Original Article

Creating a new index to evaluate imbalance in medical demand and supply when disasters occur

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Aim: This study examines the use of the medical risk/resource ratio (RRR) and need for medical resources (NMR) as new indicators of the imbalance in medical demand and supply in disasters. These indicators are used to quantify the medical demand–supply imbalance per disaster base hospital, examine the demand–supply imbalance in the region, and verify the need for medical support.

Methods: We calculated the RRR of each disaster base hospital by dividing the revised estimate of the number of patients with the number of empty beds. We calculated the required number of hospital beds as the NMR to restore the RRR of each disaster base hospital to two. The RRR and NMR were combined, and prioritization for medical support was classified into three levels.

Results: The median RRR was 23 (range, 1–101), and the median NMR was 943 (range, 0–2,124). Fifteen hospitals had a medical support priority of 1, five hospitals had a priority of 2, and 13 hospitals had a priority of 3.

Conclusion: The medical demand–supply imbalance and amount of medical support needed can be quantified using RRR and NMR, which allows examination of the priority level for medical support.

Key words: Disaster, hospital, prioritization, resource, risk

INTRODUCTION

FOLLOWING THE HANSHIN Awaji Earthquake in 1995, significant improvements have been made in the disaster medical care system in Japan. Disaster base hospitals are medical institutions that provide emergency medical care in the immediate aftermath of a disaster and are an important part of this system.[1] In addition, the predicted damage from earthquakes expected after the 2011 Great East Japan Earthquake has also been examined.[2]

Although the damage prediction for each region has received attention, few studies have explored the medical care burden at each disaster base hospital. Furthermore, the level of imbalance that could arise with respect to the medical care burden at a given hospital and the medical support capacity of each of these hospitals are unclear.

In this study, in addition to the medical risk/resource ratio (RRR),[3] the need for medical resources (NMR) was newly devised as an indicator to express a medical demand–supply imbalance. We quantified this imbalance for each disaster base hospital to classify prioritization for medical support.

METHODS

Disaster prediction data

WE USED DATA from the Kanagawa Prefecture Earthquake Anticipated Damage Survey Report,

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released by the Kanagawa Prefecture Earthquake Anticipated Damage Study Committee in March 2015, as the base data.[2] In this study, the target of investigation was the imminent danger of the occurrence of an "earthquake with an epicenter directly below the southern downtown area" with a 70% probability of occurrence in the next 30 years and for which a strengthening of countermeasures has been prescribed by law. The damage was predicted on the premise of an occurrence of an earthquake at 6:00 PM on a winter weekday. We predicted that there could be 2,990 deaths, 2,810 severe injuries, 24,680 moderate injuries, and 35,250 light injuries across the entire Kanagawa Prefecture. We also calculated the number of persons estimated to be injured for each municipality and ward in Kanagawa Prefecture. The definition of each level of severity is shown in Table 1.[2]

Calculation of disaster-induced demand and supply for medical care (medical risk)

We considered the estimated number of patients and the number of people in need of care as the demand for disaster medical care. We calculated the number of people in need of care by taking the size of the population aged under 6 years, number of those aged 75 years or older, number of pregnant woman, total number of persons needing care, number of tourists, number of people with physical disabilities, and number of mentally impaired persons and by plugging this into the following formula:

$$\text{Number of Persons in Need of Care} = a + b + c + d + e + f + g - h,$$

where a = size of the population aged under 6 years; b = number of people aged 75 years or older; c = number of pregnant women: annual number of births $\div$ 12 $\times$ 10; d = number of people certified as having physical disabilities; e = number of people understood to have mental disabilities; f = number of people in need of care: the number of those aged between 65 and 75 years $\times$ 0.169; g = tourists: total number of tourists per year $\div$ 365; h = those with multiple overlapping disabilities: number of persons certified as having physical disabilities $\times$ 0.09.

Next, we divided the number of people in need of care by the population in each administrative division and calculated the percentage of those needing care.

$$\text{Percentage of people needing care}(\%) = 100 \times \left(\frac{\text{number of people needing care}}{\text{population}}\right).$$

We assumed that those needing care have 1.5 times the normal medical care demand and calculated the revised estimate of persons injured as follows:

Table 1. Definition of levels of criticality in the event of a disaster

Category	Definition
Critically ill persons	• Patients whose life is threatened if emergency treatment is not provided or surgery is not done • Requires treatment in an intensive care unit • Handled at disaster base hospitals
Persons with moderately serious injuries	• Hospital treatment is eventually necessary but it is less urgent compared to critically ill persons (e.g. limb fractures) • Handled at disaster base hospitals, disaster co-operation hospitals, and general hospitals
Persons with light injuries	• Should be handled at temporary first-aid stations, provided with emergency relief treatment (e.g. cuts and bruises)

$$\begin{aligned}&\text{Revised estimate of persons injured}\\&= \text{number of persons injured} \times (100- \\&\quad \text{percentage of those needing care})/100\\&\quad + \text{number of injured persons} \times\\&\quad \text{percentage of those needing care}/100 \times 1.5.\end{aligned}$$

The above formula for number of persons injured was substituted with the total number of persons injured, number of those with non-serious diseases, number of those with serious diseases for each administrative division, and revised estimate of the total number of persons injured.

