

Reliability of Telecommunications Systems Following a Major Disaster: Survey of Secondary and Tertiary Emergency Institutions in Miyagi Prefecture During the Acute Phase of the 2011 Great East Japan Earthquake

Daisuke Kudo, MD, PhD;¹ Hajime Furukawa, MD;¹ Atsuhiko Nakagawa, MD, PhD;^{1,2} Yoshiko Abe, RN;¹ Toshikatsu Washio, PhD;³ Tatsuhiko Arafune, PhD;⁴ Dai Sato;⁵ Satoshi Yamanouchi, MD;¹ Sae Ochi, MD, PhD, MPH;⁶ Teiji Tominaga, MD, PhD;² Shigeki Kushimoto, MD, PhD¹

1. Department of Emergency and Critical Care Medicine/Emergency Center, Tohoku University Hospital, Sendai, Miyagi, Japan
2. Department of Neurosurgery, Tohoku University Graduate School of Medicine, Sendai, Japan
3. Human Technology Research Institute, National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan
4. Department of Engineering, University of Tokyo, Tokyo, Japan
5. Medical IT Center, Tohoku University Hospital, Sendai, Japan
6. MRC-HPA Centre for Environment and Health, Imperial College, London, United Kingdom

Correspondence:

Daisuke Kudo, MD, PhD
Department of Emergency and Critical Care
Medicine/Emergency Center
Tohoku University Hospital
1-1 Seiryō-machi, Aoba-ku
Sendai, Miyagi 980-8574, Japan
E-mail: kudodaisuke@med.tohoku.ac.jp

Conflicts of interest/funding: This research was funded by: Daiwa Securities Health Foundation 2011; SENSHIN Medical Research Foundation 2011; Special Project Research 2012 of the International Research Institute of Disaster Science, Tohoku University, Marumo Fund 2012; Daiwa Life Welfare Foundation 2012; Takahashi Industrial and Economic Research Foundation 2012; and a Grant-in-Aid

Abstract

Introduction: Telecommunication systems are important for sharing information among health institutions to successfully provide medical response following disasters.

Hypothesis/Problem: The aim of this study was to clarify the problems associated with telecommunication systems in the acute phase of the Great East Japan Earthquake (March 11, 2011).

Methods: All 72 of the secondary and tertiary emergency hospitals in Miyagi Prefecture were surveyed to evaluate the telecommunication systems in use during the 2011 Great Japan Earthquake, including satellite mobile phones, multi-channel access (MCA) wireless systems, mobile phones, Personal Handy-phone Systems (PHS), fixed-line phones, and the Internet. Hospitals were asked whether the telecommunication systems functioned correctly during the first four days after the earthquake, and, if not, to identify the cause of the malfunction. Each telecommunication system was considered to function correctly if the hospital staff could communicate at least once in every three calls.

Results: Valid responses were received from 53 hospitals (73.6%). Satellite mobile phones functioned correctly at the highest proportion of the equipped hospitals, 71.4%, even on Day 0. The MCA wireless system functioned correctly at the second highest proportion of the equipped hospitals. The systems functioned correctly at 72.0% on Day 0 and at 64.0% during Day 1 through Day 3. The main cause of malfunction of the MCA wireless systems was damage to the base station or communication lines (66.7%). Ordinary (personal or general communication systems) mobile phones did not function correctly at any hospital until Day 2, and PHS, fixed-line phones, and the Internet did not function correctly at any area hospitals that were severely damaged by the tsunami. Even in mildly damaged areas, these systems functioned correctly at <40% of the hospitals during the first three days. The main causes of malfunction were a lack of electricity (mobile phones, 25.6%; the Internet, 54.8%) and damage to the base stations or communication lines (the Internet, 38.1%; mobile phones, 56.4%).

for Scientific Research of Challenging Exploratory Research (No. 24659794) from the Japanese Ministry of Education, Culture, Sports, Science, and Technology, and supported by Manoa DNA and Takaya Yokokawa.

Keywords: communication systems; disaster medicine; information and communication; MCA wireless system; satellite mobile phone

Abbreviations:

MCA: multi-channel access
PHS: Personal Handy-phone System

Received: February 2, 2013

Revised: October 13, 2013

Accepted: October 27, 2013

Online publication: February 21, 2014

doi:10.1017/S1049023X14000119

Conclusion: Results suggest that satellite mobile phones and MCA wireless systems are relatively reliable and ordinary systems are less reliable in the acute period of a major disaster. It is important to distribute reliable disaster communication equipment to hospitals and plan for situations in which hospital telecommunications systems do not function.

