◎ 논 문

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12인승 밴 전복사고의 상해 분석

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Injury Analysis of a 12-passenger Van Rollover Accident

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Key Words : Rollover accident(전복사고), Injury severity(외상중증도), Occupant's position(탑승자 위치)

ABSTRACT

The fatality of rollover accidents in motor vehicle crashes is high despite their low incidence. Through the investigation of a 12-passenger van rollover accident in which 10 passengers were involved, we intend to analyze the correlation between the severity of the injury and the position of the occupants. We collected accident information from medical records, interviews, photo-images of the damaged van, field surveys, and the results of the Korean New Car Assessment Program (KNCAP). Based on the occupants' position, we classified injury sites and estimated injury severity. Passenger injury severity was evaluated by trauma score calculation. The initiation type of the rollover accident was passenger side 'fall-over' and the Collision Deformation Classification (CDC) code for the damaged van was 00TDZO3. The crash of the van involved 10 passengers, with an average age of 16.3±4.2 years. Few of the occupants had fastened seat belts at the time of the incident, and there was no airbag installed. One patient sustained severe liver injury and another was diagnosed with a fracture of the right humerus. The most common injuries were at the upper extremities and the neck. The average of Injury Severity Score (ISS) was 4.8±5.9, and the average ISS of right-seated, mid-seated and left-seated occupants was 7.5±9.3, 1.5±0.7, and 3.3±2.1 respectively ($p>0.05$). In the rollover (to-passenger side) accident of occupant unfastened, the average ISS of right-seated occupants (near side) was higher, but there was no statistically significant difference.

1. INTRODUCTION

In motor vehicle accidents, a rollover accident is defined as a vehicle rotation of at least one-quarter turn along its lateral or longitudinal axis[1),2)].

The National Automotive Sampling System-Crashworthiness Data System (NASS-CDS) classified it into many types according to the initiation of the rollover[3)]. They differentiated rollovers as follows: Trip-over is a type of rollover initiated by the lateral motion of the vehicle; Fall-over is a type of rollover happened when the center of gravity becomes outboard of vehicle's wheels by the downward slopes of a road in the driving direction; Flip-over is a vehicle's rotational movement along its longitudinal axis by a ramp-like obstacle; Turn-over is a type of rollover initiated by centrifugal forces from a sharp turn. Other types include: 'bounce-over', 'climb-over', 'end-over-end', and 'collision

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with another vehicle'. Of 6,159,287 police-reported crashes in the United States in 2005, only 4.1% involved a rollover motor vehicle accident, which, however, accounted for 34.4% (10,816) of all passenger vehicle fatalities[4]. The risk of rollover increases in Sports Utility Vehicle (SUV) and van because of their relatively high center of gravity, which is worsened with the addition of vehicle occupants[5]. Major injuries in rollover accidents result from occupants' collision against the vehicle interiors or direct compression by the intrusion, or ejection[6],[7]. Occupants' injuries are also affected by whether they have fastened seat belts at the time of the incident or not. Where seat belts are unfastened, occupant-to-occupant interaction may become the major cause of occupants' injuries. Roof intrusion and partial or full ejection from rollover crashes were associated with high risk auto crash, and were considered as criteria to be transported to a trauma center[8]. It is important for physicians to know the accident mechanism for evaluation and management of patients. We aim to identify correlations between injury severities and occupants' positions through the detailed evaluation of one rollover accident 'fall-over type' involving ten passengers in a 12-passenger van.

2. METHODS

2.1. Accident Summary

A 12-passenger van, which was driving 10 students to a private institute, was running on a narrow one-lane road on a winter night. The paved road was sharply curved, and the van fell over a 1.7 m precipice (Fig. 1). It turned over to the passenger side and rolled over coming to a stop in a brook with the roof down.

Fig. 1 Curve road where the rollover accident happened

All of the male students (n=6), as well as one female student, escaped from the van, but two female students had been too severely injured to leave the van, and waited for rescue. When the rescuers arrived at the accident scene, one female student had lost consciousness, and the other could not move, complaining of pain in her right arm. The two female patients were transported to a hospital via an ambulance. We analyzed a rollover accident of a 12-passenger van which had 10 occupants aboard at the time of the accident. An accident summary was made by a review of medical records, as well as interviews with the occupants and 119 rescuers. We visited the repair shop which kept the damaged van and made a photographic observation of the damaged van. We also investigated the accident scene. Four months later, all occupants of the van, including the driver, were interviewed at their private residences after oral consent, and information on pre-accident seating position and posture, accident situation, and on post-accident rescue work was obtained. The extent of vehicle deformation was expressed in terms of the Collision Deformation Classification (CDC) code provided by the Society of Automotive Engineering (SAE J224). The principal direction of force, location, and extent of the crash were recorded according to the CDC code. The CDC code was completed with the reference to the photographic images of the damaged van.

