J. Aichi Med. Univ. Assoc.
Vol. 47, No. 4, pp. 23–30 (December 15, 2019)

Estimation for Hospitals Handling the Patient Load after a Nankai Trough Earthquake in the Tokai Region

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Background: In Japan, estimates of the level of casualties if a Nankai Trough earthquake occurs have been performed for a long time, but there are not enough studies about the potential damage to hospitals. Accordingly, we estimated the extent of damage to disaster base hospitals in the Tokai region that could be caused by a Nankai Trough earthquake. We also developed a new medical care strategy based on the capacity of hospitals in the Tokai region to accept severely injured patients.

Methods: We classified disaster base hospitals into four groups (functioning group, structural damage group, evacuation group, and isolated group) by location according to the distribution of seismic intensity, risk of liquefaction, and risk of inundation by a tsunami. Then we estimated the severity of damage for each group.

Results: With regard to the estimated damage to disaster base hospitals, there were 32 functioning hospitals and 37 hospitals with some level of damage. These included 12 hospitals in the structural damage group, 12 hospitals in the evacuation group, and 13 hospitals in the isolated group.

Conclusion: When a Nankai Trough earthquake occurs, more than half of the disaster base hospitals will probably be damaged, with most of the damaged hospitals being located in coastal areas. Therefore, we estimate that handling patients within the affected prefectures by the current system would be difficult. In addition to the rapid transport of patients to outside the disaster zone, it is necessary to consider a new strategy for providing medical care in the affected region.

Key words: Nankai Trough earthquake, disaster base hospital, severely injured patient, secondary medical area, medical strategy

BACKGROUND

Japan is an earthquake-prone country because it is located at the boundaries of four ocean trench plates. A Nankai Trough earthquake caused by slipping of the Philippine Sea plate under the Eurasian continental plate occurs every 100 to 150 years[1)], and the Pacific coastal region usually suffers massive damage because of its characteristic topography. Therefore, Japan has long been preparing countermeasures for the next Nankai Trough earthquake. However, since the 2011 Great East Japan Earthquake, the countermeasures have been revised along with new estimates of the

Received November 25, 2019; Accepted December 26, 2019

damage that could be caused by a Nankai Trough earthquake[2)–5)]. The damage due to a Nankai Trough earthquake has been assessed by estimating the effects on buildings/infrastructure and the number of dead or injured people. However, the potential extent of damage to hospitals has not been investigated sufficiently.

In other countries, research on predicting the risk of injury and death in future earthquakes has also been performed[6)], with prediction of the mortality rate due to an earthquake being based on demographic, seismic, and fatality data from available records of past earthquakes[7)]. A case report of hospital evacuation has also been presented[8)]. However, no study has attempted to specifically predict earthquake damage to hospitals.

Accordingly, we estimated the extent of damage to disaster base hospitals in three prefectures of the Tokai region (Shizuoka, Aichi, and Mie) that are expected to be severely affected. We identified several issues for hospitals in the disaster zone and developed a new strategy for coping with a Nankai Trough earthquake.

MATERIALS AND METHODS

1. Estimated Damage to Hospitals

Figure 1 presents the Japanese seismic intensity scale[9)], which describes the severity of shaking at a particular location during an earthquake. It varies with the distance from the epicenter and the surface geology at each point. We determined the location of each disaster base hospital in the three prefectures of the Tokai region, and then predicted the dam-

