

New Challenge of Integrating an Accident Research System with the Medical and Engineering Network in Japan

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ABSTRACT

This study introduces the accident research system integrated with the medical and engineering network in Japan. Based on the collaborative study by Japan Automobile Research Institute (JARI), Nippon Medical School Chiba Hokuso Hospital and ITARDA (Institute for Traffic Accident Research and Data Analysis), detailed accident data have been collected, and crash, vehicle damage, and injury data were analyzed. This system provides us with the “mechanism” of injury by employing in-depth accident investigation with physical evidence, biomechanical knowledge, and medical knowledge for depicting the injury causation scenario. Moreover, vehicle safety improvement is not the only essential concern for the reduction of road accident casualties and injuries; immediate medical care, such as emergency medical treatment during road accidents, is also necessary. Therefore, the information of emergency medical activities in the post-crash was also collected in this system. This paper introduces the prototype research of the integrated pertinent medical and engineering information and proposes an effective injury-reduction system in actual traffic accidents. The case examples are provided to demonstrate the ability of this system to improve crash /injury assessment. In addition, the accident reconstruction simulation supplements this function of this accident analysis system.

INTRODUCTION

Accident investigation provides the crash information with regard to the vehicle type, the crash configuration, the restraint system, the involvement and the resulting injuries. These data are important to depict the accident scenario and utilize it for reducing the causality in road traffic crashes. ITARDA has been collecting accident data to update its databases

of vehicle crashes with varying amounts of data in Japan. The traffic accident-related data derived from the police accident reports links to establishing accident database. In order to obtain detailed information of traffic accidents, ITARDA [1] conducts the in-depth accident investigation in the local area (Tsukuba) and collects the crash information respect to the crash environment, vehicle, occupants, and injury. These data provide the detailed crash environments and vehicle damage; however, the data collection system has a limited amount of data on occupant injury outcome. In the U.S., the hospital-based accident research system called CIREN (Crash Injury Research Engineering Network) [2] was set up, and this program has been working for over twelve years. CIREN center has integrated the detailed accident information such as vehicle, occupant, and injury information, and it has used a methodology known as “Bio Tab” [3] to analyze and document the cause of injuries resulted from passenger vehicle crashes.

In the discussion of automobile crash safety, it is considered that the occupant injury depends on the crash configurations, age, gender, and physiques; thus, it is essential to examine the injury mechanisms from a medical perspective by employing medical information. Moreover, when we consider the traffic safety, it is important to figure out the relationship between the accident and the injury of the occupant who has individual characteristics. Therefore, it is necessary to study the following key points to reduce the casualty from motor vehicle crashes.

1. The impact relating to the injury outcome
2. The physiological change caused by the injury
3. Injury pattern based on the human body structure

To start discussing these points, the accident reconstruction based on the accident investigation

and the analysis of the difference of the occupant individuality should be considered. The connection between the crash condition and injury was investigated with the medical image data taken by the CT/X-ray or MRI by emergency medical doctor. **Figure 1** illustrates the injury-reduction methodology for reducing the casualty. The data-collection system includes not only the accident data but also the detailed medical records. First, a detailed accident case study is performed to estimate the injury pattern and the kinematics of the person involved in the accident. These investigation are linked to detailed medical records of the human injuries, in which emergency medical care progress, radiological image, and treatment are included. Reviews of cases are conducted to examine the causation of human injuries based on the physical evidences. In addition, a digital human model is utilized to reconstruct the injury outcome based on the accident data to understand more about the injury mechanisms of the persons involved. In this process, results from the simulation are 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 emergency medical care during the post-crash time is essential for the reduction of road accident casualties and injuries, it is also important to integrate pertinent medical and engineering information. But this kind of research has not been done in Japan. This paper introduces the pilot study of the medical and engineering network system by employing a concrete traffic accident example. If an integrated accident crash research system with the medical and engineering networks is established, it is possible to pursue injury causation mechanisms in order to further upgrade automobile safety in Japan.

