What Is the Role of Universities in Disaster Response, Recovery, and Rehabilitation? Focusing on Our Disaster Victim Identification Project

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ABSTRACT

A university provides diverse knowledge and expertise that can be mobilized readily in response to community needs in the event of a disaster. Due to its comprehensive capability, a university can contribute significantly in all phases of disaster cycles: pre-disaster preparedness, disaster response, and disaster recovery. It is this comprehensive strength that makes universities such an important part of our society, even in a disaster situation. This article summarizes Tohoku University's strength displayed in the 2011 Great East Japan Earthquake and Tsunami. As a case study of response-phase contributions, this article also focuses on the Disaster Victim Identification (DVI) project, in which authors have been involved for nearly three years.

INTRODUCTION

The Great East Japan Earthquake on March 11, 2011, often referred to as the 2011 Tohoku Earthquake, caused high-intensity ground shaking, a massive tsunami, and a serious nuclear power plant accident, resulting in a disaster of a scale unprecedented in the history of Japan. Tohoku University, as a core university located in the disaster-stricken area, found itself playing a leading role in the post-disaster response, relief, recovery, and rehabilitation process. Currently, nearly three years after the incidence of the earthquake and tsunami, Tohoku University is conducting various research and development projects for supporting regional reconstruction and economic revitalization [1].

This article addresses the question of what universities should do in the event of disaster. (See also [2, 3] for related discussions.) We first break down the process of dealing with disasters into three phases: the *preparedness* phase is the period prior to a disaster; the *response* phase is the emergency response period immediately following a disaster, and the *recovery* phase is the period of medium- and long-term recovery. Recently, university researchers and scientists are increasingly playing a role in disaster research, data collection, and analysis, which may take place in recovery phase. In this period, universities can be essential in terms of academic contributions, policy proposals, and the dispatch of longer-term student/faculty volunteers and other support. All these activities are also essential for preparing for the next disaster in the pre-disaster preparedness phase.

As for the immediate aftermath (i.e., response phase), universities do not seem to be useful compared to, say, military personnel, emergency rescue teams, and Red Cross officials. However, we learned from the 2011 disaster that a university is expected to take a leading role also in disaster response by mobilizing diverse knowledge and expertise. What we found was that universities are more effective in bringing knowledge and expertise rather than simple manpower. In the immediate aftermath of the 2011 disaster, Tohoku University provided emergency medical services, conducted victim identification, disseminated expert knowledge on earthquake, tsunami, and radiation issues, provided robot engineering technology, and promoted volunteer activities. We found that our university had a particular set of strengths and assets that were well suited to assist, and sometimes lead, the activities in all phases of the disaster cycle.

In this article, we first summarize major contributions of Tohoku University in response to the Great East Japan Earthquake and Tsunami, classifying the contributions into those in the emergency response phase and those in medium- and long-term recovery. As a typical example of response-phase contributions, this article focuses on our Disaster Victim Identification (DVI) project [4]. There are some reasons for selecting this topic for *IEEE Communications Magazine*'s readers. A major reason is that this project provides a typical case study of disaster response activity, which illustrates how engineers can overcome unforeseen challenges in catastrophic incidents. Another reason is that the authors have been involved in this project for nearly three years and can describe true problems underlying the mass fatality victim identification. The lessons learned from the project are of sig-

