Advanced Accident Research System with the Medical and Engineering Network in Japan

Koshiro Ono [1], Shinichi Takayama[1], Koji Mikami [1], Susum Ejima [1], Kunihiro Mashiko [2], Mototsugu Kono [3], Hideyuki Ohashi [4]

Abstract The improvement of vehicle safety is not the only concern essential for the reduction of road accident casualties and injuries; immediate medical care, such as emergency medical treatment at the scene of road accidents is also necessary. Current research reports support the fact that trauma death in car accidents is preventable. The purpose of this study is to integrate pertinent medical and engineering information and propose an effective injury-reduction methodology for actual traffic accidents. This paper introduces such a prototype medical-engineering system. Example cases are provided to demonstrate the ability of this system to improve crash/injury assessment. In addition, accident reconstruction simulation supplements this accident analysis system.

Keywords vehicle safety, emergency treatment, traffic accident, injury assessment, mathematical simulation

I. INTRODUCTION

Up until now, most accident research has focused on the behavior of vehicles during crashes and factors related to vehicle shapes, structures and safety devices. Such research [1], [2] has not sufficiently utilized medical treatment and paramedic data that can be obtained from hospitals. Likewise overlooked are accident data linked with emergency treatment data which could enable analyses of the mechanism of injury during an accident from both medical and engineering perspectives. These data can make it possible to investigate methods of effectively reducing the number of injuries and fatalities. In addition, an accident sampling survey conducted by the medical and engineering network makes it possible to prepare basic data on the conditions of accident occurrence, emergency medical systems, systems for transmitting accident information, etc., that had not been adequately considered before.

This is especially the case with accident data linked with emergency treatment data. Unlike the contents of conventional surveys, detailed records include information such as diagnostic methods, emergency treatment and conditions of transporting victims from the accident scene to the hospital. Using these data in conjunction with information about injury locations obtained from accident studies, it is possible to integrate the injury mechanism along with real-time information from the attending emergency physician. Furthermore, regarding the methods for utilizing information obtained from the paramedics at the accident site (as well as methods for determining the level of seriousness of the injury at the time of emergency transport of the injured individual, etc.), medical data linked with accident data can be effectively used in a number of ways, making it possible to investigate various safety measures designed to reduce injuries.

Ultimately, it should be possible to construct an integrated medical-engineering database that can enable the effective use of accident and emergency treatment data. The use of such a database will provide detailed analyses of measures for injury reduction based on the injury mechanism clarified by accident conditions. Furthermore, these analyses will help to enhance the safety of vehicle passengers and reduce the number of injuries and fatalities. Moreover, the use of video and event data recorders as new advanced data sources will effectively help to reduce injuries and enable more detailed study of accident prevention measures.

In order to obtain detailed information of traffic accidents, ITARDA [3] conducts in-depth accident investigation, collecting crash information with respect to the crash environment, vehicle, occupants and injuries. These data provide detailed information about vehicle damage and the crash environment; however, the data collection system has a limited amount of data on occupant injury outcome. In the U.S., the

Koshiro Ono is the Executive Research Adviser & Research Director at Japan Automobile Research Institute, and Senior Researcher at the Institute for Traffic Accident Research and Data Analysis (ITARDA) in Japan (Ph +81 29 856 1114, fax: +81 29 856 1433, kono@jari.or.jp). Shinnichi Takayama and Koji Mikami are Researchers at the Japan Automobile Research Institute (JARI) in Japan. Susumu Ejima is a Chief Researcher at the Japan Automobile Research Institute in Japan. Kunihiro Mashiko is Professor and Director of the Acute Emergency Department at Nippon Medical Hospital Chiba Hokuso Hospital in Japan. Mototsugu Kono is Director of Acute Emergency Department at Tsukuba Medical Center Hospital in Japan. Hideyuki Ohashi is the Chief Investigator of the Tsukuba Accident Investigation Office at the Institute of Accident Data Analysis Center in Japan

hospital-based accident research system called CIREN (Crash Injury Research Engineering Network) (http://www.nhtsa.gov/CIREN) [4] has been working for over twelve years. The CIREN center has integrated detailed accident information such as vehicle, occupant and injury information, and it has used a methodology known as “Bio Tab” [5] to analyze and document the causes of injuries resulting from vehicle crashes.

Occupant injury in large measure depends on the crash configuration and on occupant age, gender, and physique; thus, it is essential to examine the injury mechanisms from a medical perspective by employing medical information. Moreover, when we consider traffic safety, it is important to figure out the relationship between accident conditions and the injury of the occupant based on his/her individual characteristics. Therefore, it is necessary to study the following key points to reduce casualties from motor vehicle crashes: 1) the impact as it relates to the injury outcome; 2) the physiological changes caused by the injury; and 3) injury patterns based on the anatomical structure of the human body.