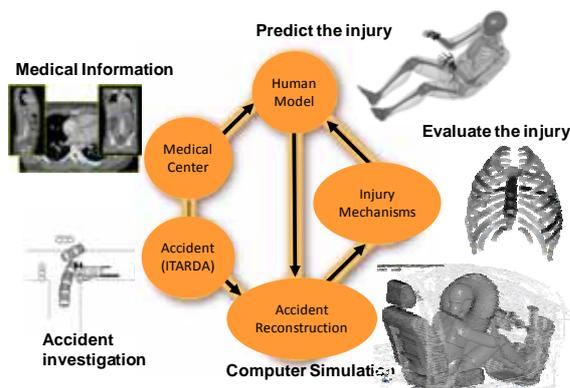


Figure 1. Medicine and Engineering Networking

METHOD

Integrating an Accident Research System

The new challenge of integrating an accident

research program started to collect the detailed crash, vehicle, occupant, and injury information, most of which sustained at least one serious or more severe injuries (AIS3+). In general, in the selection of case occupant, ITARDA selects on the basis of a severe injury of the crashed vehicle occupant. In-depth investigations of the case occupant's vehicle and crash scene are investigated via ITARDA protocol. Detailed accident case study is performed to estimate the injury pattern and the kinematics of the person involved in the accident. The accident data are linked to detailed medical records of the case occupant's injuries. These records include emergency medical care, radiological image, clinical progress, treatment, and discharge reports. The multidisciplinary review and discussion of each case are conducted by an experienced ITARDA accident investigator, a biomechanical engineer with experience in impact biomechanics research, and a trauma physician to derive the causation of the injuries based on the physical evidences, medical knowledge and injury biomechanics from the engineering point of view. In addition, a digital computer model is 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 reconfirm the crash severity and injury assessment in the real accident.

Multidisciplinary Review of the Accident Case

In-depth injury investigation based on the engineering and medical information – The foci of this integration of accident research system are on the identification and documentation of injury causation, and this system can define all the factors that have been believed necessary for the occurrence and/or severity of injury. Compared to the traditional accident data collection, the integrated data includes medical image data such as CT/X-ray and MRI, which indicate the location of the bone fracture or the tissue damage constituting the injury. In addition, the image data provide the 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 with BMD (Bone Mineral Density). In this system, the accident investigator, the trauma physician, and the biomechanical engineer collaborate to discuss and examine the injury causation considering 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 the crash condition. However, it is difficult to

confirm the actual occupant condition in the complex accident case. Therefore, the occupant kinematic caused by crash condition is predicted via computer simulation (combination of multi-body model and finite element model) [4]. This approach consists of two phases as shown in **Figure 2**. First, the vehicle motion at the accident scene is estimated from the multi-body vehicle model by using CARS3D [5] [6]. Second, the crash pulse calculated from the multi-body vehicle model is directly applied to the interior compartment of the finite element vehicle model, to which the human model is installed [7]. The advantage of this approach is to estimate the crash pulse and the vehicle motion from the multi-body model with simple geometry. On the other hand, the vehicle deformation under the external load is 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 instrumental panel, and a toe pan. The mechanical property of each component is validated with the experimental study. In this computer simulation, the occupant kinematic is simulated to complement the scenario derived from the in-depth accident investigation of the crash condition.

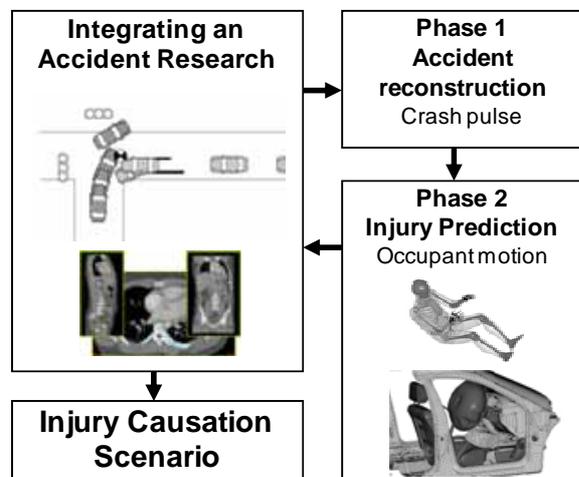


Figure 2. Injury prediction approach based on the actual car crash accident

Emergency medical information – When the occupants are injured in their vehicles in the traffic accident, the first priority is to ensure that they can receive the best medical treatment as quickly as possible. For the purpose of analyzing the injury severity based on the physiological information, the integration of accident research system collects the emergency medical activities. To understand the emergency medical activities just after the accident, Pre-hospital Record and Evaluation Sheet is utilized. This sheet is organized by the department of

emergency and rescue, and the detailed medical information of the injured is recorded on it. This sheet covers such items as a large variety of emergency process, the injury condition, activity (transportation time history), vital signs, initial evaluation, emergency medical care, medical decision, and trauma score.