Occupants' severities were represented as Glasgow Coma Scale (GCS), Revised Trauma Scale (RTS), and Injury Severity Scores (ISS). The result of evaluation for rollover risk of the accident vehicle was reviewed at Korean New Car Assessment Program (KNCAP), and we calculated the change of the Static Stability Factor (SSF)[9].

3. RESULTS

3.1. Investigation of the Damaged Van

The accident vehicle was a Hyundai STAREX® model which was a 2001 made by Hyundai Motor Company.

Investigation of the damaged van showed that roof intrusion was mainly over the right seats. The right side and rear windows were broken and the wind-shield was missing. Inspection of the interiors revealed that the seats of the folding type were damaged (Fig. 2).

The CDC code of the damaged van was as follows.

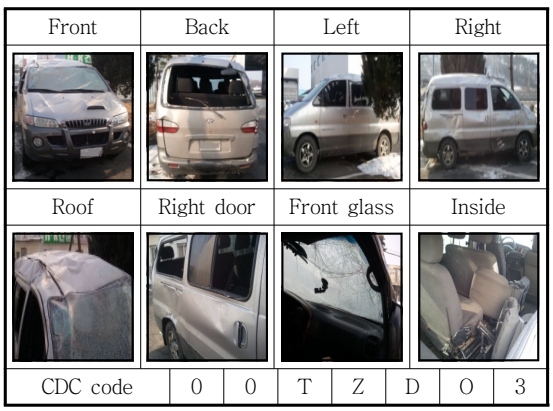

Fig. 2 Photo images of damaged vehicle on each view and description of Collision Deformation Classification (CDC) code in rollover accident

The first two figures, the direction of the force applied to the car at the collision, was 00 in the rollover. The first location of the collision was T (top), the second character of the CDC code which represents the hori-zontal location of the collision was Z (passenger and back zone), the third character of the CDC code which represents another horizontal location of the collision was D (distributed zone), and the forth character of the CDC code which represents the damage pattern was O (rollover). The last column of the CDC code which represents the deformation extent ranging from one to nine was 1. Therefore, the CDC code was 00TZDO3.

3.2. Patients' Demographics and Injury Severity

There were 10 occupants, with an average age of 16.3 ± 4.2. There were four near-side (the leading side) occupants, and four far-side (the trailing side) occupants, with the remaining two seated in the middle. They ranged in age from 14 to 17 years, except for

Table 1 Summary of injured occupants in the private institute bus at the time of the crash

Case	01	02	03	04	05	06	07	08	09	10
Sex	male	male	male	male	female	female	male	male	male	female
Age	28	17	14	15	14	15	15	15	14	14
BMI	22.0	18.8	20.1	19.3	22.0	19.0	18.9	18.8	20.4	23.3
Position	Driver's side	Row 1 mid-side	Row 1 passenger's side	Row 2 driver's side	Row 2 mid-side	Row 2 passenger's side	Row 3 driver's side	Row 3 passenger's side	Row 4 driver's side	Row 4 passenger's side
Seat belt	Yes	No	No	No	No	No	No	No	No	No
Airbag deployment	No	No	No	No	No	No	No	No	No	No
GCS	15	15	15	15	15	14	15	15	15	15
cRTS	7.84	7.84	7.84	7.84	7.84	7.84	7.84	7.84	7.84	7.84
MAIS	2	1	1	1	1	4	1	1	1	2
ISS	6	2	1	1	1	21	3	2	3	6
P value*	0.727			0.560			1.000		0.286	
P value**	0.233	0.340	0.769							
Injury site	1,4,6	3,4	3	6	6	1,5,6	3,4,7	3,6,7	1,2,3,4,6	2,3,6,7

BMI; body mass index, GCS; Glasgow coma scale, MAIS; maximal abbreviated injury scale, ISS; injury severity score, Injury site: 1 head, 2 face, 3 neck, 4 thorax, 5 abdomen, 6 upper extremity, 7 lower extremity.
Mean injury severity scores between the same row and the other rows were compared using Mann-Whitney test (P value*).
Mean injury severity scores among the driver's, mid, and passenger's side were compared using Kruskal-Wallis test (P value**).

the driver, who was 28 years old. There were three female passengers and seven male passengers.