As a starting point, the accident reconstruction based on the accident investigation and the analysis of the differences of the occupant’s individuality should be considered. The correlation between crash condition and injury was studied, with medical imaging data taken by CT, X-ray or MRI by the attending emergency medical doctor. Figure 1 illustrates the injury-reduction methodology for reducing casualties. The data collection system includes not only the accident data but also detailed medical records. First, a detailed accident case study was performed to estimate the injury pattern and the kinematics of the person involved in the accident. These investigations were linked to detailed medical records of the human injuries, wherein the progress of emergency medical care, radiological images and treatment were included. Reviews of cases were conducted to examine the causation of human injuries based on the physical evidence. In addition, a digital human model was utilized to reconstruct the injury outcome based on the accident data in order to understand more about the injury mechanisms of the persons involved. In this process, results from the simulation were validated against the accident data to ensure consistency.

In Japan, automobile crash safety engineering has focused on the development and improvement of safer vehicles so far. However, since the upgrading of post-crash emergency medical care is essential for the reduction of road accident casualties and injuries, it is also important to integrate this with medical and engineering information. Despite its significance, this kind of research has not been done in Japan. The advanced research of the medical and engineering network system was introduced by employing specific real-world traffic accident examples. An integrated accident crash research system associated with the medical and engineering networks will make it possible to pursue injury causation mechanisms in order to further upgrade automobile safety in Japan.

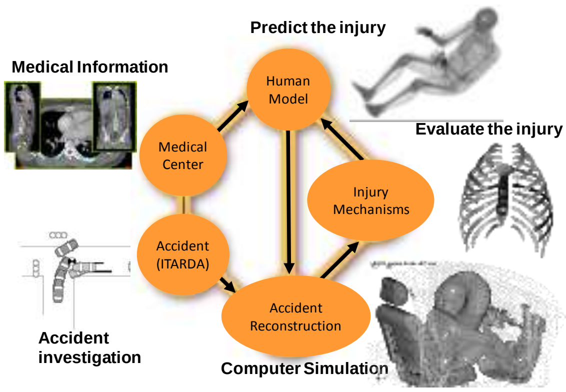


Fig. 1. Medicine and Engineering Networking

II. METHOD

Integrating an Accident Research System

The advanced accident research system started to collect detailed crash, vehicle, occupant, and injury information including the initial diagnoses of ambulance personnel/paramedics and crash investigators from ITARDA. Most of those involved in these accidents sustained at least one serious or more severe injury (AIS3+).

Following on this data collection, through a collaborative effort including the Tsukuba Fire Department, Tsukuba Medical Center Hospital and Nippon Medical School Chiba Hokusoh Hospital, as well as from an accident sampling survey conducted by the Institute for Traffic Accident Research and Data Analysis (ITARDA), it was possible to investigate injury cases that were treated in hospital. These activities led to the development of an integrated accident research system with an extended medical and engineering network as shown in Figure 2. The collaborative research conducted with the Tsukuba Fire Department, the Tsukuba Medical Center Hospital, and Nippon Medical School Chiba Hokusoh Hospital was approved after deliberation by each organization's ethics committee.

Cases for inclusion in the study were selected by ITARDA on the basis of severity of the injury of the crashed vehicle occupant. In-depth investigations of the accident vehicle and crash scene were conducted by crash investigators from ITARDA via the ITARDA protocol. Detailed accident case study was performed to estimate the injury pattern and the kinematics of the person involved in the accident. The accident data showing the injuries (emergency department information, pre-hospital record information sheet) were linked to the full medical records of the occupant.. These records included emergency medical care, radiological images, clinical progress, treatment and discharge reports. The multidisciplinary review and discussion of each case were conducted by experienced ITARDA accident investigators, biomechanical engineers with experience in impact biomechanics research and trauma physicians in order to derive the causation of the injuries based on the physical evidence, medical knowledge and injury biomechanics from the engineering point of view. In addition, a digital computer model was utilized to reconstruct the vehicle motion and injury outcome based on the accident data to understand more about the injury mechanisms of the persons involved. These reviews reconfirmed the crash severity and injury assessment in the real-life accident.

