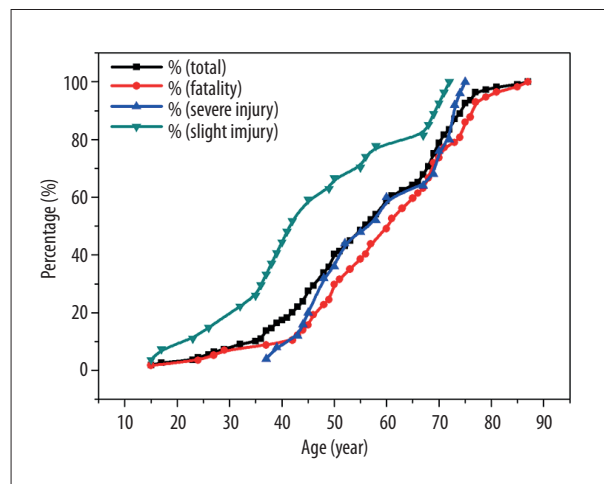
Figure 2. Cumulative distributions of age for the 109 pedestrians.

109 accident cases, the number of crashes occurred on sunny days accounts for 64.2%. In addition, 79.8% of the investigated minibuses were Changan brand. The data in Table 1 also demonstrates significant differences in injury outcome by age.

Injury patterns and impact speed

The pedestrian's head, chest and extremity were common localizations of wounds in this study, which accounts for 84.4%, 50.5% and 52.3% respectively. Other parts of body accounts for no more than 15%. The injury severity of head, chest and extremities in different age groups are shown in Table 2. However the proportion of head and thoracic AIS 3+ in different age groups suggests obvious trend toward high injury severity with increasing age. In addition, there exists a clear association between increases in chest AIS scores and more

Table 1. Study on person-, vehicle-, and environment-related variables among 3 age groups.

Variable	All n (%)		Group 1 (<44) n (%)		Group 1 (45–59) n (%)		Group 1 (>60) n (%)		P value
Gender									0.940
Male	52	(47.7%)	13	(50.0%)	15	(45.5%)	24	(48.0%)	
Female	57	(52.3%)	13	(50.0%)	18	(54.5%)	26	(52.0%)	
Injury outcome									0.002
Slight	27	(24.8%)	14	(53.8%)	7	(21.2%)	6	(12.0%)	
Severity	25	(22.9%)	4	(15.4%)	9	(27.3%)	12	(24.0%)	
Fatality	57	(52.3%)	8	(30.8%)	17	(51.5%)	32	(64.0%)	
Season									0.469
Spring	31	(28.4%)	7	(26.9%)	8	(24.2%)	16	(32.0%)	
Summer	15	(13.8%)	3	(11.5%)	2	(6.1%)	10	(20.0%)	
Autumn	27	(24.8%)	8	(30.8%)	9	(27.3%)	10	(20.0%)	
Winter	36	(33.0%)	8	(30.8%)	14	(42.2%)	14	(28.0%)	
Road type									0.125
Urban road	61	(56.0%)	19	(73.1%)	16	(48.5%)	26	(52.0%)	
Others	48	(44.0%)	7	(26.9%)	17	(51.5%)	24	(48.0%)	
Vehicle brand									0.873
Changan	87	(79.8%)	22	(84.6%)	27	(81.8%)	38	(76.0%)	
Dongfeng	8	(7.3%)	2	(7.7%)	2	(6.1%)	4	(8.0%)	
Others	14	(12.8%)	2	(7.7%)	4	(12.1%)	8	(16.0%)	
Weather									0.545
Sunny	70	(64.2%)	17	(65.4%)	22	(66.7%)	31	(62.0%)	
Rainy	14	(12.8%)	5	(19.2%)	2	(6.1%)	7	(14.0%)	
Others	25	(22.9%)	4	(15.4%)	9	(27.3%)	12	(24.0%)	
Lighting									0.065
Daytime	60	(55.0%)	10	(38.5%)	17	(51.5%)	33	(66.0%)	
Others	49	(45.0%)	7	(61.5%)	16	(48.5%)	17	(34.0%)	

Table 2. Statistics of pedestrian injury locations and severity.

