Safety of the Japanese K-Car in a Real-World Low-Severity Frontal Collision

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Objective: Kei-cars (K-cars), which are a tiny 660 cc mini-car class 3.4 m long or less, 1.48 m wide or less, and 2.00 m high or less, have become popular in Japan. To evaluate the safety of K-car drivers in frontal collisions, we retrospectively compared the severity of injuries suffered by drivers between K-cars and standard vehicles involved in frontal collisions in which at least one injury occurred.

Materials and Methods: From in-depth data provided by the Institute for Traffic Accident Research and Data Analysis from 1993 to 2010, records for 1379 drivers aged 36.8 ± 15.6 years were collected for analysis.

Results: Of the 1379 drivers, 1115 subjects were in standard vehicles and 264 were in K-cars. The mean delta $V$ of the struck vehicle was 28.6 ± 15.6 km/h. After classifying the subjects according to seat belt use and air bag deployment, the background of the drivers and delta $V$, the injury severity scores (ISSs) and Abbreviated Injury Scale (AIS) scores were compared for all body regions. Under similar conditions, no significant differences in severity of injuries of the drivers were found between K-cars and standard vehicles.

Conclusions: Although we are generally concerned that drivers of small vehicles suffer more severe injuries, our results suggest that, for real-world accidents, K-cars provide similar safety for drivers involved in frontal collisions as standard vehicles in low delta $V$ impact conditions.

Keywords: Kei-cars, small vehicles, frontal collision, driver, injury severity

Introduction

According to the Global Status Report on Road Safety 2013, the number of road traffic deaths each year has not increased but remains unacceptably high at 1.24 million per year (World Health Organization 2013). Large discrepancies in road traffic death rates are found between regions; the highest rate is in Africa (24.1 per 100,000 population) and the lowest in Europe (10.3 per 100,000). In southeast Asia and Japan, the rate (18.5 per 100,000) is slightly higher than the average, and further efforts to improve traffic safety are recommended.

Recently, small passenger vehicles have become popular in Asia, especially in Japan (Japan Light Motor Vehicle and Motorcycle Association 2012). Kei-cars (K-cars), which are a tiny 660 cc mini-car class in Japan, 3.4 m long or less, 1.48 m wide or less, and 2.00 m high or less, have become increasingly popular, because they are convenient to drive and have economic benefits, such as low purchase price and tax and good fuel economy. In 2012, K-cars accounted for 36.5 percent of all registered vehicles in Japan. Although K-cars are required to comply with the same vehicle safety standards as standard passenger vehicles in Japan, the differences in occupant injury severity in frontal collisions between K-cars and standard vehicles have not been examined. To evaluate the safety of K-car drivers in frontal collisions, we compared the injury severity for drivers in K-cars and standard vehicles involved in frontal collisions using real-world accident data.

Data Collection

Data were extracted from the records of the Institute for Traffic Accident Research and Data Analysis (ITARDA), Japan. ITARDA was founded in 1992 to investigate traffic accidents and reduce injuries in Japan. It combines its own data with accident-related data compiled by other agencies in an integrated database to enable accidents to be analyzed from as many aspects as possible. In carrying out the in-depth analysis of actual events, ITARDA’s specialized investigators visit the scene of recent collisions to interview the individuals involved and to examine the vehicles and collision characteristics. External damage profiles of the vehicles involved are prepared and internal vehicle intrusions and contact marks are documented. The vector velocity changes at the
time of impact (delta $V$) are obtained from the difference in velocity before and after collision. The vehicle velocities before collision are derived from equations of conservation of energy principle and a momentum conservation law. According to the principle of conservation of energy, the kinetic energy before collision becomes the kinetic energy after collision and the vehicle deformation energy. Here, the vehicle deformation energy is calculated from the energy absorption diagram, which was developed by Kubota and Kokubu (1995) for each vehicle type (e.g., K-cars or sedan) and makes the calculation possible according to the vehicle type. The diagrams were revised using Japanese vehicles produced from 2002 to 2005 (Oga et al. 2007). The velocities of vehicles after collision are estimated from the distance from the impact locations to vehicle stop locations. Field data are also collected on many different aspects, including emergency rescue and medical conditions. Details on physical injuries and the general condition of each subject, both before and after the collision, are then obtained. This in-depth analysis is only performed in the cities of Tsukuba and Tsuchiura and communities around them, with a combined population of 350,000.