Kudo D, Furukawa H, Nakagawa A, Abe Y, Washio T, Arafune T, Sato D, Yamanouchi S, Ochi S, Tominaga T, Kushimoto S. Reliability of telecommunications systems following a major disaster: survey of secondary and tertiary emergency institutions in Miyagi Prefecture during the acute phase of the 2011 Great East Japan Earthquake. *Prehosp Disaster Med.* 2014;29(2):204-208.

Introduction

On March 11, 2011, at 2:46 PM (local time), the Great East Japan Earthquake, with a magnitude of 9.0 and seismic intensity of 7.0, occurred.¹ The earthquake and subsequent tsunami caused damage in the northeastern area of Japan along the Pacific coast. Most of the dead and missing persons were in Miyagi Prefecture (population approximately 2.2 million). Electric power, water, and gas services stopped soon after the earthquake in all areas of Miyagi Prefecture, and 75 hospitals and 5.5% of all clinic buildings suffered more than 50% destruction.¹ Seventy-two Miyagi secondary and tertiary emergency hospitals, which included 14 disaster base hospitals, received patients injured in the acute phase of disasters. The disaster base hospitals, designated by Ministry of Health, Labor and Welfare, were base hospitals for disaster medicine.

These 14 disaster base hospitals and the other emergency hospitals required communication capability with the prefectural government, fire departments, and each other, to coordinate receiving and transporting injured patients, to secure support from medical teams, and to resupply drugs, fuels, and food. It was reported that one of the disaster base hospitals was largely unable to communicate by mobile phone and fixed-line phone and communicated by satellite mobile phone and a multi-channel access (MCA) wireless system.²⁻⁴ The disruption of communication resulted in coastal area public hospitals being isolated by the tsunami and unable to communicate with other institutions. Patients and staff members at these hospitals required evacuation two days after the earthquake.⁵

Communication systems, such as radio, satellite telephones, and the Internet, have been recommended in the Hospital Safety Index Evaluation Forms for safe hospitals published by the Pan American Health Organization.⁶ There have been few reports of whether telecommunications systems functioned correctly and were used effectively in actual disaster situations. Further, there is little evidence to address whether various types of communication systems are actually sufficient in major disaster events. The objective of this report was to clarify the problems associated with telecommunications systems in the acute phase of the 2011 Great East Japan Earthquake and to determine the reliability of telecommunications systems used at hospitals in Miyagi Prefecture.

Methods

The 72 secondary and tertiary emergency hospitals in Miyagi Prefecture were surveyed by written evaluation for information on six telecommunications systems, including satellite mobile phones, MCA wireless systems, mobile phones, Personal Handy-phone Systems (PHS), fixed-line phones, and the Internet. Hospitals were asked whether each of the telecommunications systems functioned correctly. If not, information was recorded for the cause of the malfunction during the period of the first four days after the earthquake (from March 11 through March 14,

2011). Each of the telecommunications systems was considered to be functioning correctly if the hospital staff could communicate in one or more of every three attempted calls.

The medical service area where the proportion of dead and missing people in the population, caused directly by the disaster, was greater than or equal to two percent, was designated as the severely damaged area (Table 1). The medical service area where the proportion of dead and missing people in the population, caused directly by the disaster, was less than two percent, was designated as the mildly damaged area.

Results

Valid responses were received from 53 of the 72 hospitals (73.6%): six hospitals in the severely damaged area and 47 hospitals in the mildly damaged area. Fifteen of 19 hospitals that did not respond were unable to respond because the event records were lost during the earthquake or tsunami.