All occupants, besides the driver, had unfastened seat belts at the time of the accident, and there was no airbag installed in the van. The demographic findings of subjects are shown in Table 1. The injury sites of the occupants were as follows: upper extremity (7 cases), cervical spine (6 cases), chest (4 cases), and head (3 cases) etc. In the comparison of ISS according to the occupants'seat column, the occupants seated on the right had the highest score (7.5±9.3), followed by those on the left (3.3±2.1) and those in the middle (1.5±0.7) ($p>0.05$). In the comparison of occupant's ISS according to the seating row in which they were positioned, the 2nd and 4th-row passengers suffered the highest incidences of severe injury (7.7±11.5, 4.5±2.1, respectively, $p>0.05$).

3.3. Illustrative Cases

3.3.1. Combined head, back and shoulder injury (case 1)

The 28-year-old driver (seated on the left in row 1) had multiple injuries including cerebral concussion, back sprain, and contusions at both shoulders. He alone had a fastened seat belt, but he lost consciousness at the accident scene. We postulated that he lost consciousness following head impact with the vehicle roof. We assumed that he was subjected to the greatest degree of initial rotational torque by the rollover mechanism. Fortunately, he was diagnosed with simple cerebral concussion and back sprain without fracture or internal organ injury.

3.3.2. Liver laceration with hemoperitoneum (case 6)

A 15-year-old girl seated on the right in row 2 sustained abdominal pain. She lost consciousness at the accident scene, and was rescued by 119 rescuers. When she arrived at the emergency room, she appeared drowsy, and her blood pressure was 90/60 mmHg. The finding of her abdominal CT showed liver laceration with minimal hemoperitoneum (Fig. 3A). She was admitted

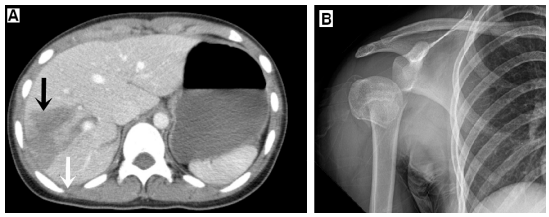

Fig. 3 CT findings of liver laceration and hemoperitoneum in case 6 (A) and fracture of right humerus neck in case 10 (B).
A. This image shows the contrast abdomen computed tomography scan in case 6, revealing liver laceration in segment 7, 8 areas (black arrow) and fluid collection (white arrow). B. This image shows cortical breakage of right humerus neck in case 10.

to the intensive care unit and was discharged without operation a month later. We assumed that she was given a lesser degree of initial rotational torque, and she had been compressed beneath two students who were seated beside her in the van.

3.3.3. Right-sided shoulder injury (case 10)

A 14-year-old girl was seated on the right in row 4. She was using her mobile phone at the moment of the accident and her arm was snapped to the broken window. Upon the arrival of 119 rescuers, she complained about pain and limitation of movement in her right arm. After arrival at the hospital, she was diagnosed with a fracture of her right humerus (Fig. 3B) as well as contusions and abrasions of the jaw. She underwent an operation of open reduction and fixation on her injured humerus.

4. DISCUSSION

Rollover motor vehicle accidents can be classified according to both the cause and the direction of rollover. Among the rollover types by NASS-CDS, 'trip-over' and 'fall-over' are the most common types of rollover accident[3]. There is another classification for passengers in the rollover crash using the degree of the rotational torque during the rollover. In this classification, outside arc and inside arc are applied to passengers, and

outside arc has a greater degree of torque than inside arc.

As the degree of passenger consequence shows considerable difference according to the type of rollover motor vehicle accidents, knowledge of the rollover type can help physicians evaluate and manage injured patients. Especially for children passengers aboard school buses, the rollover type crash is the most common mechanism leading to severe injury[10]. In the rollover accident of school bus, it is necessary to triage with some knowledge about rollover mechanism at the accident scene for the management of mass casualties. The main reason why vans tend to roll over can be explained with geometry. Because the hip-position of multiple purpose vehicles is designed to be higher than its center of gravity, the additional weight of occupants renders the center of gravity higher, which is completely contrary to the case of a passenger car (Fig. 4). The SSF is a measurement affecting rollover accidents and is calculated as the vehicle track width (mm) divided by double the height of the vehicle's center of gravity (mm). Loading the vans with passengers raises the center of gravity, and this result in a lower SSF and consequently a greater likelihood to roll over, effectively demonstrating the increased top-heaviness of the vehicle[11]. The KNCAP provides the results of evaluation for rollover risk. In our case, the total weight of occupants excluding the driver was 516 kg, which made the center of gravity height rise by as high as 15 mm. Therefore, the SSF was reduced from 1.07 to 1.05. Twelve-passenger vans have a larger payload capacity and loading these vans to their Gross Vehicle Weight Rating has an adverse effect on the rollover propensity, due to the increase in the height of the center-of-gravity. All occupants except the driver in our study were middle school students, and the injury severity of the leading side occupant in rollover accidents was higher than those of trailing side occupants. It has been reported that initial rotational torque and roof crush that the outside arc occupant experiences might be related to their mortality and injury severity[5]. In this study the belted driver who was seated outside of center during rollover experienced the highest torque and is thought to have lost his consciousness due to impact against the roof on the passenger side during the fall-over accident. The height of the fall-over was just 1.7 m, and the roof crush was not severe, and so, driver's head injury was not severe. All occupants, except the driver, were injured by passenger interaction and by collision with the interior of the car.