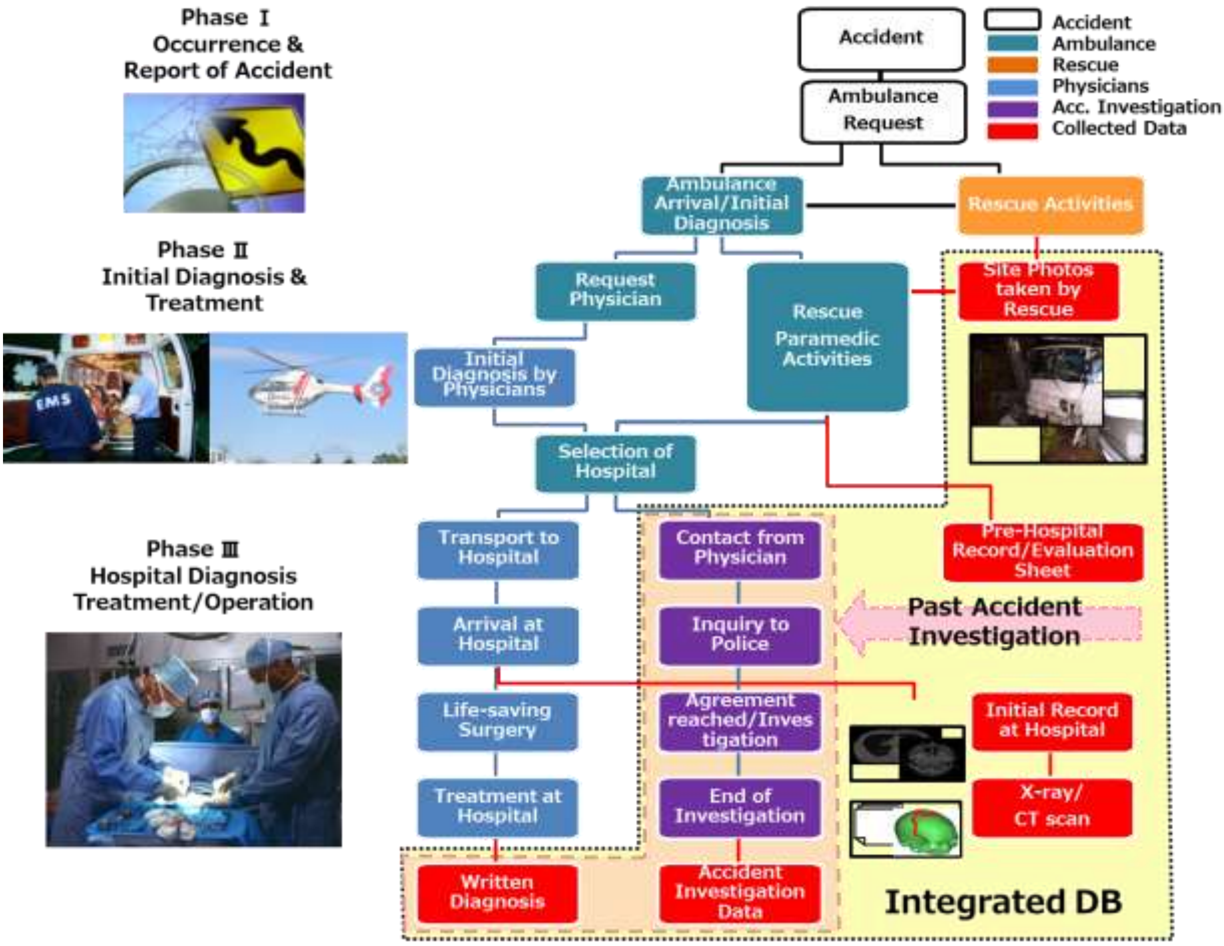


Fig. 2. Integrated Accident Research System with Extended Medical and Engineering Network.

Multidisciplinary Review of the Accident Cases

In-depth injury investigation based on the engineering and medical information – The integration of an accident research system is significant for the identification and documentation of injury causation. Such a system can define all the factors that are believed to be crucial for the occurrence and/or severity of injury. Compared to the traditional accident data collection, the integrated data include medical imaging data such as

CT, X-ray and MRI which indicate the location of bone fractures or the tissue damage that constitute the injury. In addition, the imaging data provide effective information for predicting the injury pattern related to the particular type of loading or mechanical response that can estimate the strength of the bone through BMD (Bone Mineral Density). In this system, the accident investigator, the trauma physician and the biomechanical engineer collaborate in order to discuss and examine the injury causation, considering such factors as the source of energy, direction and physical components involved.