Data on adult drivers (18 years and older) with any injuries that score 1 or higher on the Abbreviated Injury Scale (AIS), who were involved in a frontal collision from 1993 to 2010, were identified in the in-depth data of ITARDa. Frontal collision was defined as the principal direction of the force ranging from 10 to 2 o’clock. The vehicles involved were limited to sedan-type (bonnet-type) vehicles and, thus, sports-utility vehicles, light trucks, and heavy vehicles were excluded. We then classified the vehicles as a K-car or standard vehicle. A K-car was defined as a vehicle with an engine capacity of 660 cc or less, 3.4 m long or less, 1.48 m wide or less, and 2.00 m high or less. A vehicle was classified as a standard vehicle if it did not meet all of these conditions. From collision reports, we obtained data on how and where the collision occurred, the type of vehicle involved, the delta $V$ of the vehicle at the time of impact, whether a seat belt was correctly used, and whether an air bag was deployed.

Referring to a patient’s medical data, age and physical stature (body height, weight, and body mass index [BMI]), data on the injured region and injury type were examined. In addition, in reviewing the injury data, objective measures of injury severity—the injury severity score (ISS) and the ISS revision of the AIS—were determined for each occupant (Association for the Advancement of Automotive Medicine 1990; Baker et al. 1974). The AIS was used to categorize the injury type and severity in each body region, and injuries were graded from 1 (minor) to 6 (clinically untreatable). The ISS, which is useful for assessing the severity of multiple injuries, is the sum of the squares of the highest AIS score in each of the three most severely injured body regions. Maximum AIS score denotes the most severe injury in each of the body regions. Collision cases were excluded from analysis if information regarding the direction of impact, the point of collision, or the status of seat belt use was missing.

Statistical Analysis

In comparing the age and BMI of the drivers and delta $V$ of the vehicles, an F test was first performed to examine the homogeneity of variance. An unpaired t test was then used for equal variance, and Welch’s t test was used for unequal variances. The Mann-Whitney $U$ test was employed to compare the AIS scores and ISSs because they were not in normal distributions. The chi-square test was used to compare the rate of vehicle to vehicle collisions and frequency of injuries with an AIS of 2 or more between K-cars and standard vehicles. Differences with a $P$ value less than .05 were considered significant.

Results

General Aspects

During the 18-year study period, 4740 accidents were identified for in-depth analysis. Under the criteria described above, 1379 subjects (778 male and 601 female) were selected for inclusion in this study. Their ages ranged from 18 to 85 years, with a mean ($\pm$SD) of 36.8 $\pm$ 15.6 years. The distribution of the drivers’ ages is shown in Figure 1. Drivers in the accident sample were most frequently in their 20 s, followed by those in their 30 s and 40 s. Subjects had a mean height of 164.2 $\pm$ 9.0 cm (ranging from 144.0 to 188.0 cm), mean ($\pm$SD) weight of 60.2 $\pm$ 12.0 kg (ranging from 35.0 to 130.0 kg), and mean ($\pm$SD) body mass index of 22.2 $\pm$ 3.3 (ranging from 15.6 to 40.1). Of these, 1115 subjects were in standard vehicles and 264 were in K-cars. The mean ($\pm$SD) weight of all struck vehicles was 1143.2 $\pm$ 313.0 kg (ranging from 580 to 2210 kg), that of K-cars was 760.1 $\pm$ 89.5 kg, and that of standard vehicles was 1233.6 $\pm$ 276.2 kg. The mean ($\pm$SD) delta $V$ of struck vehicles was 28.6 $\pm$ 15.6 km/h (ranging from 4 to 110 km/h). All vehicles were equipped with seat belts, but some older vehicles were not equipped with air bags.

Injuries

ISSs ranged from 1 to 75 (mean: 3.7 $\pm$ 7.6). Seven hundred and two (50.9%) subjects had an ISS of 1, and 389 (28.2%) had an ISS of 2, together accounting for 67.1 percent of all subjects (Figure A1, see online supplement). In comparing injured body regions, the chest and lower extremities were the regions with the highest AIS score (mean: 0.5 $\pm$ 0.9 and 0.5 $\pm$ 0.6, respectively) followed by the neck (mean: 0.4 $\pm$ 0.6), head (mean: 0.3 $\pm$ 0.8), face (mean: 0.3 $\pm$ 0.5), upper extremities (0.3 $\pm$ 0.6), and abdomen (mean: 0.2 $\pm$ 0.7). Overall, injury

![Fig. 1. Distribution of drivers’ ages.](image-url)
levels were very low, with only 16 drivers (6.1%) of K-cars and 91 drivers (8.2%) of standard vehicles sustaining Maximum Abbreviated Injury Scale (MAIS) 3+ injuries.