Next, we calculated the revised estimate of the number of those patients at each disaster base hospital. Kanagawa Prefecture has 33 disaster base hospitals. As not every administrative division had a disaster base hospital, we used the following method to calculate the total number of people requiring medical care. If an administrative division had only one disaster base hospital, then that hospital would be in charge of all the revised estimates of persons injured in that division. If an administrative division had multiple disaster base hospitals, then the revised estimate of the number of persons injured in that administrative division divided equally by the number of disaster base hospitals would be the number of people for which each disaster base hospital would be responsible. In an administrative division with no disaster base hospital, the disaster base hospital in the adjacent administrative division would be responsible. In cases of multiple disaster base hospitals in the adjacent administrative division, the number of disaster base hospitals was divided equally by the revised estimate of persons injured to give the number of persons each disaster base hospital would be in charge of.

Calculation of the capacity to supply disaster medical care (medical resource)

The sum of the total number of hospital beds and the total number of hospital beds for the critically ill were taken to represent the capacity of each disaster base hospital to provide medical care. We assumed that the occupancy rate of hospital beds immediately after the disaster was 85% and that the number of empty hospital beds in each disaster base hospital was 15% of the total number of hospital beds.

Calculation of the medical RRR

The RRR in each disaster base hospital was calculated as follows:

$$\text{RRR for total number of injured people} = \text{revised estimate of total number of those injured} \div \text{the number of empty beds in the disaster base hospital at the time of occurrence of a disaster.}$$

$$\text{RRR for number of people with moderate injury} = \text{revised estimate of total number of those with moderateinjury} \div (\text{the number of empty beds in the disaster base hospital at the time of occurrence of disaster number of empty hospital beds used for thecritically ill}).$$

$$\text{RRR for number of critically ill people} = \text{revised estimate of the number of critically ill persons} \div \text{number of empty beds for the critically ill in the disaster base hospital at the time of occurrence of the disaster.}$$

Calculation of the amount of medical care support required (NMR)

The number of hospital beds required to restore the RRR of each disaster base hospital was defined as the NMR and was calculated as follows:

$$\text{NMR} = \text{number of modified estimated total patients} \div 2 - \text{the number of hospital beds empty in the disaster base hospital at the time of the occurrence of the disaster.}$$

Furthermore, for the distribution of medical services in the region, we calculated the proportion of the total NMR for the entire region to the NMR of each disaster base hospital (NMR%).

We used the median value for the cut-offs for RRR and NMR for the following reasons. Those values were relative estimations in those areas, and absolute values would not have a definite meaning. In addition, the distribution of the values could not be expected with a normal distribution. Thus, we used median instead of mean values.

RESULT

TABLE 2 presents the revised estimate of the number of injured people that each disaster base hospital in Kanagawa Prefecture would be in charge of (total number, number of those with moderate injuries, and number of those with serious injuries) as well as the total number of empty hospital beds, number of hospital beds for the critically ill, and both the RRR and NMR calculated with these as the basis. The revised estimate of the total number of injured persons in the whole of Kanagawa Prefecture was 67,139. The total number of empty hospital beds in the 33 disaster base hospitals was 18,108. The number of empty beds at the time of occurrence of a disaster was 2,725. According to a disaster plan for Kanagawa Prefecture, local areas are divided by using a medical administration area called the secondary medical zone. Then, we add the RRR and NMR for each secondary medical zone in Table 2. The median RRR of the total number of injured persons was 23 (range, 1–101), and the median NMR was 943 (range, 0–2,124). Only one disaster base hospital had an RRR of 1, and 32 hospitals faced an imbalance in the disaster medical care demand and supply in 32 hospitals. Figure 1 shows the NMR% along with the location of the disaster base hospitals on a map of Kanagawa Prefecture.

The disaster prediction of the region in the event of an earthquake was revised to 943 beds at the time of the disaster, which is the representative value of the capacity of supplying medical care. Furthermore, the RRR and NMR were considered to enable the quantification of the medical care demand–supply imbalance and the amount of medical support required. In addition, combining the RRR and NMR, it was possible to classify hospitals that require medical

Table 2. Number of beds, medical risk/resource ratio (RRR), and need for medical resources (NMR) for each base disaster hospital in Kanagawa Prefecture, Japan