On-site accident picture - For the purpose of medication, Nippon Medical School Chiba Hokusou Hospital has been taking the photographs at the accident scene with the support of the emergency medical service. The picture mainly focuses on the vehicle damage and the occupant condition. The photograph taken at the accident site is immediately transferred to the medical hospital via mobile phone. Based on this photograph, medical doctor evaluates the injury and prepare for the treatment in advanced.

RESULTS OF THE APPLICATION OF THE INTEGRATED SYSTEM

Collected Accident Case

Based on the collaborative study by JARI, Nippon Medical School Chiba Hokusou Hospital, and ITARDA, 18 accident cases were collected and particularly 8 of them were investigated with the medical and engineering network system. The accident types in this study were vehicle-to-vehicle, single-vehicle, and vehicle-to-pedestrian. **Table 1** shows the brief summary of each accident case and the collected items in the system are as follows.

Table 1 Summary of accident case

No.	Crash configuration	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-vehicle	A1	22	M	Driver	Serious

The list of the 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 image and report
 - Clinical process
 - Discharge report

Example of Injury Causation Analysis Using Integrating an Accident Research

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

The narrow offset frontal impact caused both the deceleration and the rotation of the vehicle, which caused the driver to move right forward relative to the vehicle interior. With no airbag deployment and relatively little space between the driver's lower extremity and the instrumental panel, the driver's knee contacted with the lower panel. There was physical evidence of the lower extremity contact on the instrumental panel as shown in the picture (blue arrow), oblique pattern noted on the driver's right femur X-ray (red arrow), consistent with the compressing load. The contact generated compression of 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, the bilateral lung contusion was caused by the steering assembly.

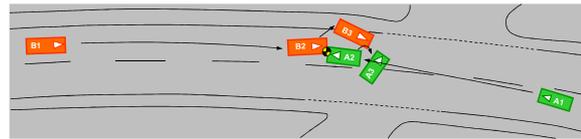


Figure 3. Case Review 1: Accident scenario with head-on collision



Figure 4. Case vehicle damage (head-on collision)

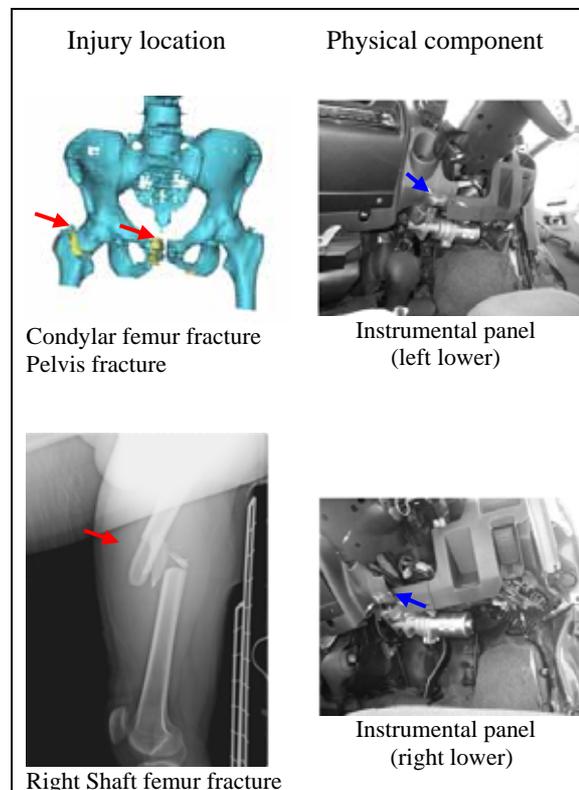


Figure 5. Occupant injury based on the physical evidence (Case Review 1)