**Comparison Between K-cars and Standard Vehicles**

To precisely compare the background and injury severity of the drivers between the types of vehicle, we stratified the subjects according to seat belt use and air bag deployment. Thus, 4 categories were examined: restrained by seat belt with air bag, restrained by seat belt without air bag, unrestrained with air bag, and unrestrained without air bag. For each vehicle type, we subdivided the occupants as above. Table 1 gives the mean age, mean BMI of the drivers and mean delta V of the vehicles. Furthermore, based on the collision opponents (vehicles or other objects), the rate of vehicle-to-vehicle collision was also shown. When comparing the values between K-cars and standard vehicles, no significant differences were found except for the age and rate of vehicle to vehicle collision of the unrestrained without air bag group (P < .05).

Next, the injury severity of the drivers was compared between K-cars and standard vehicles. Table 2 gives the mean ISS and the rate of MAIS of 2 or more (MAIS 2+). In all categories, no significant differences in the ISS and the rate of MAIS 2+ were found, except for the rate of MAIS 2+ of the unrestrained with air bag, between the vehicle types (Table 2, P = .04). Table 3 gives the AIS score of any body region in each category. No significant differences were found except for the upper extremities of the group restrained with air bag (Table A1, see online supplement, P = .04). The rates of AIS 2 or more (AIS 2+) in any body region in each category are shown in Table 3. No significant differences were found except for the lower extremities of the group unrestrained without an air bag (P = .005).

**Discussion**

In Japan, the proportion of K-cars among newly sold vehicles increased to 36.9 percent in 2012. The economic benefits of K-cars include their low tax (less than one third of that for standard vehicles) and low price. Furthermore, in Japan, approximately 84 percent of roads are narrow, with a width of less than 3.8 m, and many drivers therefore prefer smaller vehicles (Japan Light Motor Vehicle and Motorcycle Association 2012). Because the smaller car has become popular in Asian countries, we need to examine the characteristics of injuries to passengers in K-cars.

Generally, passenger protection performance for car-to-car frontal impact situations is evaluated in automobile collision tests according to each country’s vehicle safety standards. A dummy is placed on a seat and the vehicle undergoes impact. Injury criteria are measured on the dummy for the head, neck, chest, and legs. In Japan, for frontal crashes the frontal collision standard is defined in the technical standards of automobile type approval for Japanese certification: full-wrap impact against a rigid barrier at 50 km/h and offset impact against a deformable barrier at 56 km/h (National Agency for Automotive Safety & Victims’ Aid and Ministry of Land, Infrastructure, Transport and Tourism 2012). The former test is similar to the standard used in the United States (FMVSS 208; NHTSA 2012) and the latter is the same as the standard used in the European Union (ECER 94; United Nations Economic Commission for Europe 2013). In these tests, values obtained for the dummy need to be below safety thresholds. Therefore, Japanese vehicles meet the standard safety performance required in the United States and Europe in the case of frontal collisions. The above technical regulations are applied for K-cars in Japan, and safety performance similar to that of standard vehicles is ensured by national regulations.

Although the safety performance of the K-car has been examined in crash tests (National Agency for Automotive Safety & Victims’ Aid and Ministry of Land, Infrastructure, Transport and Tourism 2012), there has been no comprehensive

