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Difference in severity and distribution of bodily injuries following collision between drivers of K-cars and standard vehicles

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ABSTRACT

Background: Although K-cars, small four-wheeled vehicles with an engine capacity of <660 cc, have been used almost exclusively in Japan, they have recently become increasingly popular in other countries. Therefore, reporting the characteristics of bodily injuries sustained by K-car drivers after road traffic accidents (RTAs) may be important not only for health professionals but also for car manufacturers.
Methods: A single-center, retrospective observational study was conducted using prospectively acquired data. Between January 2010 and December 2017, 494 restrained drivers (331 men/163 women with a mean age of 45.1 years) whose vehicles had been severely damaged in RTAs underwent whole-body computed tomography prospectively. They were subsequently dichotomized into 221 K-car drivers and 273 standard vehicle drivers and compared for severity and distribution of bodily injuries.
Results: K-car drivers tended to be older and were significantly more likely to be female than standard vehicle drivers. The frequency of subjects with severe bodily injuries significantly higher among K-car drivers than among standard vehicle drivers (21.7% vs. 14.3%; $p = 0.04$), and the frequency of bowel/mesentery injuries tended to be higher in the former (9.0% vs. 4.4%; $p = 0.06$). However, the frequency of abdominal solid viscus injuries did not differ significantly between the two groups. Multivariable regression analysis showed that age [odds ratio (OR): 1.022; 95% confidence interval (CI): 0.998–1.047; $p = 0.07$] and K-cars (OR: 3.708; 95% CI: 0.984–6.236; $p = 0.05$) tended to be associated with bowel/mesentery injuries in restrained drivers. The frequency of pelvic/hip fractures also tended to be higher in K-car drivers than in standard vehicle drivers (5.9% vs. 2.6%; $p = 0.10$). By contrast, the severity and frequency of the upper torso injuries were similar between the two groups.
Conclusions: Compared to standard vehicle drivers, K-car drivers seem to experience more severe bodily injuries after severe RTAs. Despite there being no answer for the increased frequency of only hollow viscus injuries but not solid viscus injuries among restrained K-car drivers, advanced age may, at least in part, be responsible. Given the limitations inherent to this study's single-center, retrospective design, multi-center prospective studies are warranted to verify our findings.

Introduction

K-cars are defined as small four-wheeled vehicles that fulfill all of the following four criteria defined by the Road Traffic Act of Japan: (1) an engine capacity of <660 cc, (2) 3.40 m long or less, (3) 1.48 m wide or less, and (4) 2.00 m high or less [1,2] (Fig. 1). Considering that K-cars are lighter and shorter than standard vehicles, the severity and distribution of bodily injuries sustained by restrained drivers of both car groups after road traffic accidents (RTAs) may perhaps differ. Trauma pan-scan, *i.e.*, whole-body computed tomography (WBCT) performed on victims of high-energy trauma, provides a unique opportunity for comprehensively identifying injuries sustained by automobile occupants [3,4]. The objective of this study was to evaluate whether the severity and distribution of bodily injuries sustained differed between restrained K-car and standard vehicle drivers.

Patients and methods

This was a single-center, retrospective observational study using prospectively acquired data. All procedures performed were in accordance with the ethical standards of the institutional research committee and with the 1964 Declaration of Helsinki. Approval for this study was provided by our institutional research committee.

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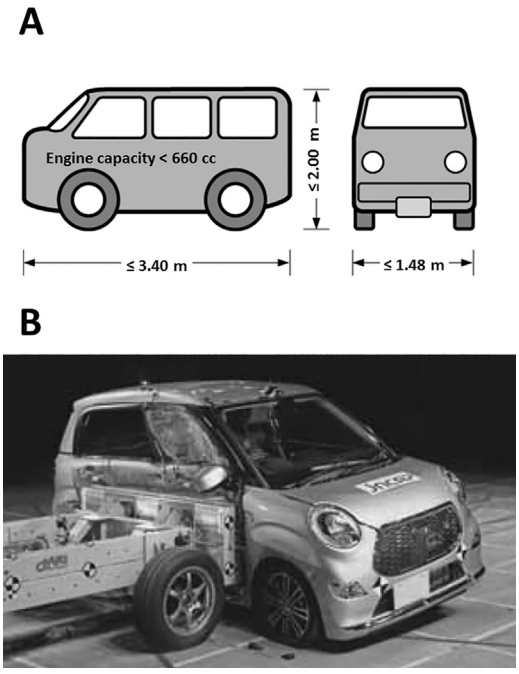

Fig. 1. A: Definition of K-car by the Road Traffic Act of Japan (Permission granted by the Light Motor Vehicle Inspection Organization of Japan). **B:** A modern K-car undergoing a crash test (Permission granted by the National Agency for Automotive Safety and Victims' Aid).