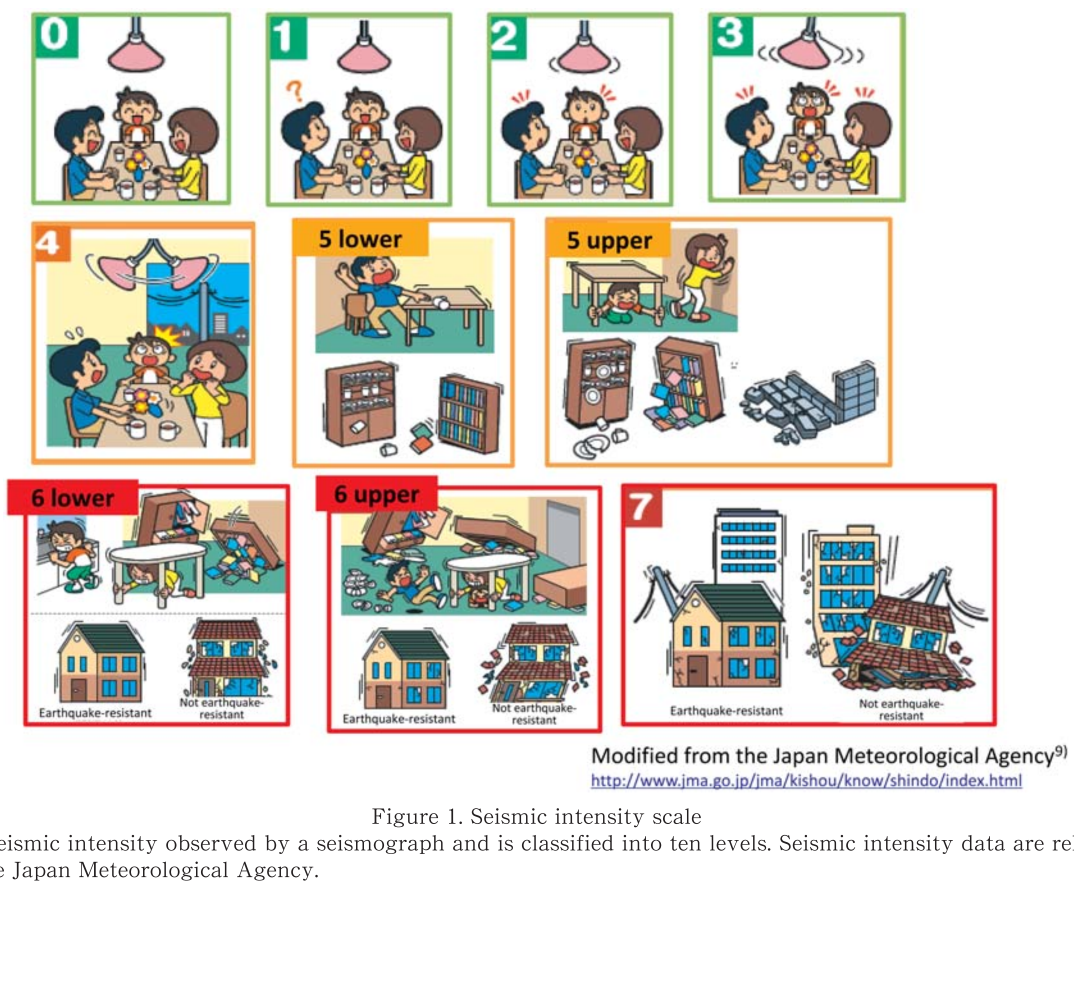

Figure 1. Seismic intensity scale
The seismic intensity observed by a seismograph and is classified into ten levels. Seismic intensity data are released by the Japan Meteorological Agency.

age from the distribution of seismic intensity, the risk of liquefaction, and the risk of inundation by a tsunami[10)–12)]. These result were shown in figure 2, which was drawn on GSI Maps (https://maps.gsi.go.jp) published by Geospatial Information Authority of Japan.

2. Classification of Earthquake Damage to Hospitals

We classified the hospitals into four groups on the basis of the predicted level of earthquake damage (Table 1). This was determined from the distribution of seismic intensity, liquefaction, and tsunami inundation.

The functioning group was defined as hospitals in areas with a seismic intensity of 6 lower or less. The structural damage group was hospitals in areas with a seismic intensity of 6 upper or areas with both a seismic intensity of