Variable	All n (%)		Group 1 (<44) n (%)		Group 1 (45–59) n (%)		Group 1 (>60) n (%)		P value
Total MAIS									0.002
1–2	27	(24.8%)	14	(53.8%)	7	(21.2%)	6	(12.0%)	
3–4	24	(22.0%)	3	(11.5%)	8	(24.2%)	13	(26.0%)	
5–6	58	(53.2%)	9	(34.6%)	18	(54.5%)	31	(62.0%)	
Head MAIS									0.002
1–2	16	(14.7%)	7	(26.9%)	6	(18.2%)	3	(6.0%)	
3–4	18	(16.5%)	0	(0.0%)	7	(21.2%)	11	(22.0%)	
5–6	58	(53.2%)	10	(38.5%)	17	(51.5%)	31	(62.0%)	
No injury	17	(15.6%)	9	(34.6%)	3	(9.1%)	5	(10.0%)	
Thoracic MAIS									0.349
1–2	14	(12.8%)	5	(19.2%)	3	(9.1%)	6	(12.0%)	
3–4	40	(36.7%)	5	(19.2%)	13	(39.4%)	22	(44.0%)	
5–6	1	(0.9%)	0	(0.0%)	0	(0.0%)	1	(2.0%)	
No injury	54	(49.5%)	16	(61.5%)	17	(51.5%)	21	(42.0%)	
Extremities MAIS									0.771
1–2	53	(48.6%)	13	(50.0%)	16	(48.5%)	24	(48.0%)	
3–4	4	(3.7%)	0	(0.0%)	1	(3.0%)	3	(6.0%)	
5–6	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	
No injury	52	(47.7%)	13	(50.0%)	16	(48.5%)	23	(46.0%)	
Abdomen MAIS									0.151
1–2	4	(3.7%)	3	(11.5%)	1	(3.0%)	0	(0.0%)	
3–4	5	(4.6%)	1	(3.8%)	2	(6.1%)	2	(4.0%)	
5–6	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	
No injury	100	(91.7%)	22	(84.6%)	30	(90.9%)	48	(96.0%)	

Table 3. A comparison of injury pattern of minibus to those of other vehicles.

	Head (%)	Chest (%)	Extremities (%)	Other (%)
This study (Minibus)	84.4	50.5	52.3	≤9.3
Zhao et al. [17] (Passager car)	68.5	24.5	68.5	≤15.8
Tanno et al. [23] (Flat-front type)	69.7	30.3	60.6	≤21.2
Tanno et al. [23] (Bonnet-front type)	60.3	11.8	63.2	≤22.1
Chen et al. [29] (Sedan, SUV, 1-Box)	38.6	11.6	27.2	≤5.3

severe outcomes. The data in Table 3 demonstrates that the injury patterns of pedestrians in minibus collisions were different from that in other car-pedestrian collisions. The cumulative distribution of impact speeds was presented in Figure 3. The median and average impact speed were 45km/h and 48±19 km/h, whereas they were 60 km/h and 60±16 km/h for the fatalities. This indicates that the impact speed is of particular importance to predict pedestrian fatality risk.

Fitting of pedestrian injury risk models

Previous studies shows that pedestrian injury risk was positively correlated with vehicle impact speed and pedestrian age, and some pedestrian injury risk models were established [11,12]. In this study, the resulting fatality and AIS3+ risk functions were derived as follows; where v and age were impact speed in km/h and age in years respectively.

$$p_1(v) = \frac{1}{1+exp\,(-0.131v+5.924)} \tag{1}$$

$$p_1(v,age) = \frac{1}{1+exp\,(-0.138v-0.040age+8.508)} \tag{2}$$

$$p_2(v) = \frac{1}{1+exp\,(-0.198v+6.465)} \tag{3}$$

$$p_2(v,age) = \frac{1}{1+exp\,(-0.222v-0.082age+11.753)} \tag{4}$$

More detailed fitting parameters of logistic regression were summarized in Table 4. The model *chi-square* and *Wald X^2* values indicate that the fitting models are acceptable. $p_1(v)$, $p_1(v, age)$ and $p_2(v)$, $p_2(v, age)$ are pedestrian fatality and AIS3+ risk. Based on Eq (1) and Eq (3), the risk of pedestrian fatality and AIS3+ are approximately 12.0% and 37.2% at an impact speed of 30 km/h, 65.2% and 96.9% at 50 km/h, 96.3% and 99.9% at 70 km/h.