### Table 1. Comparison of the background of drivers between K-cars and standard vehicles

| Seat belt | Air bag | Type    | n  | Age       | BMI | delta V (km/h) | Rate of vehicle-to-vehicle collision (%) |
|-----------|---------|---------|----|-----------|-----|---------------|-----------------------------------------|
| +         | +       | K-car   | 80 | 38.6 ± 17.8 | 22.1 ± 3.5 | 31.8 ± 13.8 | 77.5                                    |
|           |         | Standard vehicle | 268 | 38.2 ± 15.9 | 22.5 ± 3.2 | 30.6 ± 15.1 | 77.6                                    |
| P value   |         |         |     | 0.85       | 0.32   | 0.59          |                                         |
| +         | –       | K-car   | 106 | 40.9 ± 16.6 | 21.7 ± 3.2 | 24.5 ± 13.6 | 84.9                                    |
|           |         | Standard vehicle | 449 | 38.7 ± 15.5 | 22.6 ± 6.1 | 23.7 ± 13.9 | 84.6                                    |
| P value   |         |         |     | 0.2        | 0.17   | 0.68          |                                         |
| –         | +       | K-car   | 16  | 29.6 ± 14.0 | 21.2 ± 2.5 | 26.0 ± 11.2 | 68.8                                    |
|           |         | Standard vehicle | 69  | 27.9 ± 8.2  | 21.9 ± 2.9 | 41.1 ± 20.7 | 52.2                                    |
| P value   |         |         |     | 0.08       | 0.47   | 0.08          |                                         |
| –         | –       | K-car   | 32  | 41.9 ± 14.8 | 22.4 ± 3.3 | 27.1 ± 10.6 | 81.3                                    |
|           |         | Standard vehicle | 195 | 30.4 ± 13.1 | 22.1 ± 3.3 | 32.5 ± 16.1 | 57.9                                    |
| P value   |         |         |     | <0.01      | 0.67   | 0.17          |                                         |

### Table 2. Comparison of the mean ISS of the drivers between K-cars and standard vehicles

| Seat belt | Air bag | Type    | Mean ISS | Rate of MAIS 2+ (%) |
|-----------|---------|---------|----------|---------------------|
| +         | +       | K-car   | 2.5      | 15.0                |
|           |         | Standard vehicle | 3.5  | 19.0                |
| P value   |         |         | 0.88     | 0.1                 |
| +         | –       | K-car   | 2.4      | 10.4                |
|           |         | Standard vehicle | 2.3  | 12.0                |
| P value   |         |         | 0.01     | 0.6                 |
| –         | +       | K-car   | 7.9      | 18.8                |
|           |         | Standard vehicle | 8.3  | 46.4                |
| P value   |         |         | 0.05     | 0.04                |
| –         | –       | K-car   | 3.9      | 28.1                |
|           |         | Standard vehicle | 4.7  | 28.2                |
| P value   |         |         | 0.31     | 0.99                |
study on passenger safety during the frontal collision of a K-cars based on real-world accidents. Because the motion of a dummy is different from real human kinetics, and the injury severity of human occupants has not been accurately estimated as a result of the limited injury criteria, occupant injuries in real-world frontal collisions must be analyzed in detail. This is the first report to compare the severity of injury of drivers of K-cars and those of standard vehicles involved in frontal collisions. The severity of injury largely depends on the collision speed, and we examined the mean delta $V$ for each category of seat belt use and air bag deployment. Furthermore, to analyze the drivers’ injuries exactly, the physical stature of the driver was also examined. Therefore, because comparisons were made for drivers of similar age and BMI and similar delta $V$ of the vehicles, we were able to obtain reliable results.

In the present study, ISSs did not differ significantly between the drivers of K-cars and standard vehicles. This result agreed well with the above impact tests in technical regulations in Japan, although almost all of the crashes in the study occurred at much lower velocities. In the comparison of the ages of unrestrained drivers without air bag deployment, although K-car drivers were significantly older than drivers of standard vehicles, the ISS was slightly lower for K-car drivers. Because older drivers are expected to suffer more severe injuries than younger drivers under the same conditions, the difference in age does not affect our conclusion. The MAIS 2+ rate was significantly higher in drivers in standard vehicles than K-cars for the unrestrained with air bag group, though this was the group with the largest difference in mean delta $V$ between vehicle types. In addition, for the AIS scores of the body region, no significant differences were found except for the upper extremities of the restrained with air bag group. No significant differences were found for the AIS 2+ rate except for the lower extremities in the unrestrained without air bag group. Because the AIS score of upper extremities and the rate of AIS 2+ of the lower extremities in standard vehicles were significantly higher than that for K-cars, we consider that K-car drivers did not suffer from more severe injuries, and we conclude that K-cars have a safety performance as good as that of standard vehicles in limited conditions. Generally, the driver’s seat adjustment position depends on the position of the steering wheel relative to the occupant’s body size. There are no marked differences between K-cars and standard vehicles in steering wheel and passenger protection performance under the regulations. Furthermore, because the body sizes of the drivers in this study did not differ significantly between K-cars and standard vehicles, the driver kinematics in the 2 types of cars under frontal collision are similar. Therefore, the result that there are no significant differences in injury severities of the drivers between K-cars and standard vehicles is deemed appropriate. Although we are generally concerned that drivers in small vehicles will suffer injuries that are more severe, our result confirms that K-cars provide similar safety to drivers in real-world accidents involved in frontal collisions as do standard vehicles in low delta $V$ impact condition.