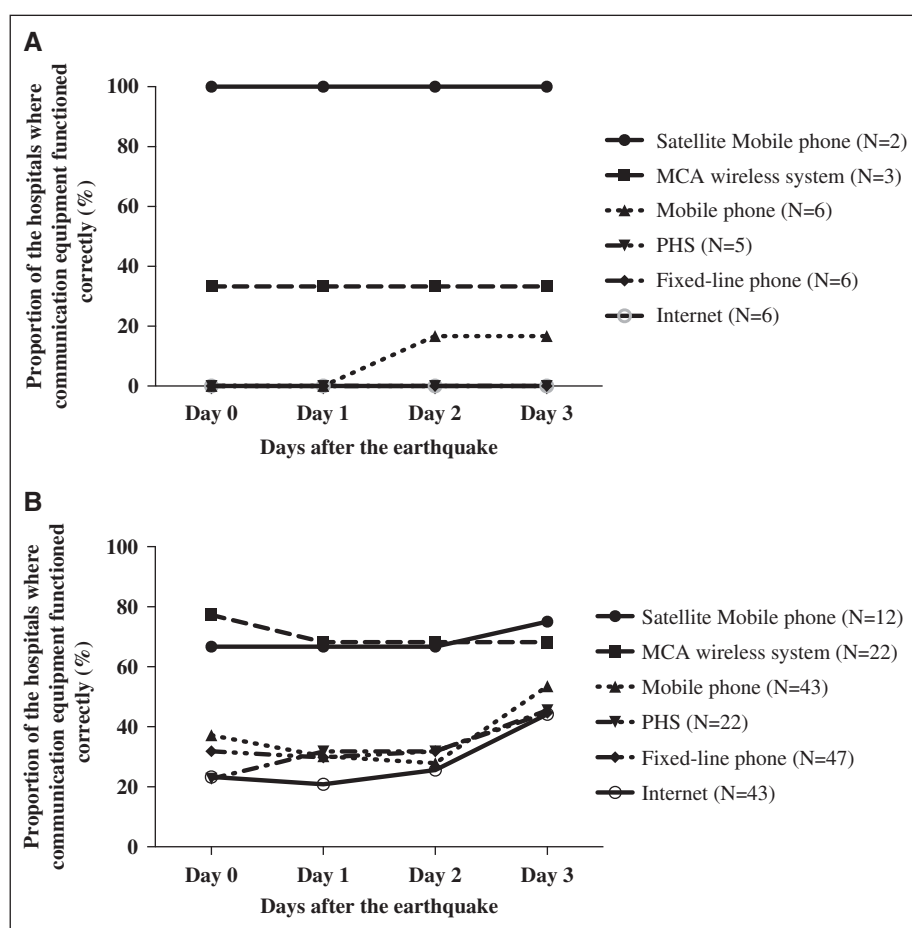
Satellite mobile phones were installed in 14 disaster base hospitals, but none of the other hospitals. Multi-channel access wireless systems were installed in 13 disaster base hospitals and 12 emergency hospitals. Of the six telecommunications systems, satellite mobile phones functioned correctly in the highest proportion of the equipped hospitals, 10 of 14 equipped hospitals (71.4%), even on Day 0 (March 11). In the severely damaged area, satellite mobile phones functioned correctly in both of the equipped hospitals (Figure 1). The four causes for satellite mobile phone malfunction were lack of electricity in one hospital, being unaccustomed to the device in two, and unknown in one (Table 2). Multi-channel access wireless systems functioned correctly at 18 of 25 (72.0%) hospitals on Day 0 (March 11), but on Day 1 (March 12) through Day 3 (March 14), functional reliability decreased to 16 of 25 hospitals (64.0%) (Figure 1). The main cause of malfunction with MCA wireless systems was damage to the base stations or communication lines at six of nine hospitals (66.7%) (Table 2).

Personal Handy-phone Systems, fixed-line phones, and the Internet did not function correctly at any hospital in the severely damaged area during the first four days (March 11 through March 14) after the earthquake (Figure 1). Mobile phones functioned correctly at only one of six hospitals in the severely damaged area after Day 2 (March 13 through March 14) (Figure 1). In the mildly damaged area, mobile phones, PHS, fixed-line phones, and the Internet functioned correctly at a maximum of 16 of 43 hospitals (37.3%) on Day 0, 7 of 22 hospitals (31.8%) on Day 1, 15 of 47 hospitals (31.9%) on Day 2, and 11 of 43 hospitals (25.6%) on Day 3, and slight recovery was seen on Day 4 (March 14) (Figure 1). The main causes of malfunction were damage to the base stations or communication lines for mobile phones in 22 of 39 hospitals (56.4%), PHS in 11 of 22 hospitals (50%), fixed-line phones in 19 of 43 hospitals (44.3%), and the Internet in 16 of 42 hospitals (38.1%), and a lack of electricity for

	Medical Service Area	Population ⁷	Dead ⁷	Missing ⁷	Dead and Missing, % of Population	Hospitals and Clinic Buildings with > 50% Destruction ¹
Severely Damaged Area	Ishinomaki	213,780	4,895	768	2.6	12 (48.0%)
	Kesennuma	90,918	1,696	462	2.4	23 (22.8%)
Mildly Damaged Area	Sendai	1,517,097	2,967	105	0.2	35 (3.6%)
	Osaki	210,816	3	2	0	1 (0.9%)
	Kennan	183,679	2	0	0	1 (1.0%)
	Tome	83,969	0	0	0	1 (2.9%)
	Kurihara	73,492	0	0	0	2 (5.0%)

Kudo © 2014 Prehospital and Disaster Medicine

Table 1. Dead and Missing People in Hospitals and Clinic Buildings with > 50% Destruction (as of October 8, 2012)



Kudo © 2014 Prehospital and Disaster Medicine

Figure 1. State of communications equipment. Proportion of hospitals where communications equipment functioned correctly (A) in the severely damaged area and (B) in the mildly damaged area of Miyagi Prefecture during the first four days after the Great East Japan Earthquake (March 11–14, 2011), N = number of responding hospitals where the system was installed.