A trauma team was activated after receiving a call from emergency medical service (EMS) staff rescuing RTA victims at the scene. Trauma patients were treated according to recent guidelines [5]. After their arrival at the emergency department (ED), the temporal sequence of resuscitative events was recorded on an integrated clinical database CAP-2000 (Nihon Kohden, Tokyo, Japan) by emergency medicine (EM) residents [6]. The severity of bodily injuries was evaluated using the Abbreviated Injury Scale (AIS) with an Injury Severity Score (ISS) of 15 or more being classified as a severe injury [7].

Restrained automobile drivers who had been brought to our ED after a RTA from January 2010 to December 2017 were identified from the database. Unrestrained drivers, as well as restrained front/rear seat passengers, were excluded from analysis. Detailed information on the RTA, including vehicle types, seatbelt usage, airbag deployment, collision patterns, and estimated precrash speed of the damaged vehicle, was provided by EMS staff in a rescue report. Vehicle types were classified into three categories (K-cars, standard vehicles, and trucks) based on the Road Traffic Act of Japan [2]. Wagons, vans, and sports utility vehicles (SUVs) with an engine capacity >660 cc were included under the standard vehicle category. Collision patterns were classified into three categories (frontal, lateral, and rollover), while rear-end collisions were excluded.

EMS staff had been trained to estimate the severity of vehicular damage, subsequently classifying the damage into three categories (mild, moderate, and severe) at the crash scene [8–10]. In 2010, we started a prospective WBCT protocol for occupants involved in RTAs on the condition that (1) their vehicle was determined by EMS staff to have sustained severe damage and (2) the estimated precrash speed had exceeded 40 km/h. EM residents comprehensively explained the benefits and risks of WBCT to the drivers or their surrogates. WBCT was not performed in drivers who refused to give consent and in those who were pregnant. Given that a CT suite was located adjacent to our ED, WBCT was performed shortly after initial resuscitation. The WBCT protocol started with an AP scout projection followed by non-contrast head and neck CT, IV contrast-medium injection, and CT of the thorax, abdomen, and pelvis in the venous phase. A 64-detector row helical CT scanner (SOMATOM Definition AS, Siemens, Erlangen, Germany) was used throughout the study period. CT diagnosis of bodily injuries had been established by a board-certified radiologist on-call.

Statistical analysis

Two-tailed Fisher's exact test was used to compare categorical variables, while Student's *t*-test was used to compare numerical variables. Data were expressed according to the SAMPL Guidelines [11]. Numerical data were expressed as mean (SD), and $p < 0.05$ was considered statistically significant. For multivariable regression analysis, SPSS for Windows Ver. 18.0 (SPSS Inc., Chicago, IL, USA) was used.

Results

Demographics

During the 7-year study period, a total of 549 restrained drivers whose vehicles had been severely damaged in RTAs underwent WBCT. Data from 35 truck drivers and 21 drivers with unidentifiable vehicle types were excluded from analysis. Data on the remaining 494 restrained automobile drivers [331 men and 163 women with a mean age of 45.1 (19.4) years] involved in RTAs were used for analysis. Among them, 221 drivers had driven a K-car, while the other 273 drivers had driven a standard vehicle.

A comparison of demographic variables is shown in Table 1. K-car drivers tended to be older [47.4 (20.2) years vs. 44.5 (18.7) years; $p = 0.10$] and significantly more likely to be female compared to standard vehicle drivers (male: female ratio of 1.63:1 vs. 2.46:1; $p = 0.04$). Airbag deployment rate did not differ significantly between the two groups (57.7% vs. 65.9%; $p = 0.16$). However, it needs to be mentioned that information on airbag deployment was missing in 167 drivers (33.8%).