However, in lateral collisions, we have found characteristic differences in injuries between occupants of K-cars and standard vehicles (Hitosugi and Tokudome 2011). In the case of unrestrained occupants of standard vehicles, those on the near side had more severe chest injuries and incidence of rib fractures than those on the far side; however, the reverse was found for occupants of K-cars. This difference is likely to arise from the size of the vehicle; when the unrestrained occupant is thrown to the opposite side in a collision, there is a greater chance of contact with the interior of the vehicle or another occupant in K-cars than in standard vehicles. Therefore, in future work, we need to compare the severity of passenger injury in other types of collisions.

This study has a number of limitations. First, because the data were obtained for collisions in suburban Japan, no collisions on highways were included. Therefore, we cannot discuss safety for collisions with extremely high delta $V$. In the full-frontal rigid barrier impact test at 50 km/h, measured injury criteria are converted into a score using a point-conversion function. The points for a standard vehicle are slightly higher than those of K-cars (National Agency for Automotive Safety & Victims’ Aid and Ministry of Land, Infrastructure, Transport and Tourism 2012). Real-world performance in crashes with delta $V$ of 50 km/h or more is potential area for future research. Second, because the mean age of the drivers was 36.8 years, we do not know whether the present results also apply to older drivers. Third, detailed information about vehicle-to-vehicle collisions—that is, extent of overlap and detail about the types of opponent vehicles—was lacking. Fourth, the intent of ITARDA is to investigate all police-reported collisions within this area. However, the cases in which the victim did not agree to the research, these data were excluded according to Japanese law. The actual number of excluded cases is unknown and there is a possibility that differences between exclusion rates by vehicle and injury type could have affected the results. Furthermore, out of a concern that there could be differences between vehicle types in the rate of reporting noninjury crashes to the police, only crashes with injuries were included in the study. A comparison including crashes without driver injury would be more meaningful. Fifth, the study was performed only for drivers and

### Table 3. Comparison of the rate (%) of AIS 2+ for drivers in each body region between K-cars and standard vehicles

| Body region     | Type   | Seat belt + | Seat belt − | Air bag + | Air bag − |
|-----------------|--------|-------------|-------------|-----------|-----------|
| Head            | K-car  | 0           | 0.9         | 6.3       | 9.4       |
|                 | Standard vehicle | 3.4        | 1.8         | 10.1      | 7.2       |
| Neck            | K-car  | 1.3         | 0.9         | 0         | 0         |
|                 | Standard vehicle | 0.7        | 1.4         | 4.3       | 1.5       |
| Face            | K-car  | 0           | 0.9         | 0         | 9.4       |
|                 | Standard vehicle | 1.1        | 1.8         | 1.4       | 3.6       |
| Chest           | K-car  | 7.5         | 4.7         | 18.8      | 9.4       |
|                 | Standard vehicle | 6.7        | 4.2         | 10.1      | 8.7       |
| Abdomen         | K-car  | 1.3         | 1.9         | 12.5      | 9.4       |
|                 | Standard vehicle | 3.7        | 0.4         | 15.9      | 3.6       |
| Lumbar          | K-car  | 1.3         | 1.9         | 0         | 0.0       |
|                 | Standard vehicle | 2.2        | 0.4         | 0.0       | 2.6       |
| Upper extremities | K-car | 2.5         | 1.9         | 0         | 3.1       |
|                 | Standard vehicle | 5.2        | 2.9         | 13.0      | 3.6       |
| Lower extremities | K-car | 6.3         | 0.9         | 6.3       | 0         |
|                 | Standard vehicle | 6.3        | 2.7         | 18.8      | 20        |

* $P < .01.$
not for other passengers. To overcome these problems, further research based on real-world accidents is needed.

Because K-cars contribute to a reduction in CO₂ emissions and fuel savings and are inexpensive, the use of K-cars may be considered in countries other than Japan. We believe that the present result is useful not only to the users of K-cars but also to scientists and technicians contributing to traffic safety.

Supplemental Material

Supplemental data for this article can be accessed on the publisher’s website.

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