Abbreviation: MCA, multi-channel access; PHS, Personal Handy-phone System.

mobile phones in 10 of 39 hospitals (25.6%), PHS in 9 of 22 hospitals (40.9%), fixed-line phones in 21 of 43 hospitals (48.8%), and the Internet in 23 of 42 hospitals (54.8%) (Table 3).

Discussion

This is the first report to survey telecommunications system disruption in hospitals as a result of the 2011 Great East Japan

	Satellite Mobile Phone n (%)		MCA Wireless System n (%)	
	SDA (n = 0)	MDA (n = 4)	SDA (n = 2)	MDA (n = 7)
Damaged equipment	-	-	1 (50.0)	-
Stopped electric power supply	-	1 (25.0)	-	2 (28.6)
Damage of base stations and/or lines	-	-	1 (50.0)	5 (71.4)
Origination restriction or congestion	-	-	-	-
Other	-	3 (75.0)	-	-
No answer	-	-	-	-

Kudo © 2014 Prehospital and Disaster Medicine

Table 2. Reasons for Malfunction of Communication Equipment During Disaster (March 11-March 14, 2011), n = number of hospitals where equipment malfunctioned

Abbreviations: MCA, multi-channel access; MDA, mildly damaged area; SDA, severely damaged area.

	Mobile Phone n (%)		PHS n (%)		Fixed-line Phone n (%)		Internet n (%)	
	SDA (n = 6)	MDA (n = 33)	SDA (n = 4)	MDA (n = 18)	SDA (n = 6)	MDA (n = 37)	SDA (n = 6)	MDA (n = 36)
Damaged equipment	-	1 (3.0)	-	-	-	1 (2.7)	-	-
Stopped electric power supply	-	10 (30.3)	-	9 (50.0)	-	21 (56.8)	1 (16.7)	22 (61.1)
Damage of base stations and/or lines	5 (83.3)	17 (51.5)	3 (75.0)	8 (44.4)	5 (83.3)	14 (37.8)	4 (66.7)	12 (33.3)
Origination restriction or congestion	-	2 (6.1)	-	1 (5.6)	-	1 (2.7)	-	-
Other	-	1 (3.0)	-	-	-	-	-	1 (2.8)
No answer	1 (16.7)	2 (6.1)	1 (25.0)	-	1 (16.7)	-	1 (16.7)	1 (2.8)

Kudo © 2014 Prehospital and Disaster Medicine

Table 3. Reasons for Malfunction of Ordinary Communication Equipment (March 11-March 14, 2011), n = number of hospitals where equipment malfunctioned

Abbreviations: MDA, mildly damaged area; PHS, Personal Handy-phone System; SDA, severely damaged area.

Earthquake. Systems designed for disasters, such as the satellite mobile phone and MCA wireless systems, functioned correctly at many of the equipped hospitals during the acute period of the earthquake. Ordinary or common communication systems, such as mobile phones, PHS, fixed-line phones, and the Internet, did not function at most of the hospitals during the first three days (March 11-13) after the earthquake. It has been recommended that any of these various types of telecommunications systems be installed in every hospital for disaster.⁶ However, as shown in this report of a large-scale disaster, consistent telecommunications service was not achieved when hospitals were equipped with various types of telecommunications systems.

Because of prior experience reported by Miyamoto and coworkers,⁸ satellite mobile phones were installed in the 14 disaster base hospitals of Miyagi Prefecture before the Great East Japan Earthquake. Satellite mobile phones are a robust and

reliable disaster communication system because radio waves travel via a stationary satellite on the equator and the system functions correctly even when the other systems on the earth's surface are damaged.⁹ However, satellite mobile phones have several difficulties in use, such as fixation of the antenna, obstacles in the direction of the satellite, difficulty in operational transmission and reception, and high cost.⁹ Also, satellite mobile phones only allow one-way transmission between users and are not extremely useful for general information sharing.