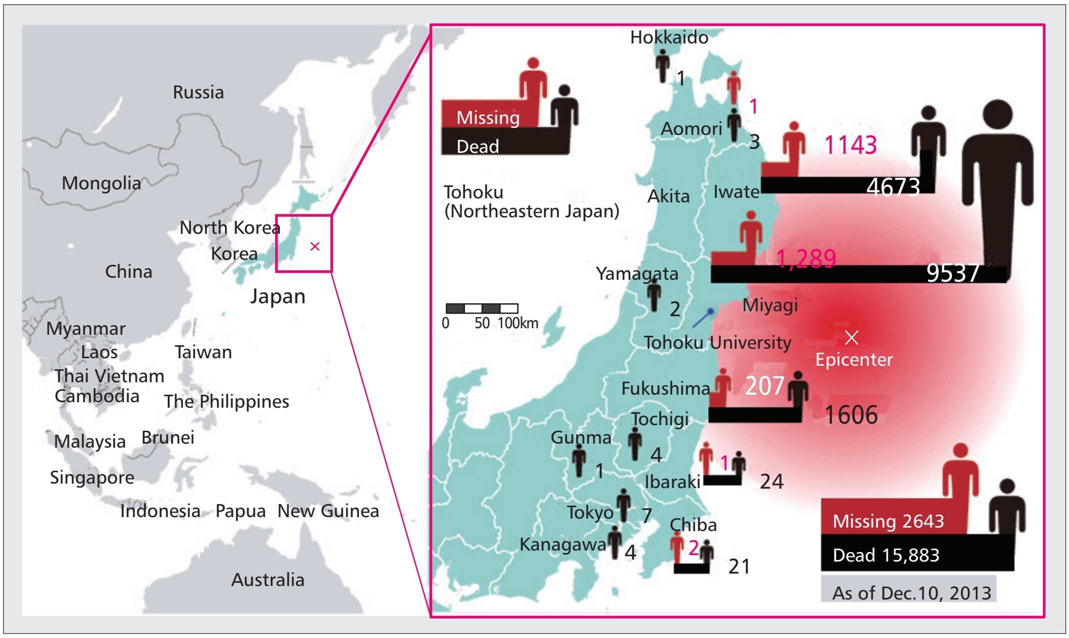

Figure 1. *Statistics of human damage reported by the National Police Agency of Japan as of December 10, 2013.*

nificant value in preparing for future mass fatality incidents. This article ends with a summary of recent progress of research projects conducted by Tohoku University for restoring disaster-affected area and revitalizing regional economies from long-term perspective.

The University in a Disaster

The Great East Japan Earthquake was a magnitude 9.0 undersea megathrust earthquake off the coast of Japan that occurred on March 11, 2011. The epicenter of the earthquake was approximately 130 km (81 mi) east of the Oshika Peninsula in Miyagi Prefecture. The earthquake triggered massive tsunami waves that reached heights of up to 40.1 m (132 ft) in Iwate Prefecture, and in the Sendai area travelled up to 6 km (4 mi) inland. The tsunami washed away several coastal cities, destroyed critical infrastructure, and claimed the lives of thousands of people. As of December 10, 2013, the National Police Agency of Japan has confirmed 15,883 deaths and 2643 people missing across 12 prefectures [5], as depicted in Fig. 1. The tsunami also caused a level 7 accident at the Fukushima Daiichi Nuclear Power Plant. The associated evacuation zones affected hundreds of thousands of residents in Fukushima.

Tohoku University is located in Sendai, the capital city of Miyagi Prefecture, which lies in the Tohoku region. The word Tohoku means northeastern in Japanese. Immediately following the earthquake on March 11, 2011, the university established the emergency headquarters, and put all our efforts into confirming the safety of the students, faculty, and staff. The task took almost three weeks and was completed on March 30, when we confirmed the safety of 18,572 students (including 1499 from overseas) and 11,590 faculty and staff. We were greatly saddened by the news that three students died off campus in the tsunami, while no fatalities were reported for faculty and staff. As for educational affairs, the university decided to cancel the degree conferment ceremony for the 2010 academic year (starting from April and ending in March) and to reschedule the commencement of classes from April to May.

Our campus was also severely damaged. One of the most important post-earthquake activities is to determine the safety and functionality of campus buildings and facilities. Our Facilities Department staff began to evaluate the damaged buildings immediately after the earthquake. Through quick inspection of 588 campus buildings, we found out that 28 buildings were not safe for occupancy, and needed some structural and non-structural retrofitting. Among the 28 buildings, three severely damaged buildings are completely under reconstruction now. A rough estimate of the total cost of damage to buildings is about ¥30 billion yen (US$285 million) and that to facilities is about ¥24.5 billion (US$233 million). In the immediate aftermath, all those connected with the university came together to work toward the early restoration of damaged buildings and facilities, and the swift resumption of the university's functions.

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Tohoku University's Strength Displayed in the Disaster

Tohoku University, whose own facilities suffered damage as described above, played a key role in initiating and implementing disaster recovery and revitalization efforts in the affected region. Its contributions are classified into those in the disaster response phase (including the early recovery phase) and those in the medium- and long-term recovery phase. Figure 2 illustrates these two types of activities in the disaster recovery continuum.

The 2011 disaster was the first disaster in history where many robotic systems were applied. Tohoku University's robot Quince was used for monitoring and investigation in the nuclear reactor buildings at Fukushima Daiichi Nuclear Power Plant since June 24, 2011.