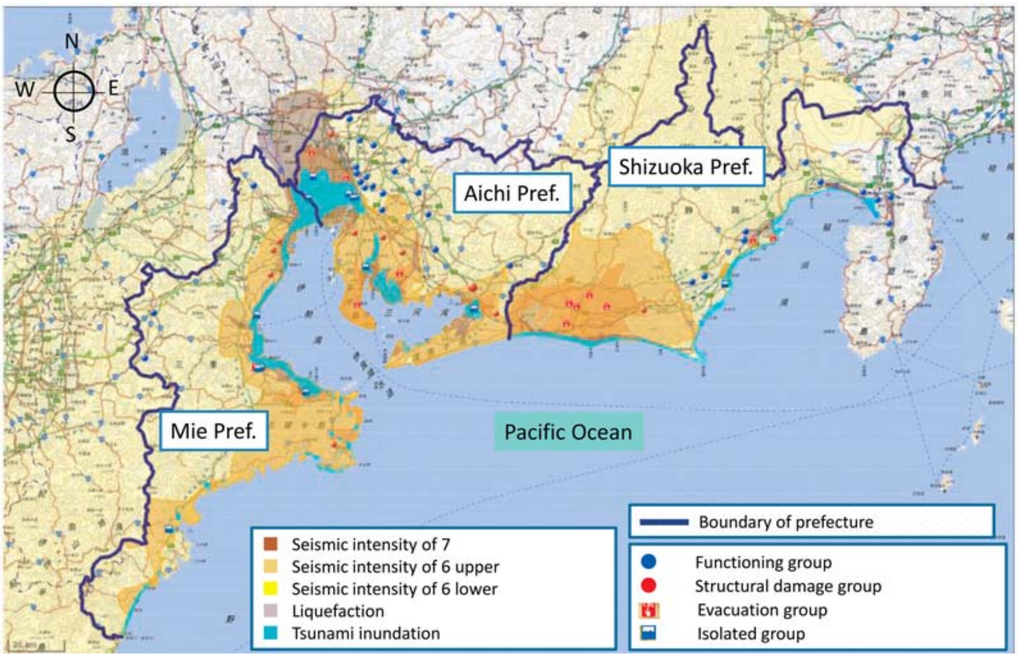

Figure 2. Map of the predicted damage to disaster base hospitals in each prefecture
This map shows the locations of all disaster base hospitals in Shizuoka, Aichi, and Mie prefectures and the predicted level of damage based on the distribution of seismic intensity, the risk of liquefaction, and the risk of tsunami inundation based on references 10)–12).

Table 1. Classification of hospitals into groups based on the severity of damage and the capacity to accept patients

Group	Type of Damage	Capacity to Accept Patients
Functioning group	Hospitals in areas with a seismic intensity of 6 lower of less	Can accept patients.
Structural damage group	Hospitals in areas with a seismic intensity of 6 upper or areas with both a seismic intensity of 6 lower and liquefaction	Cannot accept new patients, but can provide medical care to hospitalized patients.
Evacuation group	Hospitals in areas with a seismic intensity of 7 or areas with both a seismic intensity of 6 upper and liquefaction	Need to transfer hospitalized patients.
Isolated group	Hospitals in areas that were predicted to be flooded by a tsunami	

6 lower and liquefaction. The evacuation group was hospitals in areas with a seismic intensity of 7 or areas with both a seismic intensity of 6 upper and liquefaction. The isolated group was hospitals in areas that were predicted to be flooded by a tsunami.

3. Capacity of Disaster Base Hospitals in Each Group to Accept Patients

We estimated the capacity of disaster base hospitals in each damage category to accept patients based of the severity of damage reported after the Great Hanshin Earthquake and the Great East Japan Earthquake. In the former earthquake, many hospitals in areas with a seismic intensity of 7 collapsed or were severely damaged, even though they were new buildings with earthquake-resistant steel frames[13)–15)]. Therefore, we assumed that disaster base hospitals located in areas where the seismic intensity reached 7 would require evacuation of their current patients because hospital functions would be lost, and continuing treatment would be difficult. In the Great East Japan Earthquake, damage to earthquake-resistant buildings in areas affected by liquefaction was more severe than in regions without liquefaction[13)]. Therefore, hospitals in regions with a seismic intensity of 6 upper and a risk of liquefaction were assumed to suffer the same level of damage as hospitals in regions where the seismic intensity was 7. In the structural damage group, hospitals located in regions with a seismic intensity of 6 lower and a risk of liquefaction were assumed to suffer the same level of damage as hospitals in regions with a seismic intensity of 6 upper.

Based on these assumptions, the estimated capacity of hospitals in each category to accept patients is shown in Table 1 and Figure 3.

Disaster base hospitals in the functioning group will still accept new patients because there will be little structural damage. In the structural damage group, base hospitals will not accept new patients because of damage to