Multi-channel access wireless systems have the advantage of enabling users to communicate with more than one recipient at the same time. These systems also have the potential to communicate quickly and precisely across large distances. It is reported that MCA wireless systems functioned well during the Great Hanshin-Awaji Earthquake, and were distributed to disaster base hospitals in anticipation of a large earthquake in

Miyagi Prefecture before the Great East Japan Earthquake occurred.^{10,11} In addition, four relay stations were in place in Miyagi Prefecture with communication lines connecting the four relay stations. Relay stations were not damaged by the earthquake and tsunami, and private electric generation for relay stations worked when the general electricity supply was cut off. However, communication lines connecting the various areas were damaged and users were not able to communicate beyond their own areas.

Mobile phones, PHS, fixed-line phones, and the Internet functioned less reliably during the acute period of the disaster. The main causes of malfunction were the failure of the power supply and damage to base stations and communication lines. To make these systems more reliable during disasters, earthquake-resistant fixed base stations and lines, mobile base stations designed for disaster, and priority telephone links during disaster are needed. Concerning the Internet, a social network service was reported to be useful in the period of the disaster by some media,^{12,13} but the Internet was available to less than 40% of hospitals in Miyagi Prefecture during the first four days, and none of the hospitals in the severely damaged area, so social network services may not always be useful during the acute period of disasters.

Limitations

This study was limited by the fact that enquiry responses were based on data elicited from process records (event chronologies), reports, and materials from each hospital at the time of the 2011 Great East Japan Earthquake, and these data may not necessarily be valid due to widespread confusion at the time of the disaster.

Conclusions

This study showed that satellite mobile phones functioned correctly, even during the acute period of the disaster, and that MCA wireless systems have the potential to become useful after further improvement. Common communication systems, such as mobile phones, PHS, fixed-line phones, and the Internet were less reliable.

Acknowledgment

Data were collected from the Miyagi Prefecture Medical Provision Department and the disaster base hospitals in Miyagi Prefecture. The authors are grateful to Yayoi Okano, a research administrator, and Masahiro Tanno, a research assistant, Department of Neurosurgery, and Shizuka Osaki, a clinical research coordinator, Department of Neurosurgery and Emergency and Critical Care Medicine, Tohoku University Hospital.

References

1. Miyagi Prefecture Disaster Medicine Headquarters. Report of the questionnaire about the Great East Japan Earthquake [in Japanese]. *Miyagiken Ishikaiho*. 2011;787:529-542.
2. Miyagi Medical Association. Look back over the Great East Japan Earthquake [in Japanese]. *Miyagiken Ishikaiho*. 2011;789:713-735.
3. Satomi S. The Great East Japan Earthquake: Tohoku University Hospital's efforts and lessons learned. *Surg Today*. 2011;41:1171-1181.
4. Nakagawa A, Furukawa H, Kudo D, et al. Lessons from chronological analysis during first 72 hours after the Great East Japan Earthquake: report from Tohoku University Hospital [in Japanese]. *Journal of Japanese Congress on Neurological Emergencies*. 2012;24:24-31.
5. Yamanouchi S, Inoue J, Yamada Y, et al. Actions of the Miyagi Prefectural Operational Headquarters for DMAT regarding the Great East Japan Earthquake [in Japanese]. *Japanese Journal of Disaster Medicine*. 2012;17:38-44.
6. Pan American Health Organization. *Hospital Safety Index: Evaluation Forms for Safe Hospitals*. Washington D.C., USA: PAHO; 2008:19.
7. The situation of damage of the Great East Japan Earthquake [in Japanese]. Miyagi Prefecture Website. <http://www.pref.miyagi.jp/kikitaisaku/higasinihondaisinsai/higaizyoukyou.htm>. Accessed Oct 30, 2012.
8. Miyamoto M, Sako M, Irie M, et al. Great earthquakes and medical information systems, with special reference to Telecommunications. *JAMIA*. 1999;6: 252-258.
9. Logistics Telecommunication Training in disaster [in Japanese]. In: Training Program Investigation Committee of DMAT Secretariat eds, *Manual for Students of Japan DMAT Member Training Course*, ver. 3.0.:107-114.
10. Minoura K, Imamura F, Sugawara D, et al. The 869 Jogan tsunami deposit and recurrence interval of large-scale tsunami on the Pacific coast of northeast Japan. *J Natural Disaster Sci*. 2001;23:83-88.
11. Tome Y. Experience in the disaster medicine [in Japanese]. *Miyagiken Ishikaiho*. 2011;785:336-337.
12. The disaster and SNS [in Japanese]. Nikkei Trendy Net. <http://trendy.nikkeibp.co.jp/article/pickup/20110427/1035385/>. Accessed December 27, 2012.
13. Analysis of action and mind of 88000 people in Japan during the tsunami and earthquake occurring [in Japanese]. Weather News Website. http://weathernews.com/ja/nc/press/2011/pdf/20110428_2.pdf. Accessed December 27, 2012.