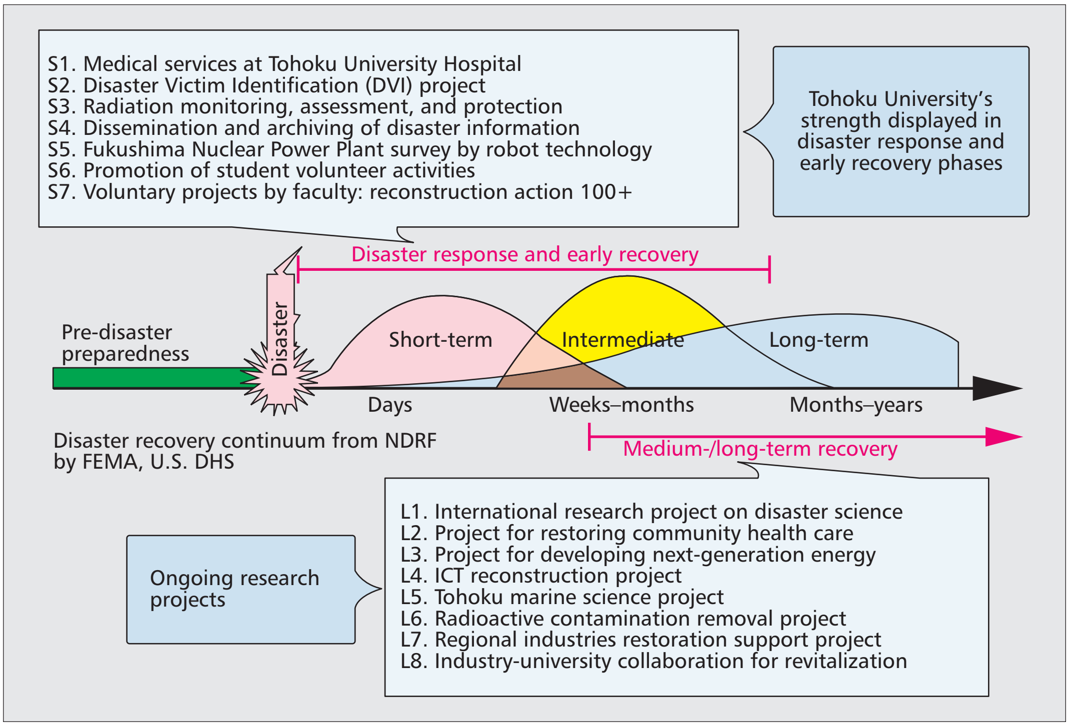

Figure 2. *Overview of Tohoku University's contributions in the Great East Japan Earthquake and Tsunami.*

Listed below are major contributions in the disaster response and early recovery phases.

S1: Medical Services at Tohoku University Hospital

Immediately after the disaster occurred, Tohoku University Hospital sent emergency medical teams to the disaster affected areas and carried out medical relief activities. The hospital also endeavored to secure medicine and medical materials via university networks and academic societies. The university hospital took a central role in accepting patients from hospitals in the disaster area, transporting patients to hospitals outside the prefecture, and dispatching doctors and providing medical supplies to the affected region.

S2: Disaster Victim Identification Project

Tohoku University provided techniques for identifying human remains using dental records. In this disaster, it was proven that dental identification was much more effective than fingerprint/palmprint identification and DNA-based identification. The Graduate School of Dentistry dispatched forensic odontologists to the disaster area in the immediate aftermath. Also, the authors' team designed and implemented a workflow of dental identification in close cooperation with the Miyagi Prefectural Police and Miyagi Dental Association.

S3: Radiation Monitoring, Assessment and Protection

Responding to requests from local governments, such as Miyagi Prefecture, Sendai City, Fukushima Prefecture, and others, our professional team monitored radiation levels in vegetables, milk, tap water, the atmosphere, the soil, and the sea, and provided information on the radiation levels to local municipalities and local residents. The team also cooperated with efforts to remove contaminated soil from the playgrounds of nursery schools in Fukushima Prefecture.

S4: Dissemination and Archiving of Disaster Information

Utilizing the academic potential of the arts and sciences, Tohoku University's specialists from a variety of fields reported on the disaster situation. The specialists group has also developed a comprehensive disaster archive for sharing the disaster knowledge and findings at the national and international levels to improve disaster preparedness.

S5: Fukushima Nuclear Power Plant Survey by Robot Technology

The 2011 disaster was the first disaster in history where many robotic systems were applied. Tohoku University's robot Quince has been used for monitoring and investigation in the nuclear reactor buildings at the Fukushima Daiichi Nuclear Power Plant since June 24, 2011. Quince succeeded in measuring air radiation dose rate, taking high resolution photos, sampling contaminated dust in the air, and checking the conditions of valves, pipes, floors, equipment, and so on.