Multivariate analysis for chest injury versus no chest injury

Multivariate logistic regression analysis was performed to confirm the relative likelihood of having a chest injury versus not having a chest injury. All multivariate analysis results are shown
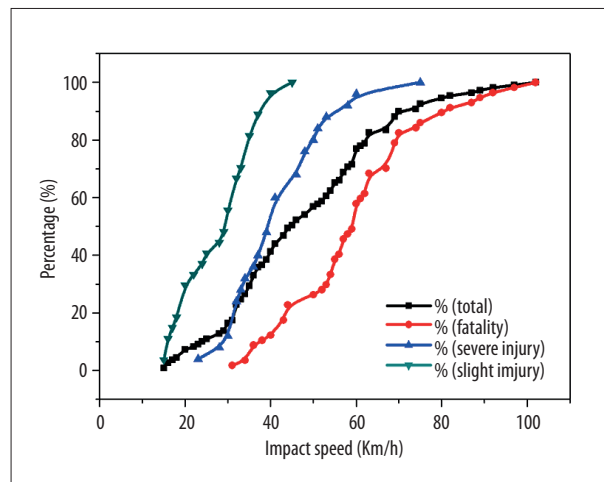

Figure 3. Cumulative distributions of impact speed for the 109 pedestrians.

in Table 5. There were no significant differences in the risk of chest injury based on pedestrian sex or seasonal conditions. Elderly people were more than twice as likely younger people to sustain a chest injury and the chest injury more likely to be combined with a severe injury outcome. Increasing impact speed raised the risk of chest injury, with highest relative risk (approximately 7.4-fold) observed for impact speed over 70 km/h.

Discussion

For the purpose of determining pedestrian injury patterns and risk in minibus collisions in China, 109 accident cases that met sample criteria were investigated and analyzed. A team of several researchers was responsible for collecting accident data in detail. Great efforts were made to ensure the accuracy and reliability of the collected data. The impact speeds were determined based on skid marks, pedestrian throwing distance, accident reconstruction, and surveillance video analysis. In this study, the pedestrian injury information was derived from medical records, medico-legal examination reports, and postmortem CT scans. Post-mortem CT scans were useful in non-invasively determining internal injuries.

Table 4. Summary of the logistic regression analysis.

	Variable	Estimate	Stand. error	Wald X^2	Model chi-square	−2 Log likelihood
Fatality risk	**Without age (Eq.1)**				63.441***	87.436
	Intercept	−5.924	1.109	28.566***		
	Impact speed	0.131	0.024	29.606***		
	With age (Eq.2)				68.059***	82.817
	Intercept	−8.508	1.876	20.557***		
	Impact speed	0.138	0.026	27.882***		
	Age	0.040	0.020	4.178*		
AIS3+ risk	**Without age (Eq.3)**				61.301***	60.736
	Intercept	−6.465	1.608	16.153***		
	Impact speed	0.198	0.046	18.950***		
	With age (Eq.4)				73.186***	48.850
	Intercept	−11.753	2.933	16.061***		
	Impact speed	0.222	0.055	16.414**		
	Age	0.082	0.028	8.548***		

a. *** means $p<0.001$; ** means $p<0.01$; * means $p<0.05$; b. The goodness of fit increased with decreasing the −2 log likelihood value.

Table 5. Results of multivariate analysis on chest injury versus no chest injury.

