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Review

Transfusion under triple threat: Lessons from Japan's 2011 earthquake, tsunami, and nuclear crisis

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ABSTRACT

The Great East Japan Earthquake of March 11, 2011 provoked tsunami waves with inland penetration up to 5 km and run-up heights to 40 m. More than 400 km² were flooded, mainly along the northeast coast of Japan's largest island, Honshu. Nearly 20,000 human lives were abruptly taken by this natural disaster. Four coastal nuclear facilities went into automatic shutdown; at one, Fukushima Daiichi, cooling system failures resulted in the meltdown of three reactor cores, accompanied by explosive release of radioisotopes.

Essentials of modern blood banking and transfusion medicine were lost: roads, vehicles, blood collection venues, and facilities for blood testing and processing. Normal channels of communication were interrupted, not only by physical damage but also due to circuit overload as mobile phone users sought information and tried to exchange messages about their own and others' health, welfare, and whereabouts.

The Japanese Red Cross, as a monopoly supplier of allogeneic blood, responded with a nationally coordinated effort that met the transfusion demands of a disaster characterized by immediate mass fatality rather than mass injury. Japan's routine transfusion demands are also met by hospital-based autologous blood programs, which could be pressed into service for emergency allogeneic collections. Herein we report institutional and personal experience in anticipation of future disasters, in which transfusion needs might differ from routine demand.

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1. Introduction

Japan is a volcanic archipelago within a “Ring of Fire” encircling the Pacific Ocean, from which most of the world’s earthquakes originate. Seismic activity can provoke major tsunamis, such as the 2004 Sumatra-Andaman Earthquake and Boxing Day Tsunami that took more than 225,000 lives [1]. Earthquakes in developed areas can also result in fire, such as Japan’s 1995 Great Hanshin Earthquake, in which fire was implicated in 504 of more than 6400 deaths. Burn injuries [2], crush syndrome [3–7], and mental health issues [8–15] from that event have been reported. Following the Great Hanshin Earthquake, the Japanese Red Cross (JRC) developed new Risk Management Guidelines for large-scale earthquakes, remote island disasters, nuclear accidents, and other scenarios [16]. The 2011 Great East Japan Earthquake led JRC to implement specific changes in affected blood centers, and further revise its Risk Management Guidelines [17].

On March 11, 2011 at 14:46 Japan Standard Time, a magnitude 9.0 earthquake started from an underwater epicenter about 130 km east of Sendai, the capital city of Miyagi Prefecture (see Fig. 1). Sendai is where JRC had established one of six “Block” centers around Japan to consolidate increasingly complex laboratory and administrative tasks associated with modern blood banking. The Tohoku Block Center in Sendai serves the three Pacific coast prefectures most affected by the tsunami (north to south: Iwate, Miyagi, Fukushima), and three adjoining prefectures with coastlines along the inland sea facing Korea (north to south: Aomori, Akita, Yamagata). These six prefectures comprise Tohoku, the northeast part of Japan’s main island, Honshu. Each of these prefectures has an eponymous blood center administratively affiliated with the Tohoku Block Center.

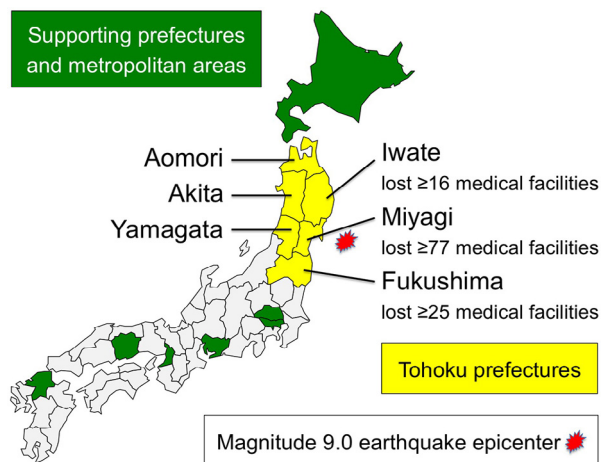


Fig. 1. Prefectural and metropolitan subdivisions within the four main islands of Japan. Tohoku’s prefectures are named. The other highlighted subdivisions are prefectures and metropolises where Japanese Red Cross Blood Centers were especially involved in supporting Tohoku after the Great East Japan Earthquake. From lower left to upper right, they are Fukuoka, Okayama, Aichi, Osaka, Tokyo, Saitama, and Hokkaido. A more detailed map can be seen on the last page of http://www.jrc.or.jp/activity/blood/pdf/ketsueki_kirokushi_02_preface.pdf, corresponding to pages x–xi of Ref. [17].

In various places, the earthquake interrupted utilities such as electricity, running water, and gas. Utility distribution lines were directly damaged, and nuclear plants on Tohoku’s Pacific coast went into automatic shutdown. Even in shutdown, not generating electricity, reactor cores continue to produce immense heat. Cooling these cores requires energy, if not from the electrical grid, then on-site, from emergency back-up generators and/or batteries. All six power lines leading from Japan’s grid into the Fukushima Daiichi nuclear power plant were destroyed by the tsunami [18].

The first tsunami waves reached land within 20 minutes. The Sendai Plain, closest to the epicenter, is the most populous part of Tohoku. Along its coast, the mean inundation height was 10 m, with a maximum of 19.5 m. The tsunami reached as far as 5 km inland [19,20]. Sendai Airport, just 1 km inland, was flooded up to the second level of its terminal, where more than 1000 people were stranded until March 13 [16].

North of the Sendai Plain, tsunami run-up heights exceeded 30 m along 180 km of the Sanriku Coast from Onagawa in Miyagi Prefecture to Noda in Iwate Prefecture. In-between, Iwate’s city of Ofunato encountered a run-up height of 40 m [19,20].

To the south, tsunami run-up heights at the Fukushima Daiichi nuclear power plant reached 14–15 m where the main buildings were located, and in some places, in excess of 17 m. Based on licensing documents that assumed a maximum tsunami height of 3.1 m above sea level, seawater pumps for heat exchange were placed 4 m above sea level, behind which a slope extending to a height of 10 m was intended to protect the turbine and reactor buildings. Water-cooled emergency diesel generators were installed in the turbine buildings, below the 10 m grade; they and the seawater heat-exchange pumps were flooded, as were most of the backup batteries [18]. The inevitable core meltdowns were not publicly acknowledged by the plant’s operator until mid-May [21].

Overall, the tsunami was reported to have rendered at least 118 medical facilities on the Pacific coast unusable: 16 in Iwate Prefecture, 77 in Miyagi Prefecture, and 25 in Fukushima Prefecture, including one within a 20 km exclusion zone established around the Fukushima Daiichi nuclear plant [22].

2. Blood center response by prefecture

As described in Section 1, six JRC blood centers, one for each prefecture in Tohoku, function within the jurisdiction of the Tohoku Block Center. What follows is a prefecture-by-prefecture summary of events and countermeasures made in response to the March 11 earthquake, tsunami, and subsequent nuclear crisis. We begin with (Section 2.1) Miyagi Prefecture, for being closest to the earthquake epicenter and being host to the Tohoku Block Center as well as the Miyagi Red Cross Blood Center, both in Sendai City. Proceeding counterclockwise, Iwate (Section 2.2), Aomori (Section 2.3), Akita (Section 2.4), Yamagata (Section 2.5), and Fukushima (Section 2.6) prefectures will be reported. Unique to Fukushima, it is where the Tokyo Electric Power Company’s Fukushima Daiichi and Daini (Fukushima 1 and Fukushima 2) nuclear power plants are located. Core meltdowns and the explosive release of isotopes from Fukushima

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