S6: Promotion of Student Volunteer Activities

In June 2011, about 1000 students registered for the university's volunteer association. These volunteers actively provided help at nursing homes for the elderly and administrative support at the Prefectural Office. In addition, in response to requests from Miyagi Prefecture, over 40 students were sent daily to Yamamoto Town to provide support at evacuation centers. Students also visited Kesennuma to deliver relief supplies to evacuation centers. In Sendai, student volunteers provided learning support for children in evacuation centers and temporary housing.

S7: Voluntary Projects by Faculty: Reconstruction Action 100+

Reconstruction Action 100+ (Plus) is the generic name of more than 100 various voluntary projects to support the affected community in which faculty and staff members have engaged in. Reconstruction Action 100+ was born from our thoughts when asking ourselves what we should do for the recovery and regeneration of the Tohoku region. The staff/faculty have promoted those wide ranging activities such as support for affected people, survey and understanding of the extent of damage, recovery and reconstruction tasks, disaster prevention and mitigation measures, improvement of infrastructure and facilities, and industrial revitalization.

As a typical example of early-phase contributions, this article focuses on the S2 DVI project [4]. Through this case study, we attempt to give readers some insight into the hardships and unpredictability in conducting emergency response phase actions. Our experience in DVI implies that disaster response/recovery plans, programs, policies, and practices must be flexible and adaptable to meet unforeseen, unmet, and evolving needs. Also, IEEE members may understand how our engineering expertise and skills can be applied to achieve breakthroughs against real difficult problems in a disaster.

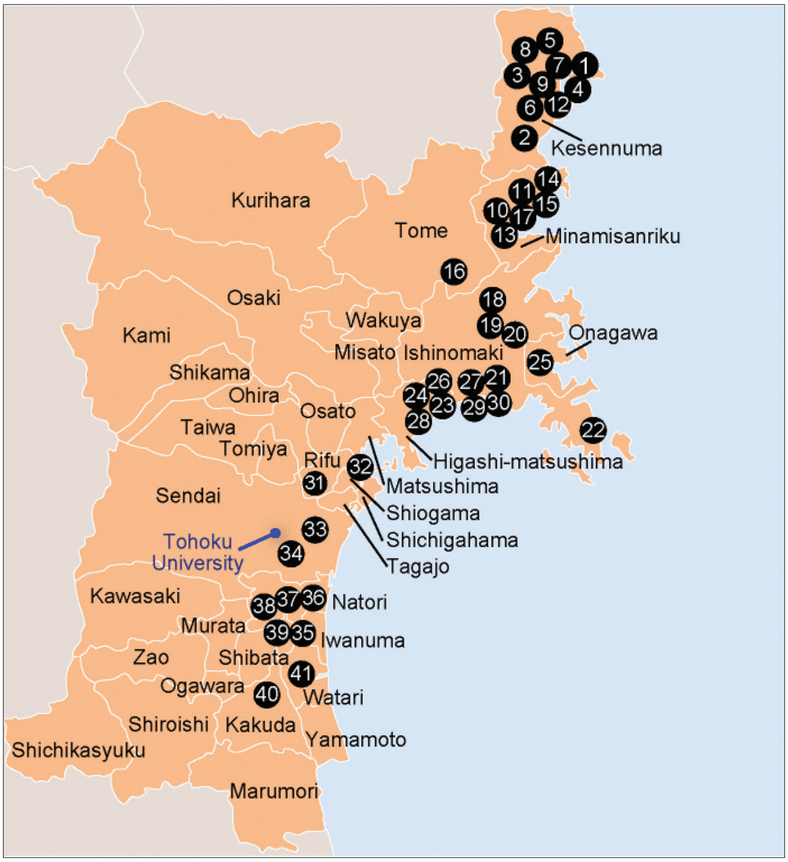

Figure 3. *Locations of morgue stations in Miyagi Prefecture.*

Disaster Victim Identification Project: A Case Study

DVI Overview

As illustrated in Fig. 1, 15,883 people have been confirmed dead, and 2643 are still missing. Miyagi, Iwate, and Fukushima are the worst-hit prefectures in terms of human fatality. The largest number of victims were confirmed in Miyagi Prefecture, where there were 9537 deaths (60 percent of the total deaths) and 1289 people missing. Japanese police data showed that 90.6 percent of the fatalities recovered by March 11, 2012 were by drowning. The tsunami brought serious damage to an extremely wide range along the Pacific coastline of Tohoku region. Some persons who disappeared in Miyagi Prefecture were recovered in Iwate and Fukushima Prefectures. The widespread tsunami destruction along the coastline region made DVI even more difficult.