Injury severity

A comparison of injury severity is shown in Table 2. Accordingly, 48 of the 221 (21.7%) K-car drivers involved in severe RTAs

Table 1
Comparison of demographic variables between K-car and standard vehicle drivers involved in road traffic accidents.

Demographic variables	K-car (n = 221)	Standard vehicle (n = 273)	*p*
Mean age (SD)	47.4 (20.2)	44.5 (18.7)	0.10
Male: Female	137: 84 (1.63:1)	194: 79 (2.46:1)	0.04
Collision type (Frontal: Lateral: Rollover)	124: 63: 34	176: 70: 27	
Lateral collision	63 (28.5%)	70 (25.6%)	0.54
Rollover collision	34 (15.4%)	27 (9.9%)	0.09
Airbag deployment	80/139 (57.6%) (N/A in 82)	123/188 (65.4%) (N/A in 85)	0.18

N/A = not available, SD = standard deviation.

Table 2
Comparison of injury severity between K-car and standard vehicle drivers involved in road traffic accidents.

Injury severity	K-car (n = 221)	Standard vehicle (n = 273)	*p*
ISS ≥ 15	48 (21.7%)	39 (14.3%)	0.04
Mean ISS (SD)	6.5 (8.6)	4.9 (7.2)	0.02
<24 h mortality	10 (4.5%)	6 (2.2%)	0.23

ISS = Injury Severity Score.

sustained severe bodily injuries (ISS ≥ 15), whereas only 39 of the 273 (14.3%) standard vehicle drivers sustained the same, the difference being statistically significant (p = 0.04). K-car drivers also exhibited significantly higher mean ISS than standard vehicle drivers [6.5 (8.6) vs. 4.9 (7.2); p = 0.02]. However, no significant difference in 24-h mortality had been observed between the two groups (4.5% vs. 2.2%; p = 0.23).

Injury distribution

Bodily injuries identified using WBCT, excluding superficial skin/soft tissue injuries, were classified according to 12 anatomical categories (brain injury, spine/spinal cord injury, upper extremity fracture, hemopneumothorax/lung injury, heart/aorta injury, sternum/rib fracture, liver injury, spleen injury, kidney injury, bowel/mesentery injury, pelvic/hip fracture, and lower extremity fracture), and their frequencies were compared between the two groups (Fig. 2). The frequency of bowel/mesentery injury requiring laparotomy tended to higher in K-car drivers than in standard vehicle drivers (9.0% vs. 4.4%; p = 0.06). Similarly, the frequency of pelvic/hip fractures tended to be higher in K-car drivers than in standard vehicle drivers (5.9% vs. 2.6%; p = 0.10). No significant differences in the frequency of bodily injuries in other categories had been observed between the two groups (Fig. 2).

Subsequently, the frequency of severe bodily injuries, defined as those with a maximum AIS score ≥ 3 (MAIS 3+), was compared between the two groups after classifying bodily injuries according to five regions (head/neck, face, chest, abdomen, and extremities) (Fig. 3). Although the frequencies of MAIS 3+ chest injuries and pelvic/extremity injuries were higher in K-car drivers than in standard vehicle drivers (Fig. 3), the difference was not statistically significant.

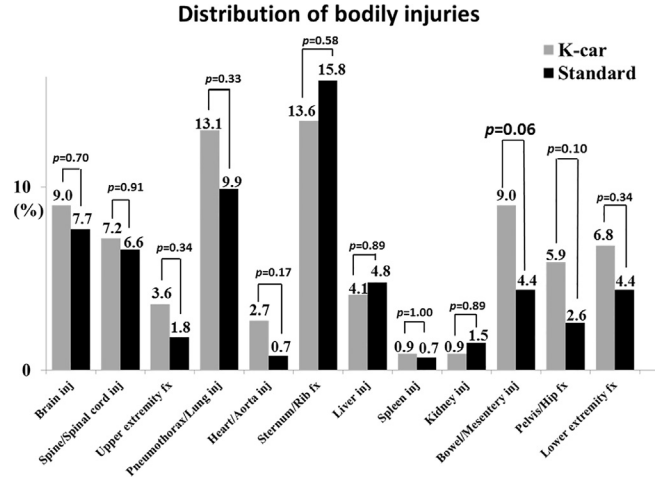

Fig. 2. Bodily injuries were classified according to 12 anatomical categories, and their frequencies were compared between K-car and standard vehicle drivers. The frequency of bowel/mesentery injury tended to be higher in K-car drivers than in standard vehicle drivers (9.0% vs. 4.4%; p = 0.06). Similarly, the frequency of pelvic/hip fractures tended to be higher in K-car drivers than in standard vehicle drivers (5.9% vs. 2.6%; p = 0.10).