Accident Reconstruction with Computer Simulation - In-depth accident investigation provides the injury causation scenario that can estimate the physical motion of the occupant under a particular crash condition. However, it is difficult to confirm the actual occupant condition in a complex accident case. Therefore, the occupant kinematics caused by a particular crash condition was predicted via computer simulation (combination of multi-body model and finite element model) [6]. This approach consisted of two phases as shown in Figure 3. First, the vehicle motion at the accident scene was estimated from the multi-body vehicle model using CARS3D [7]-[8]. Second, the crash pulse calculated from the multi-body vehicle model was directly applied to the interior compartment of the finite element vehicle model onto which the human model was installed [9]. The advantage of this approach is in estimating the crash pulse and the vehicle motion from the multi-body model with simple geometry. However, the vehicle deformation under the external load was not calculated in the interior compartment of the finite element vehicle model. Therefore, this approach has a limitation when the target case occupant vehicle has a large deformation in the vehicle interior. The vehicle interior model consists of a standard three-point belt system, an airbag, a steering wheel, an instrument panel and a toe pan. The mechanical property of each component is validated with the experimental study. In this computer simulation, the occupant kinematic was simulated to complement the scenario derived from the in-depth accident investigation of the crash condition.

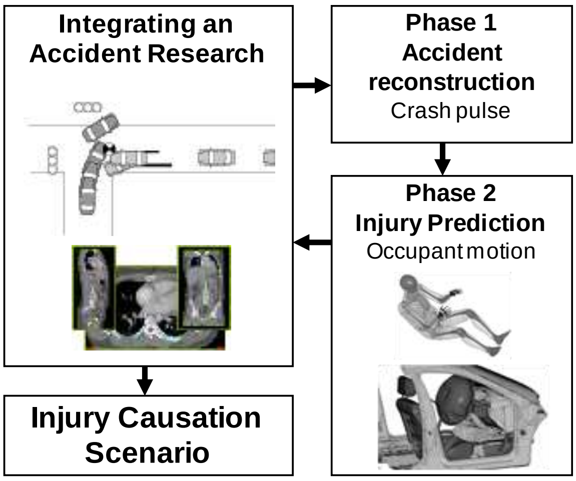


Fig. 3. Injury prediction approach based on an actual car crash accident.

Emergency medical information – When occupants are injured in their vehicles in a traffic accident, the first priority is to ensure that they receive the best medical treatment as quickly as possible. For the purpose of analyzing the injury severity based on the physiological information, the integrated accident research system collects the necessary emergency medical activity information. To understand the emergency medical activities that occurred just after the accident, Pre-hospital Records and Evaluation Sheets were utilized. These information sheets were organized by the Department of Emergency and Rescue, and detailed medical information of injured individuals is recorded on them. These sheets cover such information as specific emergency medical procedures administered at the scene, the injury condition, and transportation time history of ambulance to hospital, vital signs, initial evaluation, emergency medical decisions taken and trauma score.

On-site accident photography - For the purpose of evaluation of medical treatment, Nippon Medical School Chiba Hokuso Hospital has been taking photographs at the accident scene with the support of the emergency medical service. The pictures mainly focus on the vehicle damage and the occupant condition. The photographs taken at the accident site are immediately sent to the medical hospital via mobile phone. Based on the photographs, medical doctors evaluate the injury and prepare for the appropriate treatment in advance.

III. RESULTS OF THE APPLICATION OF THE INTEGRATED SYSTEM

Collected Accident Cases

Based on the collaborative study by JARI, Tsukuba Medical Center Hospital and Nippon Medical School Chiba Hokuso Hospital and ITARDA, 45 accident cases were collected and in particular, 8 of them were investigated with the medical and engineering network system. The accident types used in this study were vehicle-to-vehicle, single-vehicle and vehicle-to-pedestrian. Table 1 shows a brief summary of each accident case and the collected items in the system:

Table 1 Summary of accident cases

No.	Crash configration	Vehicle	Age	Gender	Position	Injury severity
1	Frontal	A1	23	M	Driver	Serious
		B1	62	M	Driver	Slight
2	Frontal	A2	73	M	Passenger	Serious
		A1	20	M	Driver	Slight
		B1	50	M	Driver	Slight
3	While working on road	A1	37	F	Driver	Non
		B1	92	M	Seniorcar	Fatal
4	Crossing collision	A1	31	F	Driver	Slight
		B1	30	M	Driver	Non
5	Others	B1	1	M	Pedestrian	Serious
6	Rear	A1	26	M	Driver	Fatal
7	Crossing collision	A1	20	M	Driver	Slight
		B1	55	M	Driver	Slight
8	Single-vheicle	A1	22	M	Driver	Serious

The list of items:
1. Crash and medical summary
2. Accident site information
   - Environment: roadway, traffic, and weather
   - Type: collision angle, speed, and CDC
3. Accident car information
   -Vehicle: make/model/year, size, weight
   - Analysis result: delta V, EBS
4. Detailed medical records
   - Emergency medical process
   - Radiological images and report
   - Clinical process
   - Discharge report