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 case occupant 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 in reconstructing the exact accident situation. **Figure 6** 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 the 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 3: A3 - green vehicle**). If the curbstone is not taken into consideration, the opposite vehicle (white vehicle) stop position was different from the actual accident vehicle (**Figure 3: B3 - orange vehicle**). Next, the crash pulse was extracted from the vehicle, and this information was input into the interior car compartment to predict the occupant motion and injury mechanisms. **Figure 7** 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 at the instrumental panel, and the impact load was transferred to the pelvis through the knee and femur. Because the chest contacted to the steering just after the knee contacted to the instrumental panel, the chest was fairly compressed. The occupant's torso restrained to the steering, and the head moved forward relative to the torso. As a result of this phenomenon, there is a possibility that the face contacted to the steering assembly or the windshield.

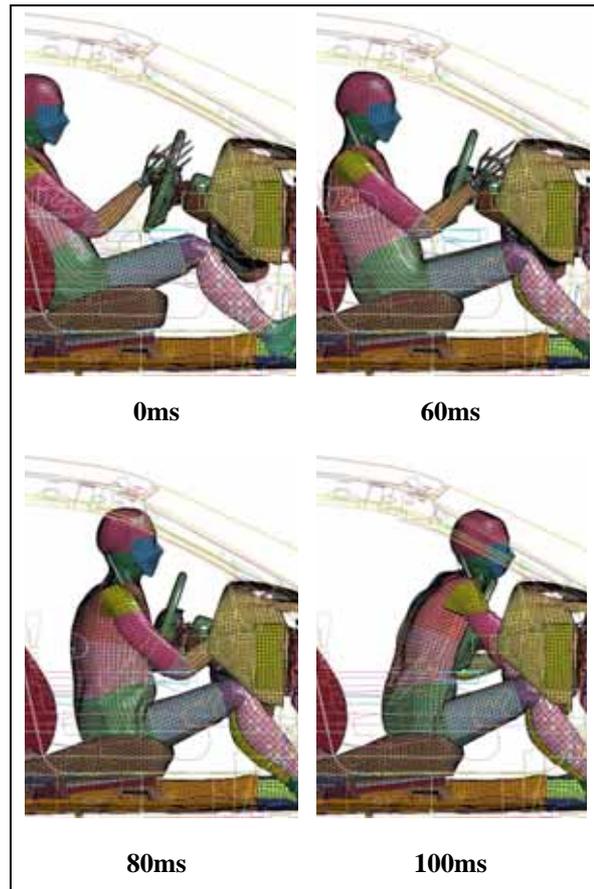


Figure 7. Prediction of the occupant motion by using finite element human model

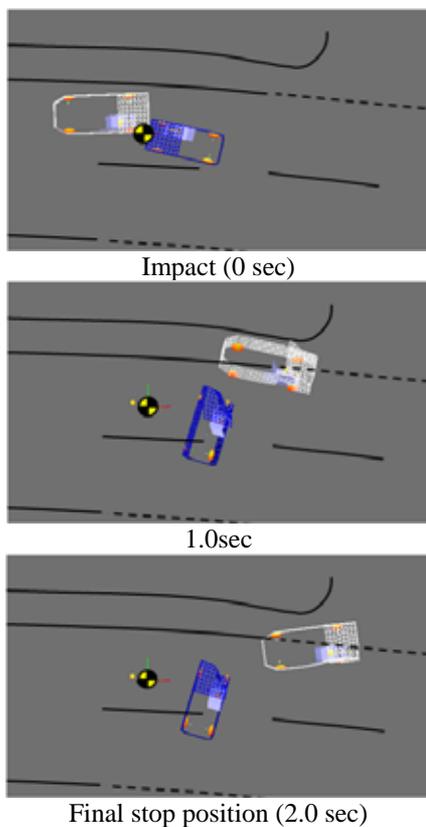


Figure 6. Accident reconstruction simulation with rigid-body model (CARS3D)

Case Review 2 - In this crash, a 22-year-old male fell asleep at his wheel, and the vehicle diverged from the roadway, and the right front struck against a telephone pole as shown in **Figure 8**. The vehicle damage (CDC code = 01FRW4) shown in **Figure 9** was severe, and the delta V was calculated at 30 km/h. The lower extremity was caught between the seat and the intruded instrumental panel, and 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 scenario for these fracture are described as follow.