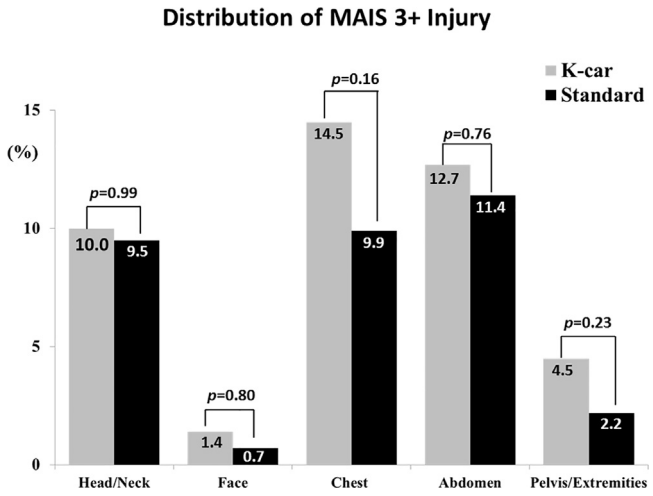

Fig. 3. The frequency of severe bodily injuries, defined as MAIS 3+ injuries, was compared between K-car and standard vehicle drivers after classifying bodily injuries according to five regions. Although the frequency of MAIS 3+ pelvic/extremity injuries was higher in K-car drivers than in standard vehicle drivers, the difference was not significant (p = 0.23).

Risk factors for bowel/mesentery injury

Multivariable regression analysis was performed to identify variables associated with bowel/mesentery injuries among the 327 restrained drivers in whom data on airbag deployment had been available. Variables included age, gender, airbag deployment, frontal collision, and K-car. Age [odds ratio (OR): 1.022; 95% confidence interval (CI): 0.998–1.047; p = 0.07] and K-car (OR: 3.708; 95% CI: 0.984–6.236; p = 0.05) tended to be associated with bowel/mesentery injuries (Table 3).

Discussion

For decades, K-cars have been produced and used almost exclusively in Japan. However, they become increasingly popular in several large countries, such as India, Brazil and Indonesia, because of their easier drivability in narrow roads, affordable price, and low CO_2 gas emissions. According to the definition by the European Commission, K-cars may be equivalent to A-segment cars [12]. Considering the paucity of English literature on the safety profiles of K-cars, reporting the characteristics of bodily injuries sustained by K-car drivers after RTAs may be useful for not only health professionals but also car manufacturers. This study is unique in that it aimed to comprehensively characterize bodily injuries, both major and minor, using a prospective WBCT protocol. Given the apparent differences in injury severity, unrestrained drivers who sustained bodily injuries in RTAs were excluded from analysis.

The demographics of K-cars drivers involved in severe RTAs had been different from those driving standard vehicles in that the former tended to be older and was more likely to be female (Table 1). This tendency might have been a reflection of the easy

Table 3
Multivariable regression analysis to predict bowel/mesentery injuries in drivers involved in road traffic accidents.

Variables	OR	95 % CI	*p*
Age	1.022	0.998–1.047	0.070
Male sex	1.477	0.542–4.026	0.446
Airbag deployment	0.419	0.146–1.201	0.105
Frontal collision	0.628	0.231–1.713	0.364
K-car	3.708	0.984–6.236	0.054

CI = confidence interval, OR = odds ratio.

drivability and affordable price of K-cars. A difference in collision type was also observed in that K-car drivers had experienced rollover collisions more frequently, which cause greater damage to automobile occupants than frontal collisions (Table 1) [13–15]. Both mean ISS and ratio of subjects with ISS > 15 were significantly higher in K-car drivers than in standard vehicle drivers (Table 2). Accordingly, a greater proportion of K-car drivers exhibited high ISS mainly because they sustained multiple bodily injuries more often than standard vehicle drivers. Considering that vehicle mass is an important factor influencing fatality odds for crash configurations and that K-cars are lighter and shorter than standard vehicles [16], the findings presented here are reasonable.