In April 2011, the authors joined the DVI team of the Miyagi Prefectural Police to introduce advanced dental identification techniques in collaboration with the Miyagi Dental Association. In Miyagi Prefecture, the peak number of bodies recovered in a day exceeded 1000 in March 2011; the number decreased to around 10 per day in May, 1–3 per day in July, and 1–2 per week in October 2011. Figure 3 illustrates locations of major morgue stations in Miyagi Prefecture; the total number of temporary morgues was 41, which were dynamically relocated over time. Great efforts were needed to manage these morgue stations to collect postmortem data systematically.

In the immediate aftermath, victim identification was mainly based on physical characteristics and belongings (including clothing, jewelry, and other effects). This was because victims' bodies recovered from cold water in March were likely to be less damaged and, in some cases, looked as though they were still alive. A few months after the earthquake, newly recovered bodies were disfigured to such an extent that visual identification by a family member was neither reliable nor desirable. For such severely damaged bodies without personal belongings, primary individual identifiers are:

- Dental records
- Fingerprints/palmprints
- DNA

In this disaster, dental identification played a key role for decomposed human remains. The statistics of identification methods in Miyagi Prefecture on December 10, 2013 are: physical characteristics and belongings 86 percent, dental records 10 percent, fingerprints/palmprints 3 percent, and DNA 1 percent. Listed below are our observations related to these statistics.

- As for victim identification using biometric features, forensic dentistry/odontology plays a major role (about 10 percent).

Figure 4. *Instruments package for postmortem dental examination.*

- Fingerprint/palmprint identification cannot be applied to very decomposed bodies; therefore, DNA and dental identifications become more effective as time passed.
- DNA identification was not fully effective in this disaster, since antemortem DNA samples are often lost in tsunami attacks. Instead, DNA parentage and relatedness testing was used for finding possible candidates for unidentified human remains, where the number of tests was 1376 at the end of 2013.
- The combination of dental identification and DNA parentage/relatedness testing is very effective for identifying highly decomposed bodies. The two biometric techniques played complementary roles in this tsunami disaster.

As a result, the identification rate of recovered bodies approached 99.7 percent at the end of 2013.

DVI WITH DENTAL RECORDS

Note that DNA profiling is used frequently in today's criminal investigations; hence, the National Police Agency can provide full DNA testing capability for victim identification even in mass disasters. A major problem in DVI in this disaster was that the police agency did not have any systematic methodology for dental identification that can be applied to mass fatality situations. Addressing this problem, in April 2011, the authors' group joined the DVI team of the Miyagi Prefectural Police and Miyagi Dental Association to introduce advanced dental identification techniques with necessary information system support. Since then, we have been working together very hard to create an effective framework. Listed below are our major contributions.

Preparation of Instruments Package for Postmortem Dental Examination — We introduced advanced instruments for postmortem dental examination: a portable dental X-ray machine; a waterproof, shockproof, and dust-resistant camera and mirrors for intra-oral photos; and a mobile PC, X-ray protective aprons and gloves, disposable clothing (gowns, gloves, masks, and caps), documents, and manuals, and more, as shown in Fig. 4. In Miyagi Prefecture, at an early stage of postmortem dental recording, the dentist DVI team focused on the collection of handwritten dental charts. At the end of April 2011, we introduced systematic procedures for collecting intra-oral photos and dental X-rays for all the bodies recovered afterward. The established framework of advanced dental recording includes lectures and manuals for dentists who are not familiar with DVI.

Development of Dental Record Matching Software: Dental Finder — *Dental Finder* is a software tool for dental record matching, which has three basic functions:

- A function to store postmortem (PM) dental records in a database, where PM records are obtained from dental charts of recovered bodies
- A function to store antemortem (AM) dental records in a database, where AM records are the digests of dental treatment records of missing persons obtained from their dental clinics
- A function to recommend possible candidates of genuine AM-PM matching pairs by evaluating similarity for every pair

We started the development of Dental Finder in May 2011, and since then we have continuously improved the software, which is distributed free of charge. Details of Dental Finder are described in the next section.

Design and Implementation of the Overall Workflow of Dental Identification — By preparing the instruments for PM examination and the dental record matching software, as described above, we established the overall workflow of dental DVI as illustrated in Fig. 5. For implementing the workflow, we defined the role and responsibility of every DVI team member as follows:

- The Miyagi Prefectural Police control the overall operation of the workflow.
- The Miyagi Dental Association provides expert knowledge of odontology, and is responsible for dental record interpretation and dental identity tests.
- Tohoku University (our group) provides expert knowledge of information technology and dental radiology, and is responsible for maintaining the workflow with computers and other instruments.