For the right fibula, intrusion of instrumental panel is a contributing factor of bending the long bone. The fracture pattern of fibula in **Figure 10** also explains the effect of bending from the X-ray image. For the right tibia, the telephone pole intruded inside the interior compartment and tope-pan was damaged because of the impact intrusion. This phenomenon is a critical factor of breaking the local region of the bone in the injury causation scenario.

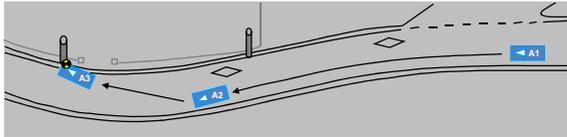


Figure 8. Case Review 2: Accident scenario with single-vehicle



Figure 9. Case vehicle damage (single-vehicle)

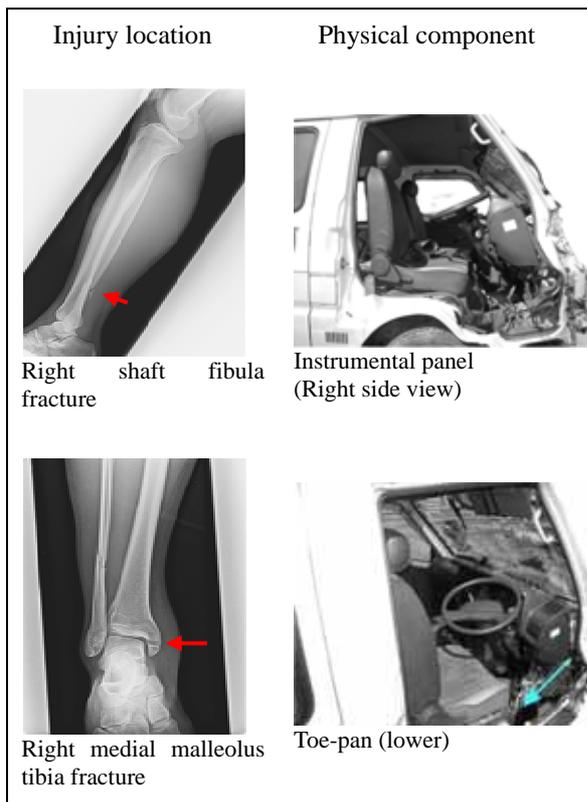


Figure 10. Occupant injury based on the physical evidence (Case Review 2)

In this case occupant, emergency medical summary was recorded. The occupant made an emergency call from his mobile phone after the accident, and it took 18 minutes to contact with EMS (Emergency Medical Service). Because of the rescue operation, it took extra 35 minutes to move the injured to the

ambulance at the accident site. During the rescue operation, EMS took the on-site information (photograph) and transferred it to the medical center for the purpose of the injury evaluation by the trauma physician. On-site information shows that the telephone pole intruded in the driver side of the front bumper in the case occupant vehicle. This specific physical evidence is the 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 easily be done in the damaged vehicle, was conducted by emergency services. In this case, the right lower extremity recognized the tenderness, contusion, and bloating at the right leg region and malleolus medialis. EMS suspected the 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 vital-sign from the accident site to the hospital.

Table 2. Time history of the occupant condition

	Time Period [min]	Transportation					Hospital	
		0	27	52	55	61	67	
Vital	JCS		Lucidity	Lucidity	Lucidity	Lucidity	0	
	E			4			4	
	V			5			5	
	S			6			6	
Signs	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[]		10	10	10	10		
	SpO ₂ [%]			100	100	100	100	