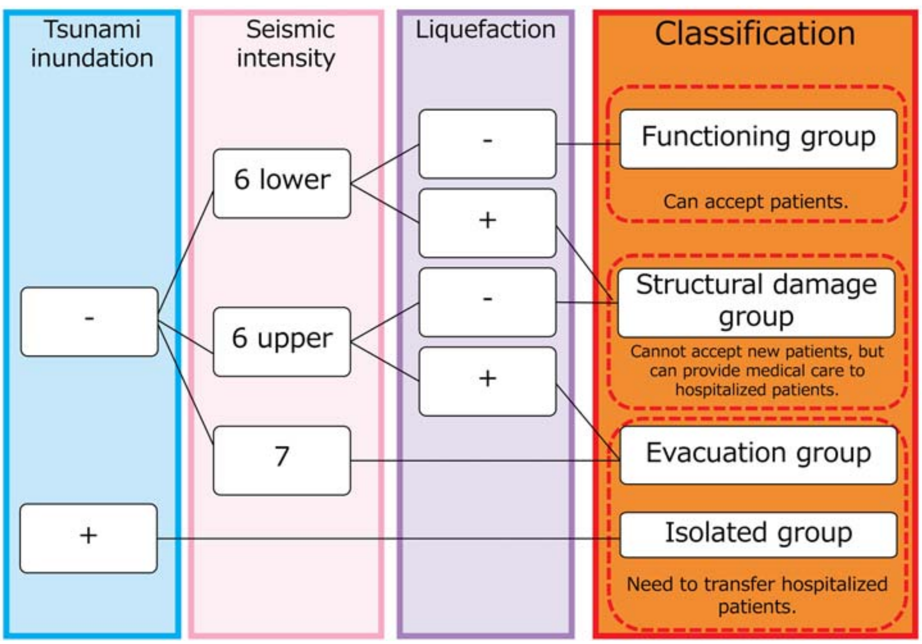

Figure 3. Flowchart for predicting the level of earthquake damage to disaster base hospitals
Each category is classified according to the distribution of seismic intensity, tsunami inundation, and liquefaction for more details see text.

the buildings but could continue to provide medical care to their current patients. In the evacuation group, the disaster base hospitals will have to transfer their patients elsewhere (if feasible) because the buildings are heavily damaged, and it will be difficult to continue provide medical care. In the isolated group, the disaster base hospitals will also have to transfer their patients elsewhere (if feasible) because access is disrupted by the tsunami and essential services are affected.

RESULTS

Figure 2 demonstrates the extent of damage to the disaster base hospitals in each prefecture. While there were 32 functioning hospitals (46%), 37 hospitals were damaged to some extent (53%). These comprised 12 hospitals (17%) in the structural damage group, 12 hospitals (17%) in the evacuation group, and 13 hospitals (19%) in the isolated group. In Shizuoka prefecture, 12 hospitals (57%) were estimated to be functioning, 1 hospital (5%) was estimated to suffer structural damage, 7 hospitals (33%) were estimated to require evacuation, and 1 hospital (5%) was estimated to become isolated. In Aichi prefecture, 17 hospitals (49%) were estimated to be functioning, 7 hospitals (20%) were estimated to suffer structural damage, 4 hospitals (11%) were estimated to require evacuation, and 7 hospitals (20%) were estimated to become isolated. In Mie prefecture, 3 hospitals (23%) were estimated to be functioning, 4 hospitals (31%) were estimated to suffer structural damage, 1 hospital (8%) was estimated to require evacuation, and 5 hospitals (38%) were estimated to become isolated (Figure 4).

DISCUSSION

The prefectures of Shizuoka, Aichi, and Mie in the Tokai region have the following topographic characteristics. A plateau formed by a

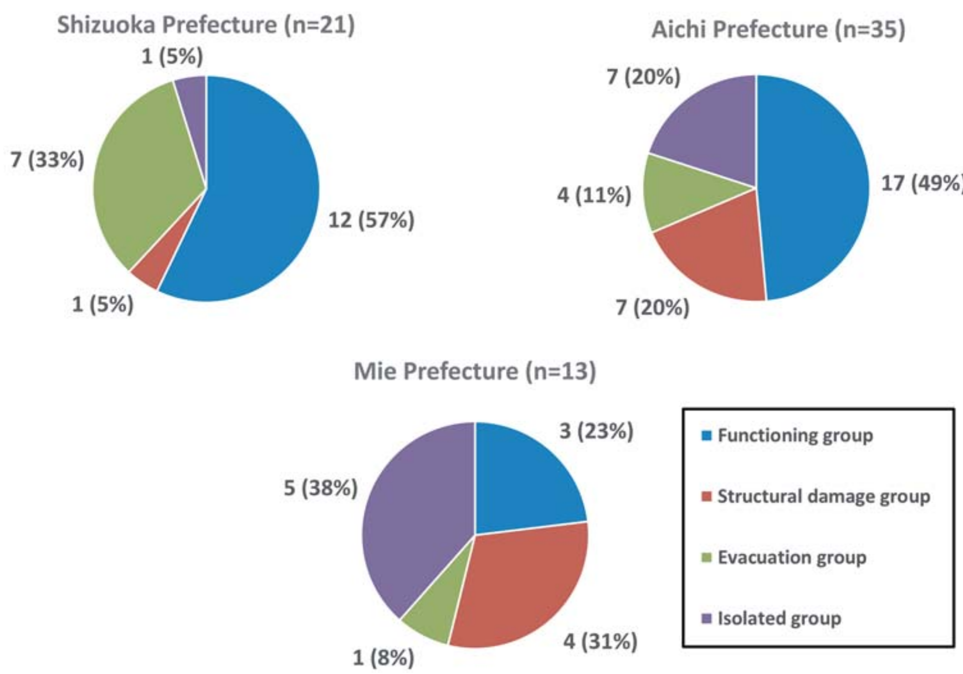

Figure 4. Classification of disaster base hospitals in each prefecture into damage groups
The diagrams present the number and percentage of disaster base hospitals belonging to each of the four damage groups in each prefecture.