Example of Injury Causation Analysis Using Integrated Accident Research

Case Review 1 - This case involved a 23-year- old unbelted male driver in a head-on collision in a small car as shown in Figure 4 (green vehicle). As his vehicle approached a gentle left curve at a high speed, he failed to negotiate a left turn and collided with an oncoming car. The delta V was 70 km/h and the vehicle damage (CDC code = 12FZEW5), shown in Figure 5, was to the front and major. There was intrusion of the vehicle interior components into the driver's space and a steering-wheel airbag was not installed in this vehicle. As shown by the CT scan of Figure 6, the driver sustained fractures of the pelvis and femur. These fractures are classified as an AIS 2 injury for the pelvis and AIS 3 for the femur. In this case, the occupant's chest also made contact with the steering wheel and sustained a bruise and a bilateral lung contusion (AIS 3). The injury causation scenario for this injury is as follows:

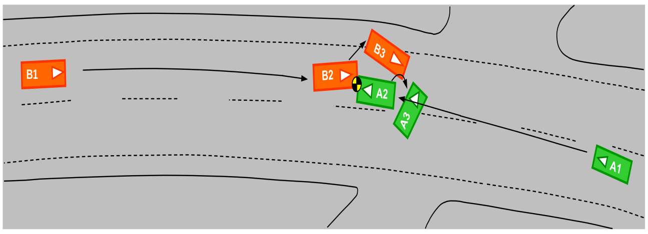


Fig. 4. Case Review 1: Accident scenario with head-on collision


Fig. 5. Case vehicle damage (head-on collision)

The narrow offset frontal impact caused both the deceleration and the rotation of the vehicle, which caused the driver to move right and forward relative to the vehicle interior. With no airbag deployment and with relatively little space between the driver's lower extremity and the instrument panel, the driver's knee made contact with the lower panel. There was physical evidence of the lower extremity making contact with the instrument panel as shown in Figure 6 (blue arrow). The oblique pattern noted on the driver's right femur X-ray (red arrow) is consistent with a compressing load. The contact generated compression of the femur and, coupled with a resulting bending load of the femur head, caused the femur head and pelvis fractures observed in the pelvis 3D-CT image (red arrow). Because of the intrusion of the vehicle interior components, a bilateral lung contusion was caused by the steering assembly.

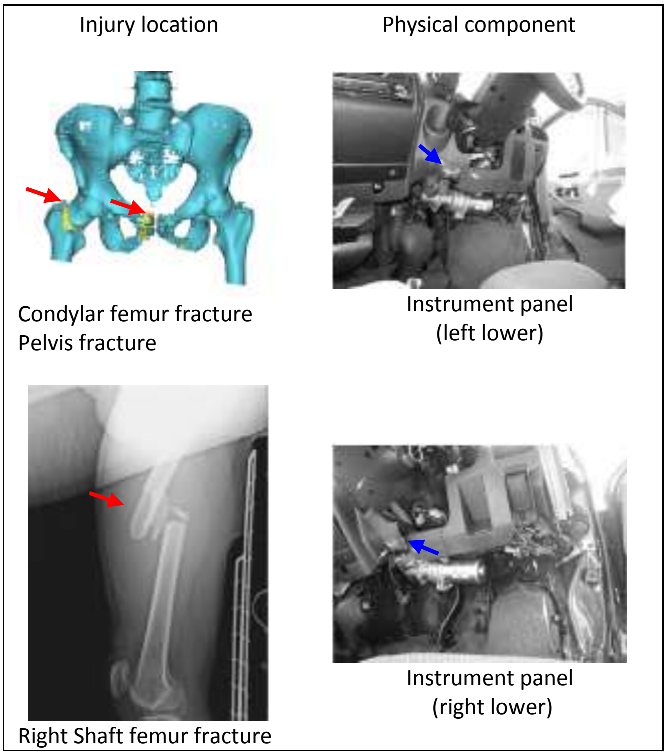


Fig. 6. Occupant injury based on the physical evidence (Case Review 1)