An unbelted rollover crash is different from a belted rollover crash in that the one is likely to have a much greater rate of occupant ejection and a corresponding increase in mortality rates compared to the other. It has been reported that the risk of death following a rollover was 1.6 times higher for the belted outside

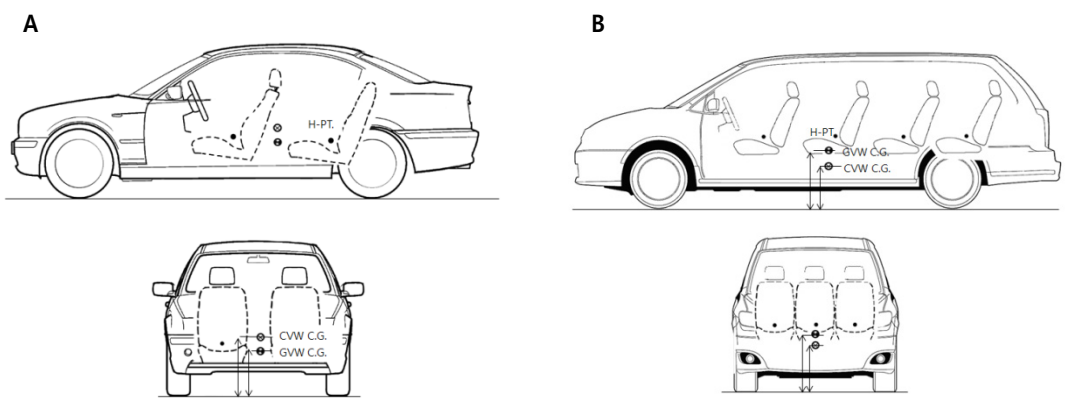

Fig. 4 Layout of Center of Gravity and Hip-Point for Sedan (A) and multi-purpose vehicle (B). h-PT: hip point, CVW C.G: center of gravity in curb vehicle weight, GVW C.G: center of gravity in gross vehicle weight.

arc occupants when compared with the inside arc occupants because the torque also increased as the distance from the pivot point of the rollover increased[5].

In rollover crashes with unfastened seat belts, occupant-to-occupant interactions can be factored in the injury causes of rollover accidents. The evidence of occupant-to-occupant interaction is difficult to detect and investigate in motor vehicle accidents.

In the investigation of the effect of occupant-to-occupant impacts in side-impact vehicle crashes, the NASS data showed an 8.3% increased injury risk for the driver on the impact side if the front passenger' belt is fastened and a 30% higher injury risk if the front passenger is unbelted[12]. Just as occupants on the impact side of a vehicle in side-impact vehicle crashes can be injured by occupant-to-occupant interaction, occupants on the near side of rollover may be injured by the collision with an adjacent unbelted occupant in the same row. We could investigate occupant-to-occupant interaction by occupants' interviews after the accident and found out that leading side occupant was held down by an adjacent unbelted occupant so that injury severity was higher in leading side occupants than in trailing side occupants.

This study was accomplished through review of medical records and interviews with patients of a rollover accident involving 10 passengers in a 12-passenger van. Although we are still far from any general conclusion about injury mechanism at rollover accidents for the lack of nationwide data about school van accidents, especially ones full of passengers at the time of accident, it was evident that the initial rotational torque and the occupant's position in the rollover motor vehicle accident could make differences to the occupants' injury severities. Moreover, occupant-to-occupant interaction might aggravate the injury of the leading side occupant in rollover motor vehicle crash (MVC). Rollover MVCs have many types. To understand which type of rollover MVC has occurred and which is the leading side may help paramedics and emergency physicians perform rescues, field triage, and patient's evaluations.

5. CONCLUSION

In the fall-over accident of a 12-passenger private school van, most unbelted passengers were injured by contact with other occupants and the interior. The injury severity of leading side occupant was higher than those of trailing side occupants because of occupant-to-occupant interaction with unbelted adjacent occupants. The rollover accident of the school van caused severe injuries to the passengers. Understanding of detailed mechanism about rollovers may help physicians or rescuers triage and manage patients at the accident scene, and help evaluations at in-hospital phase.

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