A typical victim identification procedure starts with searching potential candidates of AM-PM matching pairs using Dental Finder. Then dentists perform manual identity tests for these AM-PM candidates by carefully examining their original PM records (e.g., dental charts, intra-oral photos, and radiographs) and original AM records (e.g., dental treatment records, photos, radiographs, and dental casts). The Miyagi Prefectural Police check the results and make a final decision by examining other findings such as appearance, clothing, belongings, fingerprints, palmprints, DNA, and other physical characteristics.

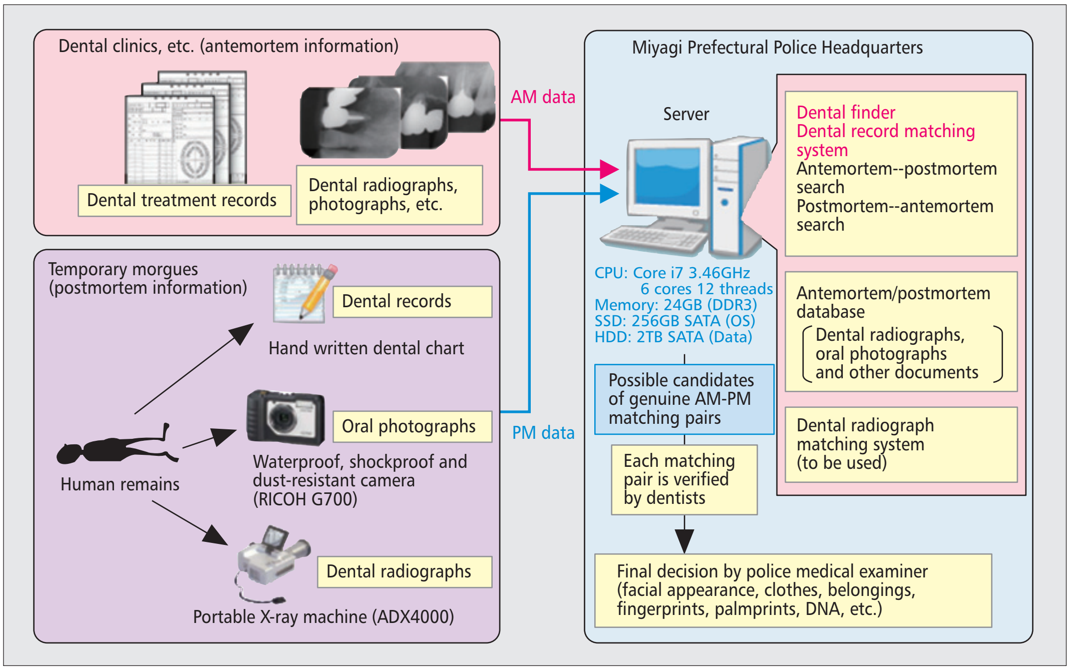

Figure 5. *Overall dental DVI workflow.*

Tohoku University established the International Research Institute of Disaster Science (IRIDeS) to pursue sustainable and resilient societies that will respond promptly, sensibly and effectively to future emergencies.

IMPACT OF INFORMATION TECHNOLOGY IN DVI

For victim identification in a mass fatality incident, the use of information technology is essential. However, the National Police Agency did not have a systematic workflow for large-scale dental identification. Therefore, our team decided to start from scratch and developed everything, including a software tool, Dental Finder, for dental record matching. The purpose of Dental Finder is to provide automatic batch matching on AM and PM dental data, and to produce a possible candidate list for forensic examination, which leads to significant speedup of the decision making process in DVI. In order to compare the status of each tooth in an AM dental record and that in a PM dental record in computer software, we need some sort of encoding scheme for representing the status of every tooth. In Dental Finder, we decided to adopt the simplest scheme of encoding, where we classify the tooth status into simple five classes:

1. Sound tooth, decayed tooth, and partial restoration with tooth-colored materials (e.g., resin filling, cement filling, glass ionomer filling)
2. Partial restoration with metal materials (e.g., inlay, onlay, amalgam filling, partial crown)
3. Full crown restoration (e.g., full cast crown, facing crown, jacket crown)
4. Remaining root and missing tooth
5. No information

The major reason for selecting this encoding scheme is that it is simple enough to be handled by non-specialists (e.g., police officers and computer engineers). One can easily translate complex dental records described by dentists into 5-class data (5-valued 32-digit data) using this encoding scheme. Also, we can rapidly develop search engines for 5-class dental data. It took only two weeks to develop a basic search engine for Dental Finder. We found that this simplest encoding scheme can achieve a sufficient level of matching accuracy.