The injury causation scenario was reconstructed by means of computer simulation. As previously described, the interior compartment of the finite element vehicle model did not calculate the large deformation of the interior compartment of the occupant's case vehicle. Therefore, only the initial stage of the occupant kinematic motion was calculated in this accident reconstruction to complement the accident scenario. In this sense, the simulation approach of this prototype study has a limitation as far as reconstructing the exact accident situation. Figure 7 shows the crash behavior of the head-on collision with a rigid body model. First, the vehicle model whose size and weight were adjusted based on the specification and the boundary condition analyzed by the accident investigation was applied to both vehicle models. This result shows that the final stop position of the target vehicle (blue vehicle) was close to the position which was investigated at the accident scene (Figure 4: A3 - green vehicle). If the curbstone is not taken into consideration, the opposite vehicle's (white vehicle) stop position was different from the actual accident vehicle (Figure 4: B3 - orange vehicle). Next, the crash pulse was extracted from the vehicle and this information was inputted into the interior car compartment to predict the occupant motion and injury mechanisms. Figure 8 indicates the sequential image of predicted occupant motion at the initial stage (0 -100ms) after the impact by using the finite element human model. Because the driver was unbelted, the occupant hit his knee on the instrument panel and the impact load was transferred to the pelvis through the knee and femur. Because the chest made contact with the steering wheel just after the knee made contact with the instrument panel, the chest was fairly compressed. The occupant's torso was restrained by the steering assembly and the head moved forward relative to the torso. As a result of this phenomenon, there is a possibility that the face made contact with either the steering assembly or the windshield. However, bruising of the patient's face was not included in the reports that came from the crash investigators and medical personnel.

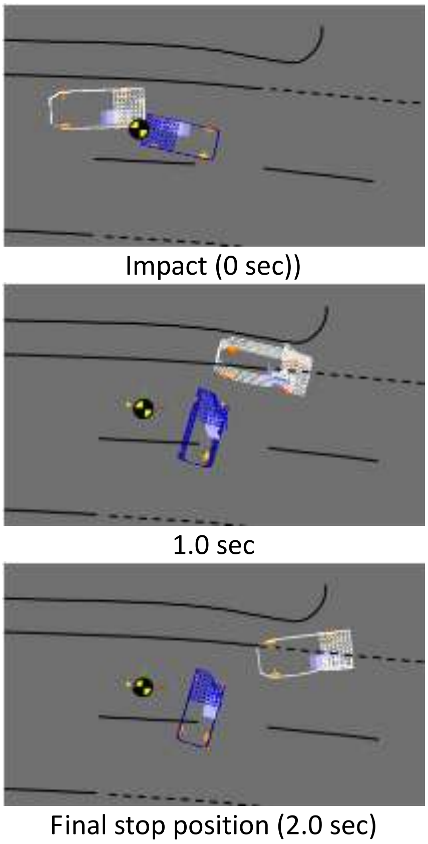


Fig. 7. Accident reconstruction simulation with rigid-body model (CARS3D)

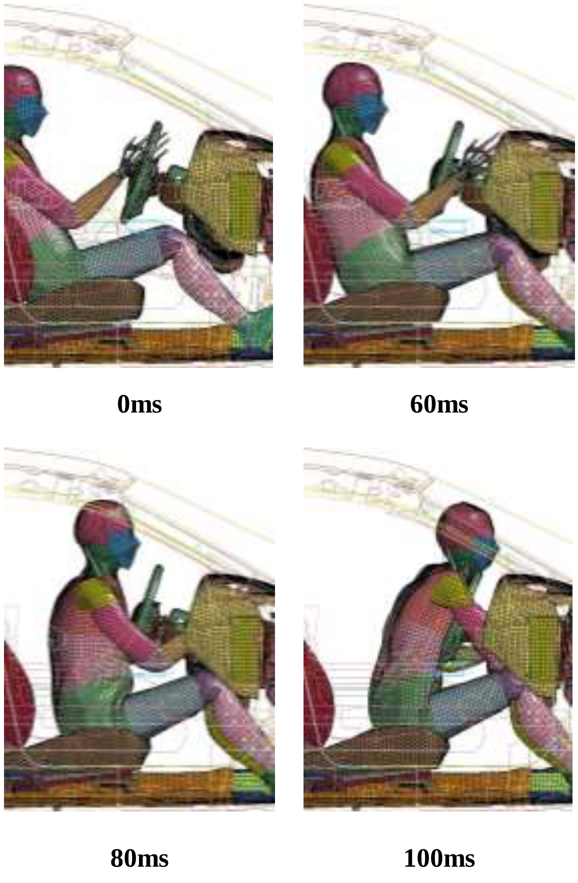


Fig. 8 Prediction of the occupant motion by using finite element human model

Case Review 2 - In this crash, a 22-year-old male fell asleep at the wheel, the vehicle swerved from the roadway and the right front of the vehicle struck a telephone pole as shown in Figure 9. The vehicle damage (CDC code = 01FRW4) shown in Figure 10 was severe and the delta V was calculated at 30 km/h. The lower extremity was caught between the seat and the intruding instrument panel, but the occupant was pulled out alive from the damaged compartment by the rescue team. The case occupant sustained right medial malleolus tibia fracture and shaft fibula fracture as shown in the X-ray image of Figure 10. The injury causation scenarios for these fractures are described as follows:

For the right fibula, intrusion of the instrument panel was a contributing factor in bending the long bone. The fracture pattern of the fibula in Figure 11 also explains the effect of bending from the X-ray image. For the right tibia, the telephone pole intruded inside the interior compartment and the toe pan was damaged because of the impact from the intrusion. This phenomenon is a critical factor in breaking the local region of the bone in the injury causation scenario.