drop in the sea level extends from western Shizuoka prefecture to eastern Aichi prefecture. In addition, a large plain formed by river sediment is located within western Aichi and northern Mie prefectures. Finally, a ria coastline (a deeply indented coastline) extends from the central to southern parts of Mie prefecture. Due to these characteristics, all three prefectures have suffered massive damage in previous major earthquakes owing to tsunami inundation and liquefaction. Accordingly, we would expect damage to hospitals in these three prefectures when a Nankai Trough earthquake occurs.

The extent of damage to the disaster base hospitals would depend on the topographic characteristics of each prefecture and was estimated to be as follows. In central and western Shizuoka prefecture, many hospitals were classified into the evacuation group because the predicted seismic intensity was 7 in this region. In the coastal regions of Aichi and Mie prefectures, many hospitals were classified into the isolated group because inundation by a tsunami was predicted. In western Aichi prefecture, many hospitals were classified into the evacuation and structural damage groups because inundation by a tsunami was predicted to occur at 0 meters above sea level and liquefaction was also expected.

In general, when we consider medical strategies focusing on patient transport, it is necessary to move patients to areas outside the disaster zone. However, Anan (2016) et al. investigated the capacity of hospitals to accept severely ill patients in unaffected areas and found that there were only 1532 ICU beds in the unaffected areas. They also reported on the limitations of the methods of transportation, e.g., Self-Defense Force aircraft may only be able to transport 340 patient per day, and air ambulances may only transport 423 patients every 3 days[16]. Additionally, with respect to evacuation of a large number of patients, there have been reports about various problems that arose during hospital evacuation in the Kumamoto earthquake, which included safety management at the time of evacuation, finding a large number of hospital beds in other areas and methods of transportation to move patients, and management of the hospital itself after evacuation[17].

If a Nankai Trough earthquake causes the most severe predicted damage to the Tokai region, there may be 133,000–250,000 patients in Shizuoka, Aichi, and Mie prefectures[18]. Therefore, transportation of patients to areas outside the disaster zone will not overcome the issue of where they can go.

In disasters that have occurred in recent years, disruption of essential services has also been a problem that has affected medical care. This not only includes loss of local supplies, but also the effect on essential services due to disruption of water purification plants, pumping stations[19], or power plants[20], which may lead to long-term and widespread disruption. On the other hand, in the torrential rain of July 2018 and the 2018 Hokkaido Eastern Iburi Earthquake, large-scale hospital evacuation was avoided through the maintenance of essential services[21].

When a Nankai Trough earthquake occurs, it is highly likely that occurrence of the above-mentioned problems will be widespread and complex. Therefore, the medical strategy for a Nankai Trough earthquake would require prompt transportation of patients to hospitals outside the disaster zone using all possible modes of transportation, and a new strategy is needed for providing medical care in the affected areas. The new medical strategy that we propose is set out below.

① Decide which hospitals should be prioritized in terms of support for essential services to enable continuing provision of effective medical care in the disaster zone, including hospitals where it is difficult to transport patients or to continue activities owing to disruption of services.

② Utilize medical resources such as closed beds and spare beds to enable expansion of hospital capacity to accept patients within the disaster zone.

③ Provide resuscitation, including salvage surgery, and intensive care as much as possible within the disaster zone and transfer patients after they have been stabilized to buy some buffer time until definitive care is available.

In support for essential services, efficient support and prioritization can be achieved by grasping in advance the information necessary for support. (ex. presence/absence of emergency generators, type of fuel oil for emergency generators, generating time, etc.) For that purpose, it is important to collect information exhaustively in advance by the local governments and the Ministry of Health, Labor and Welfare. On the other hand, in order to materialize the new medical strategy of ② and ③, it will be necessary to examine the number of patients to enable to accept and the number of patients to need to transfer other hospitals at each disaster base hospitals.

LIMITATIONS

In this study, classification of hospital damage due to earthquake and the capacity of disaster base hospitals to accept patients was estimated from data on the conditions for certifying disaster base hospitals[22], government reports, and past research. According to a report on the availability of spare beds during disasters[23], few disaster base hospitals have enough spare beds. Therefore, the capacity of disaster base hospitals to accept patients would be limited. Furthermore, some government reports were about old disasters. In this study, secondary disasters such as landslides and levee breaks were not considered. Therefore, more damage may occur depending on the location of the disaster base hospital.

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