DISCUSSION

New integration of accident research system with medical and engineering network is applied to the real accident case to determine and document injury causation and injury mechanisms. Although the accident reconstruction simulation has a limitation, the detailed medical information with the 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 accident research system compared to the traditional approach of recording injury causation and mechanisms. These examples demonstrate how this system associates injuries with a particular crash event by using the physical evidence and medical image data to establish the injury causation scenario. In this process, injury causation was explained based both on the involved physical component inspected by the experienced and trained ITARDA accident investigator from the accident vehicle and on the medical information diagnosed by the emergency

medical doctor and the biomechanical engineer with experience in impact biomechanics research. In Case Review 1, there existed clear evidence of knee contact to the lower instrumental panel, and the typical lower extremity injury mechanism was explained with the medical image data. Moreover, in order to complement the injury causation scenario and the mechanism established in the accident investigation, the accident reconstruction simulation was demonstrated. This simulation was conducted as a preliminary computational study of the accident reconstruction under the limitation. The result of occupant behaviors complemented the scenario which was estimated in the discussion with the medical and engineering network. In Case Review 2, this integration of accident research system identified intrusion that are critical to the occupant injury in this case, and one-site picture contributed to providing the effective information to the medical doctor for preparation.

Probability of severity score

In general the survival possibility of a person involved in an accident can be evaluated by the “Golden Hour Principle” [8]. This phrase means the time period within which the casualty should be brought to the hospital following an accident. During this time period, the casualty has the best chance to avoid significant deterioration of his/her conditions.

By using Case Review 2, the Probability of severity score (Ps) [9], which is commonly employed for the evaluation of survival in the area of emergency medical care, is calculated. In this case occupants, it took 35 minutes to bring the injured to the ambulance at the accident site, because the vehicle occupants were trapped in their vehicles, and the rescue team was called for right after EMS arrived. Ps is calculated by the TRISS (Trauma and Injury Severity Score) [10] based on the physiological factor (RTS: Revised trauma score), anatomical damage score, (ISS: Injury Severity Score) and Age. Ps is utilized as the objective assessment index when the judgment of the preventable trauma death is made. RTS consists of GCS (Glasgow Coma Scale), SBP (Systolic Blood Pressure), and RR (Respiration Rate). Therefore, it should change from the accident site to the hospital. **Figure 11** indicates the Ps respect to the RTS. The Case Review 2 occupant has a relatively large Ps value, which increases during the transportation from the accident site to the hospital by the medication. 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.

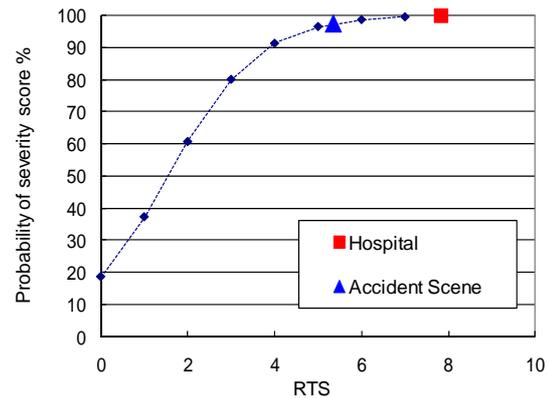


Figure 11. The case occupant Ps calculated from the TRISS method.

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 interior components. Therefore, the accuracy of the quantitative evaluation such as the dynamic loading condition to the lower extremity and the stain distribution in the long bone during the impact was not enough to predict the injury in the Case Review 1. The large deformation of vehicle interior should be the critical factor in estimating the injury in the accident. In the next phase of this research, the multi-body vehicle model should enhance the accuracy of the estimation of the intrusion during the accident, and these information should be applied to the interior compartment of the finite element vehicle model for more accurate injury prediction.

CONCLUSION

This data-collection system provides not only the detailed crash environments but also the causation of injuries in automobile crashes. Even though the intrusion of the vehicle is not calculated in the simulation, the digital human model helps to provide the possible occupant motion under the impact in the real traffic accident. Moreover, the emergency medical care process and the damaged vehicle photograph recorded by EMS (Emergency Medical Service) at the accident site provide effective information in predicting the situation and degree of human injury. In particular, the survival possibility of a person involved in an accident can be evaluated by employing the biological information reported at the instant of the emergency.

The research of this system has just started, and the number of the accident cases is limited. Therefore, accident data should be continually corrected and updated in order to understand the injury and reflect the result for the improvement of vehicle safety and emergency post-crash medical care. In addition, this

medical and engineering network was attempted for the first time in Japan, and the digital human model has a possibility to be an effective tool for predicting the degree and situation of occupant's injury.

ACKNOWLEDGEMENT

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