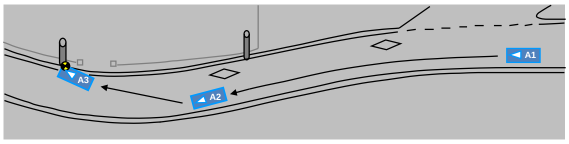


Fig. 9. Case Review 2: Accident scenario with single-vehicle

Fig. 10. Case vehicle damage (single-vehicle)

Injury location | Physical component

Right shaft fibula fracture

Instrument panel (Right side view)

Right medial malleolus tibia fracture

Toe-pan (lower)

Fig. 11 Occupant injury based on the physical evidence (Case Review 2)

Table 2. Time history of the occupant condition

			Transportaion					Hospital
Vital Signs	Time Period [min]		0	27	52	55	61	67
	JCS		I	Lucidity	Lucidity	Lucidity	Lucidity	0
	GCS	E	4					4
		V	5					5
		S	6					6
	Respiration [times/min]		Fast	24	24	24	24	22
	Beat [times/min.]		Normal		82	82	84	100
	BP	upper [mmHg]			137	136	158	170
		lower [mmHg]			79	94	82	120
	SpO_2	Oxygen[ℓ]		10	10	10	10	
		SpO_2 [%]			100	100	100	100

In this occupant case, the emergency medical summary was recorded. The occupant made an emergency call from his mobile phone after the accident and it took 18 minutes for the EMS (Emergency Medical Service) to arrive at the scene. Because of the rescue operation, it took an extra 35 minutes to move the injured occupant to the ambulance at the accident site. During the rescue operation, EMS took on-site information (photograph) and transferred it to the medical center for the purpose of injury evaluation by the trauma physician. On-site information shows that the telephone pole intruded into the driver side of the front bumper of the case occupant vehicle. This specific physical evidence was valuable information for predicting the injury. After the rescue operation, the injured was brought to the ambulance and the initial evaluation of each body region, which could not be easily done in the damaged vehicle, was conducted by the emergency service. In this case, the right lower extremity exhibited tenderness, contusion and bloating at the right leg region and malleolus medialis. EMS suspected a compartment syndrome with his leg at the accident site. Therefore, the emergency medical care center was selected to transfer the injured. Table 2 shows the time history of the occupant's vital signs from the accident site to the hospital.

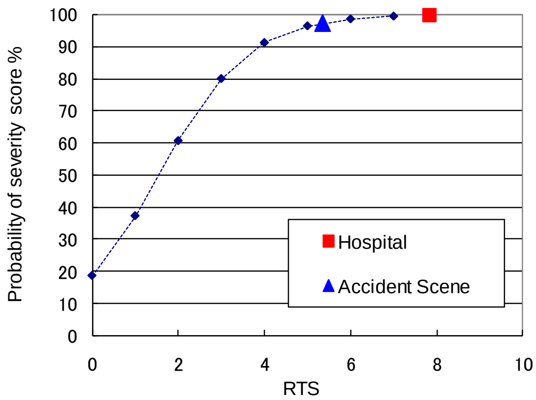
IV. DISCUSSION

An advanced integrated accident research system with a medical and engineering network was applied to real accident cases to determine and document injury causation and injury mechanisms. Although the accident reconstruction simulation has limitations, detailed medical information with computer simulation complement the injury causation scenario estimated from in-depth accident investigations and injury data.

In-depth accident analysis with medical and engineering network: The two cases described in this paper show the advantage of the integration of an accident research system compared to the traditional approach of recording injury causation and mechanisms. These examples demonstrate how this system is able to associate injuries with a particular crash event using physical evidence and medical imaging data to establish the injury causation scenario. In this process, injury causation was explained based both on the involved physical component, with the accident vehicle inspected by an experienced and trained ITARDA accident investigator, and on the medical information as diagnosed by the attending emergency medical doctors and the biomechanical engineer with experience in impact biomechanics research. In Case Review 1, there existed clear evidence of knee contact with the lower instrument panel and the typical lower extremity injury mechanism was explained with the use of medical imaging data. Moreover, the accident reconstruction simulation, although with some limitations as noted, was shown to complement the injury causation scenario and the mechanism established in the accident investigation. The simulated occupant kinematics complemented the scenario which was estimated in the discussion within the medical and engineering network. In Case Review 2, this integration of an accident research system identified the intrusion that was critical to the occupant injury in this case and on-site photographs contributed in providing more effective information for the medical doctors to use for necessary preparations.