There have only been a few papers on the safety profile of K-car drivers in English literature. Hitosugi and Matsui reported that injury severity and distribution were similar between K-car drivers and standard vehicle drivers after low-severity frontal collisions [1]. Unlike their study, however, our cohort included many drivers who sustained severe, high-velocity lateral/rollover collisions in addition to frontal collisions (Table 1), which may explain the difference between the two studies. It should also be mentioned that no distinction between abdominal hollow viscus injury and solid viscus injury had been made in that study.

This study also revealed differences in bodily injury distribution between K-car and standard vehicle drivers. Although the upper torso was protected no less effectively in K-car drivers than in standard vehicle drivers, the bowel/mesentery was more likely to be injured in the former (Fig. 2). Multivariable regression analysis also suggested K-cars to be a risk factor for bowel/mesentery injuries (Table 3). Interestingly, the frequency of abdominal solid viscus injuries did not differ between the two groups (Fig. 2), which in turn might have resulted in the lack of difference in the frequency of MAIS 3+ abdominal injuries (Fig. 3). In other words, the difference observed for hollow viscus injuries might have been offset after combining solid and hollow viscus injuries. K-cars undergo crash tests identical to standard vehicles, and safety profiles of K-cars have been believed to be no less inferior to those of the latter [17]. Naturally, a question arises as to why only hollow viscus injuries but not solid viscus injuries had occurred more frequently among the K-car drivers. Although seatbelt-induced hollow viscus injuries have been known for decades [18,19], hollow viscus injury models using either dummies or finite element analysis are more difficult to replicate than solid viscus injury models, with only a limited number of literature available on the subject [20,21]. This study alone cannot provide a clear answer for the question, and we expect other researchers to address this issue in order to verify causal relationship between K-cars and hollow viscus injuries. Based on multivariable regression analysis (Table 3), advanced age may, at least in part, explain why hollow viscus injuries occurred more frequently in K-car drivers. As described earlier, elderly Japanese individuals tend to prefer K-cars to standard vehicles (Table 1). Hollow viscus injuries in restrained drivers are caused mainly by the lap belt of the three-point seatbelt system. Elderly drivers, with reduced abdominal muscle strength, may be vulnerable to the sudden rise in intra-abdominal pressure through impact-induced lap belt tightening, resulting in bowel rupture or mesenteric artery avulsion. Similarly, a prior study on CIREN cases also determined advance age to be a risk factor for hollow viscus injuries [19]. In addition to abdominal hollow viscus injuries, K-car drivers sustained pelvic and lower extremity injuries more frequently than standard vehicle drivers (Figs. 2 and 3). Compared to the upper torso, the lower torso is less protected by seatbelts and airbags. Given their shorter front overhang, K-cars may perhaps be more vulnerable to intrusion from the floor after frontal collision than standard vehicles, resulting in higher frequencies of pelvic and lower extremity injuries [22].

This study has some limitations worth noting. First, given that vehicular damage had not been evaluated by collision specialists, it remains unclear whether the degree of intrusion had actually been greater in K-cars. Moreover, the actual incidence rate or injury risk might be greater because of the lower rate of exposure for K-car occupants. Second, the sample size was small due to the single-center retrospective study design. Multi-center prospective studies are warranted to verify our findings. Third, the decision to perform WBCT had been made by an on-call EM physician after discussing the degree of vehicular damage with EMS staff. The recognition of severe vehicular damage may have differed among the EMS staff, which in turn might have led to difference in the indication of WBCT. Finally, data on airbag deployment had been available only in two-thirds of the 494 drivers, which impaired data reliability. Despite these limitations, however, we believe that this study may provide useful information to healthcare providers and car manufacturers and help improve the safety profile of future K-cars.

Conclusions

This study evaluated the severity and distribution of bodily injuries in drivers of both K-cars and standard vehicles, subsequently determining that injury severity was significantly greater in the former. Although the frequency of abdominal hollow viscus injuries tended to be higher among K-car drivers, the frequency of abdominal solid viscus injuries did not differ significantly. The frequency of severe pelvic/extremity injuries was also higher among K-car drivers. Given the limitations inherent to this study's single-center, retrospective study design, multi-center prospective studies are warranted.

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Conflict of interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Approval for this study was provided by our institutional research committee.

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