Because of the extreme simplicity of 5-valued encoding, we can easily store AM and PM dental records into Dental Finder using the data input interface shown in Fig. 6. Dental Finder evaluates the similarity between every pair of AM and PM dental records based on the following four similarity metrics:

- The number of completely matched teeth in 5-class representation
- The number of matched teeth with class 2 or class 3 label
- The number of teeth with consistent AM-to-PM state transition
- The matching score computed using a score table defined for all possible combinations of AM-PM transitions, such as 1-1, 1-2. 1-3, …, 5-5

(This 5 × 5 score table is optimized in advance using known genuine AM-PM pairs.) In addition to the above similarities, we introduce matching priority metrics so that AM-PM data pairs with higher matching priority should be examined preferentially. The matching priority metrics was very effective for reducing the complexity of AM-PM examination in this disaster.

To end this section, we would like to point out a major problem in our DVI project. Note here that all the components appearing in the dental DVI workflow (Fig. 5) were prepared and developed during the tumultuous period of disaster response. This is one of the major reasons our DVI project required a period of more than one year. If we could prepare the overall workflow in advance, drastic speedup of the DVI process is possible. It is clear from this case study that we engineers must take a central role and responsibility in pre-disaster preparedness planning.

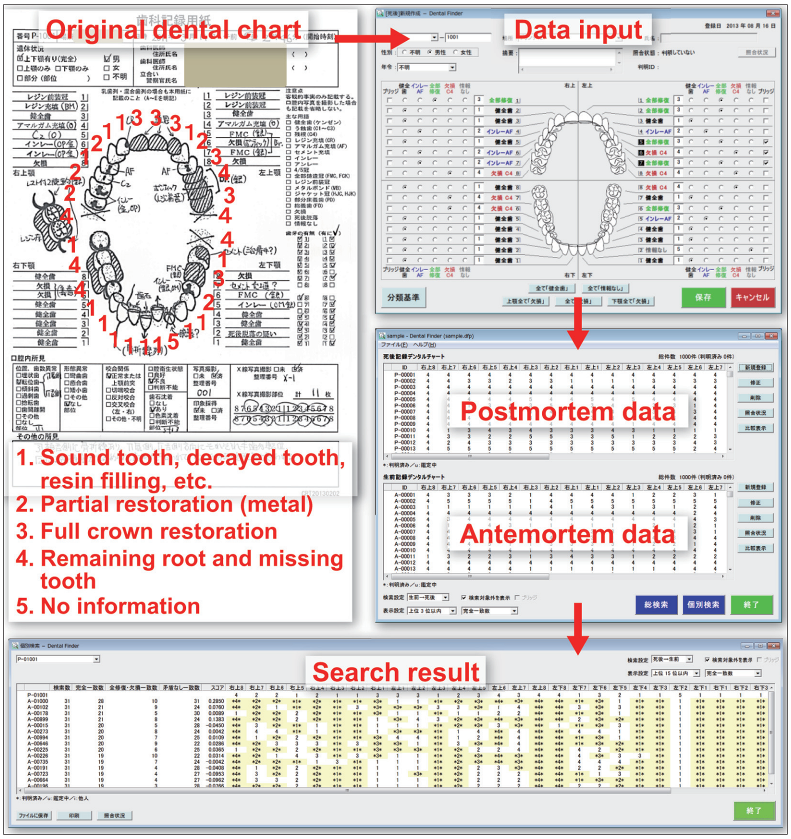

Figure 6. *Dental record matching using Dental Finder.*

Ongoing Research Projects

Today, nearly three years after the earthquake, the nature of support to affected regions has already changed from emergency assistance to long-term assistance. What is the role of universities in this period? A research university has unique abilities to help long-term recovery and post-disaster revitalization of affected communities through a series of well coordinated, strategic, and effective research projects. Currently, Tohoku University has launched eight core projects, L1—L8, as listed below (Fig. 2), which were designed to bring together national and international universities, research institutes, governments, industries, and local communities to form a collaboration framework for reconstructing the Tohoku region [1].