Probability of severity score: In general the survival probability of a person involved in an accident can be evaluated by the "Golden Hour Principle" [8]. This phrase pertains to the time period within which individuals involved in an accident should be brought to the hospital following an accident. During this time period, the injured has the best chance to avoid significant deterioration of his/her conditions.

By using Case Review 2, the Probability of survival (Ps) [11], which is commonly employed for the evaluation of survival in the area of emergency medical care, is calculated. In this case, it took 35 minutes to bring the injured occupant to the ambulance at the accident site because the occupant was trapped in the vehicle and the rescue team was called only after EMS arrived. Ps is calculated by the TRISS (Trauma and Injury Severity Score) [12] based on physiological factors (RTS: Revised trauma score), anatomical damage score (ISS: Injury Severity Score) and Age. Ps is utilized as the objective assessment index when judgment of preventable trauma death is made. RTS consists of GCS (Glasgow Coma Scale), SBP (Systolic Blood Pressure) and RR (Respiration Rate). Therefore, these should change from the accident site to the hospital. Figure 11 indicates the Ps with respect to the RTS. The Case Review 2 occupant has a relatively large Ps value which improved to medication administered during transport from the accident site to the hospital. Ps evaluates the physiological index of the case occupant and this logic is effective information when the severity of injury at the accident site is discussed.



$$\mathrm{Ps} = \frac{1}{1+e^{-b}} \quad (1)$$

$$\mathrm{b} = b_0 + b_1 \times RTS \times b_2 \times ISS + b_3 \times Age \quad (2)$$

$$\mathrm{RTS} = 0.9368 \times \mathrm{GCS} + 0.7326 \times \mathrm{SBP} + 0.2908 \times \mathrm{RR} \quad (3)$$

Fig. 11. The case occupant Ps calculated from the TRISS method [11].

V. LIMITATION OF THIS STUDY AND SUGGESTION FOR FURTHER RESEARCH

In the accident reconstruction simulation, the approach applied did not calculate the intrusion of the vehicle's interior components. Therefore, the accuracy of the quantitative evaluation such as dynamic loading condition to the lower extremity and the strain distribution in the long bone during impact were not enough to predict the injury in the Case Review 1. The large deformation of the vehicle interior should be a critical factor in estimating the injury from an accident. In the next phase of this research, a multi-body vehicle model should enhance the accuracy of the estimation of the intrusion during the accident and this information will be applied to the interior compartment of the finite element vehicle model for more accurate injury prediction.

VI. CONCLUSIONS

We were able to collect information about accident surveys, life-saving activities and details of injuries. In addition, through a five-member association consisting of the Tsukuba Fire Department, Tsukuba Medical Center Hospital, Nippon Medical School Chiba Hokusoh Hospital, Institute for Traffic Accident Research and Data Analysis (ITARDA) and Japan Automobile Research Institute (JARI), we were able to construct a system for examining case studies of accidents in which the injured were transported to hospitals. Furthermore, from discussions between engineers and physicians about detailed injury information obtained from the Tsukuba Fire Department, Tsukuba Medical Center Hospital and Nippon Medical School Chiba Hokusoh Hospital, and vehicle damage conditions obtained from accident surveys, it may be possible to conduct even more detailed analyses than what has been done up to now.

This data-collection system provides not only detailed crash environments but also the causation of injuries in automobile crashes. Even though the intrusion of the vehicle was not calculated in the simulation, the digital human model helped provide possible occupant motion under impact in the real traffic accidents. Moreover, the emergency medical care process and the damaged vehicle photographs recorded by EMS (Emergency Medical Service) at the accident site provide effective information in predicting the status and degree of human injury.

In addition, we were able to acquire a very detailed understanding of the state of emergency activities at the time of an accident from newly acquired accident scene information, medical treatment data and so on. Furthermore, multi-faceted analyses of this information will make it possible to consider methods for ascertaining the degree of injury that take the attributes of the victim into account and detailed studies about the state of information transmission systems related to ambulance transport will likewise be used to examine various safety measures that will be needed in the future.

The knowledge obtained from such approaches will be used as a basis for starting discussions about physiological information (vital signs) that are needed for automatic information reporting systems. Future plans call for examination of such things as the future direction of effective injury reduction countermeasures and associated methodology.

VII. ACKNOWLEDGEMENT

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