Risk Factor	Unadjusted OR (95% CI)		Adjusted OR (95% CI)	
Sex				
Male	1.0	(ref)	1.0	(ref)
Female	1.572	(0.653, 3.718)	1.036	(0.488, 2.196)
Age				
14–44	1.0	(ref)	1.0	(ref)
45–59	0.808	(0.226, 72.885)	1.506	(0.530,4.278)
>60	0.954	(0.285, 3.193)	2.210	(0.838, 5.825)
Total AIS				
1–2	1.0	(ref)	1.0	(ref)
3–4	4.713	(1.074, 20.685)	4.400	(1.250, 15.484)
5–6	5.772	(1.233, 27.010)	8.360	(2.750, 25.413)
Season				
Spring	1.0	(ref)	1.0	(ref)
Summer	2.655	(0.601, 11.738)	1.600	(0.458, 5.586)
Autumn	0.633	(0.198, 2.024)	0.853	(0.303, 2.404)
Winter	1.162	(0.379, 3.564)	1.192	(0.456, 3.118)
Impact speed				
0–39	1.0	(ref)	1.0	(ref)
40–69	1.889	(0.589, 6.060)	3.325	(1.387, 7.592)
>70	3.512	(0.544,22.671)	7.436	(1.750, 31.592)
Weather condition				
Sunny	1.0	(ref)	1.0	(ref)
Rainy	1.194	(0.304,4.687)	1.187	(0.377, 3.744)
Others	2.066	(0.698,6.121)	2.111	(0.823, 5.417)

The relationship between the occurrence of minibus/pedestrian crashes and weather were simply established from the presented results, and our conclusion that crashes are more likely on a sunny days is supported by previous studies [17,30].

This may be attributed to higher pedestrian exposure level, and increased preference to go outside on sunny days compared with rainy days. The environment-related factors are descriptively summarized in Table 1. It is evident that the majority

of crashes occurred in urban areas, consistent with that reported by Zhao et al. [17], probably due to the higher population density and traffic in urban areas. The minibuses in this study were mostly Changan brand, probably because it is the most common brand in use in China. The proportion of fatalities was higher for elderly than non-elderly pedestrians. In addition, almost no seasonal pattern was found.

In this study, multiple injuries were common in the injured or killed pedestrians. The head and chest were the most often injured areas of the body in minibus/pedestrian collisions. The proportion of injuries in the head, extremities, and chest were 84.4%, 52.3%, and 50.5%, respectively. The proportion of head and chest injuries was approximately 1.2 and 1.7 times that of flat-front vehicle-pedestrian injuries reported by Tanno et al. [23]. The proportion of head and chest injuries in that study were also higher than that reported by Zhao et al. [17], which suggests that the pedestrians involved in minibus collisions are more likely to sustain head and chest injuries.

Undoubtedly, vehicle impact speed has the most influence on pedestrian mortality, and the increasing impact speed of course increases injury risk. In the present study, regardless of pedestrian age, high-impact speeds exceeding 75 km/h all resulted in death, whereas there were no fatalities at impact speeds under 34 km/h. To estimate pedestrian injury risk, a logistic regression analysis was performed. However, the fact that mortality risk increased steadily with impact speed concurs with that documented in other studies on passenger car-pedestrian collisions. According to our results, the fatality risk at 50 km/h is more than 5 times higher than that at 30 km/h. Compared with that reported by Kong [10] and Rosén [11], both pedestrian fatality and AIS3+ risk are significantly higher in the present study for 2 main reasons: (1) difference in vehicle type, and (2) less efficient emergency and medical care. In addition, pedestrian age played a less important role in predicting injury outcomes. Minibus/pedestrian collisions more often kill elderly than non-elderly pedestrians.

In the present study, the tendency toward high chest-injury risk in minibus/pedestrian collisions concurs with previous studies [20,22,23]. Multivariate analysis of chest injury risk showed that there is no difference between males and females. The elderly had twice the chest injury risk of non-elderly pedestrians. However, no seasonal difference in chest injury was found. The association between increased impact speed and increased likelihood of chest injury is obvious in this study, and the chest injury risk at an impact speed exceeding 70 km/h was more than 7 times higher than that for 0–39 km/h.

Conclusions

An investigation of minibus/pedestrian collisions was performed in this study. We believe that these findings provide some insights into the minibus/pedestrian crash occurrence. Equations 1–4 presented in this report could be helpful in predicting pedestrian injury risk in China. A higher likelihood of chest injury was associated with being older and with impact speeds of over 40 km/h in minibus/pedestrian collisions. Our data suggests that the injury patterns of pedestrians in minibus collisions differ from that in other vehicle/pedestrian collisions. This study could contribute to better understanding of the injury patterns and risk of pedestrians in minibus collisions in China, which may play an important role in developing measures to improve safety. Further studies will be performed to develop extensive and comprehensive data on risk and injury mechanisms involved minibus/pedestrian collisions.

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Statement

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