L1: International Research Project on Disaster Science

Tohoku University established the International Research Institute of Disaster Science (IRIDeS) to pursue sustainable and resilient societies that will respond promptly, sensibly, and effectively to future emergencies. IRIDeS will create a new discipline of practical disaster mitigation through seven research activities:
- Hazard and risk evaluation
- Human and social response
- Regional and urban reconstruction
- Basic disaster science
- Disaster medical science
- Disaster information management and public collaboration
- Business–academia collaboration

L2: Project for Restoring Community Health Care

Tohoku University established the Comprehensive Training Center for Community Medicine to restore community health care. The center accepts medical staff from affected areas, teaches them cutting-edge medical care, and offers them opportunities to take a leading role in community medicine. The university also established the Tohoku Medical Megabank Organization (ToMMo) to conduct three programs:
- Advanced medical support for disaster areas
- Creation of a large-scale biobank combining medical and genome information
- Education of a variety of experts such as bioinformatics researchers and genetic counselors

L3: Project for Developing Next-Generation Energy

The consortium on Next-Generation Energies for Tohoku Recovery (NET) was formed by three universities and local governments in affected areas. The NET members conduct research on
- Renewable energy from ocean waves and currents
- Micro-algae biofuels
- Integrated energy management systems for smart cities

L4: ICT Reconstruction Project

Tohoku University established the Research Organization of Electrical Communication (ROEC) and concluded a comprehensive collaboration agreement with the National Institute of Information and Communications Technology (NICT). To develop disaster resilient ICT infrastructures, the ROEC promotes research on the following topics:
- Improved transmission capability that can handle rapid traffic growth
- Wide-area distributed cloud storage and data protection
- ICT support for medicine and agent systems
- Ultra-low-power communication devices
- Traffic congestion control and never-die networks
- Highly dependable communication links

L5: Tohoku Marine Science Project

Tohoku University, through its Tohoku Ecosystems-Associated Marine Sciences (TEAMS) project, established partnerships with the University of Tokyo and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). TEAMS conducts fishery environment surveys and aquaculture environment surveys in a variety of locations (e.g., Onagawa Bay, Sendai Bay, Shizugawa Bay) as well as surveys on the offshore seabed ecosystem.

L6: Radioactive Contamination Removal Project

Tohoku University established the Research Center for Remediation Engineering of Living Environments Contaminated with Radioisotopes (REER) to develop the following three technologies:

- New methods to extract and condense radioactive cesium in contaminated soil and to make effective use of collected radioactive substances
- Cultivation methods for radiation-free agricultural products
- Large-aperture gamma ray detection technology for rapid contamination detection

A project on analyzing comprehensive doses in disaster-affected animals is also being conducted to reveal the environmental impact of the Fukushima nuclear power plant accident.

L7: Regional Industries Restoration Support Project

Tohoku University established the Regional Innovation Research Center to develop human resources for supporting the revitalization of Tohoku industries. The center conducts comprehensive research on the process of regional industry restoration and provides training programs for fostering post-disaster business innovators.

L8: Industry-University Collaboration for Revitalization

To revitalize the regional economy, Tohoku University strongly promotes industry–university collaboration in a variety of areas (e.g., materials engineering, information technology, next-generation automobiles, and medical equipment and devices).

Conclusion

What is the role of universities in the event of disaster? It is quite difficult for us to answer the question in simple words. The potential contributions of universities span all phases of the disaster cycle and can cover an extremely wide range of pre-/post-disaster activities. Through our experience in the Great East Japan Earthquake and Tsunami, we can clearly conclude that a university plays multiple roles in the disaster response and recovery process, since it has comprehensive capabilities by nature. Universities provide diverse knowledge and expertise that can readily be mobilized in response to emergency community needs. Universities have access to a variety of professionals, motivated volunteers, great leaders who can achieve breakthroughs against difficult issues, as well as access to advanced technology, engineering skills, state-of-the-art equipment, and cutting-edge facilities. It is this comprehensive strength that makes universities such an important part of our society, even in a disaster situation. Universities should go much further, playing a central role in all phases of the disaster recovery continuum.

Through our experience in the Great East Japan Earthquake and Tsunami, we can clearly conclude that a university plays multiple roles in disaster response and recovery process, since it has comprehensive capabilities in nature.

Acknowledgments

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Biographies

Takafumi Aoki (aoki@ecei.tohoku.ac.jp) received B.E., M.E., and D.E. degrees in electronic engineering from Tohoku University, Sendai, Japan, in 1988, 1990, and 1992, respectively. He is currently a professor in the Graduate School of Information Sciences (GSIS) at Tohoku University. Since April 2012, he has also served as the vice president of Tohoku University. His research interests include theoretical aspects of computation, computer design and organization, LSI systems for embedded applications, digital signal processing, computer vision, image processing, biometric authentication, and security issues in computer systems. He has received more than 20 academic awards as well as distinguished service awards for his contributions to victim identification in the 2011 Great East Japan Disaster.

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