Base disaster hospital	Region	No. of total beds (*a*)	No. of estimated available beds (*b* = *a**0.15)	No. of beds for serious pts (*c*)	No. of estimated available beds for serious pts (*d* = *c**0.15)	No. of modified estimated total pts (*e*)	No. of modified estimated moderate pts (*f*)	No. of modified-estimated serious pts (*g*)	Total pts RRR (*e*/*b*)	Moderate pts RRR (*f*/*b*)	Serious pts RRR (*g*/*d*)	Total pts NMR (*e*/2 − *b*)	Moderate pts NMR (*f*/2 − *b*)	Serious pts NMR (*g*/2 − *d*)	No. of estimated available beds for each secondary medical zone	No. of modified estimated total pts for each secondary medical zone	RRR for each secondary medical zone	NMR for each secondary medical zone
A	Yokohama city	584	88	52	8	2,178	890	108	23	10	14	1,001	357	46	374	11,424	31	5,338
B	Yokohama city	650	98	19	3	4,444	1,824	230	42	19	81	2,124	814	112				
C	Yokohama city	691	104	37	5	1,788	700	78	16	7	14	790	246	34				
D	Yokohama city	560	84	64	9	3,014	1,224	150	31	15	16	1,423	528	66				
E	Yokohama city	518	78	53	8	2,619	1,046	128	24	13	16	1,232	445	56	315	7,112	23	3,241
F	Yokohama city	410	62	6	1	1,750	680	81	28	11	90	813	278	40				
G	Yokohama city	650	98	32	5	1,442	774	88	14	8	18	623	289	39				
H	Yokohama city	510	77	64	11	1,301	529	67	13	7	6	574	188	23				
I	Yokohama city	726	109	65	11	1,990	860	118	17	8	11	886	321	48	479	5,150	11	2,096
J	Yokohama city	500	75	8	1	700	323	38	8	4	37	275	87	18				
K	Yokohama city	654	100	26	4	295	114	16	2	1	4	48	0	4				
L	Yokohama city	655	100	10	2	295	114	16	2	1	4	48	0	6				
M	Yokohama city	634	95	10	3	1,870	740	88	19	8	36	840	275	41				
N	Yokosuka city	725	109	45	6	2,338	876	80	22	10	12	1060	329	34	181	4,676	26	2,157
O	Yokosuka city	482	72	4	1	2,338	876	80	33	13	80	1,097	366	39				
P	Kawasaki city	713	107	18	3	3,324	1,312	150	31	13	56	1,555	549	72	255	9,130	36	4,310
Q	Kawasaki city	372	56	34	5	2,903	1,131	130	52	22	26	1,396	510	60				
R	Kawasaki city	610	92	18	3	2,903	1,131	130	32	13	48	1,360	474	62				

Table 2. (Continued)

Base disaster hospital	Region	No. of total beds (*a*)	No. of estimated available beds ($b = a*0.15$)	No. of beds for serious pts (*c*)	No. of estimated available beds for serious pts ($d = c*0.15$)	No. of modified estimated total pts (*e*)	No. of modified estimated moderate pts (*f*)	No. of modified-estimated serious pts (*g*)	Total pts RRR (*e*/*b*)	Moderate pts RRR (*f*/*b*)	Serious pts RRR (*g*/*d*)	Total pts NMR ($e/2 - b$)	Moderate pts NMR ($f/2 - b$)	Serious pts NMR ($g/2 - d$)	No. of estimated available beds for each secondary medical zone	No. of modified estimated total pts for each secondary medical zone	RRR for each secondary medical zone	NMR for each secondary medical zone
S	Kawasaki city	400	60	0	0	2,462	1,011	130	41	17	180	1,171	446	65	297	8,178	28	3,792
T	Kawasaki city	376	56	10	2	1,792	721	90	32	13	60	840	305	43				
U	Kawasaki city	1,208	181	59	6	3,924	1,592	190	22	9	21	1,781	615	89				
V	Sagamihara city	132	20	0	0	2,018	745	83	101	37	83	989	353	42	241	7,605	32	3,562
W	Sagamihara city	437	66	40	6	2,018	745	83	31	12	14	943	307	36				
X	Sagamihara city	1,033	155	102	15	3,569	1302	136	23	9	9	1,630	496	53				
Y	Yamato city	403	60	12	2	2,368	886	103	39	15	52	1,124	383	50	105	6,637	63	3,214
Z	Atsugi city	303	45	8	1	4,269	1,564	160	95	36	160	2,090	737	79				
AA	Fujisawa city	530	80	27	4	2,699	986	92	34	13	23	1,270	413	42	140	3,479	25	1,600
AB	Chigasaki city	401	60	37	5	780	280	23	13	5	4	330	80	7				
AC	Isehara city	804	121	120	18	909	318	34	8	3	2	334	38	0	231	3,157	14	1,348
AD	Hiratsuka city	410	62	18	3	1,395	491	35	23	8	12	636	184	15				
AE	Hadano city	320	48	4	1	853	309	35	18	7	35	379	107	17				
AF	Matsuda town	290	44	4	1	30	4	0	1	0	0	0	0	0	107	591	6	189
AG	Odawara city	417	63	26	4	561	214	0	9	4	0	218	44	0				
Total/ median		18,108	2,725	1,032	157	67,139	26,312	2,970	23	10	18	943	321	41	2,725	67,139	26	3,214

a, size of the population aged under 6 years; *b*, number of people aged 75 years or older; *c*, number of pregnant women: annual number of births ÷ 12 × 10; *d*, number of people certified as having physical disabilities; *e*, number of people understood to have mental disabilities; *f*, number of people in need of care: the number of those aged between 65 and 75 years × 0.169; *g*, tourists: total number of tourists per year ÷ 365; *h*, those with multiple overlapping disabilities: number of persons certified as having physical disabilities × 0.09; pts, patients.

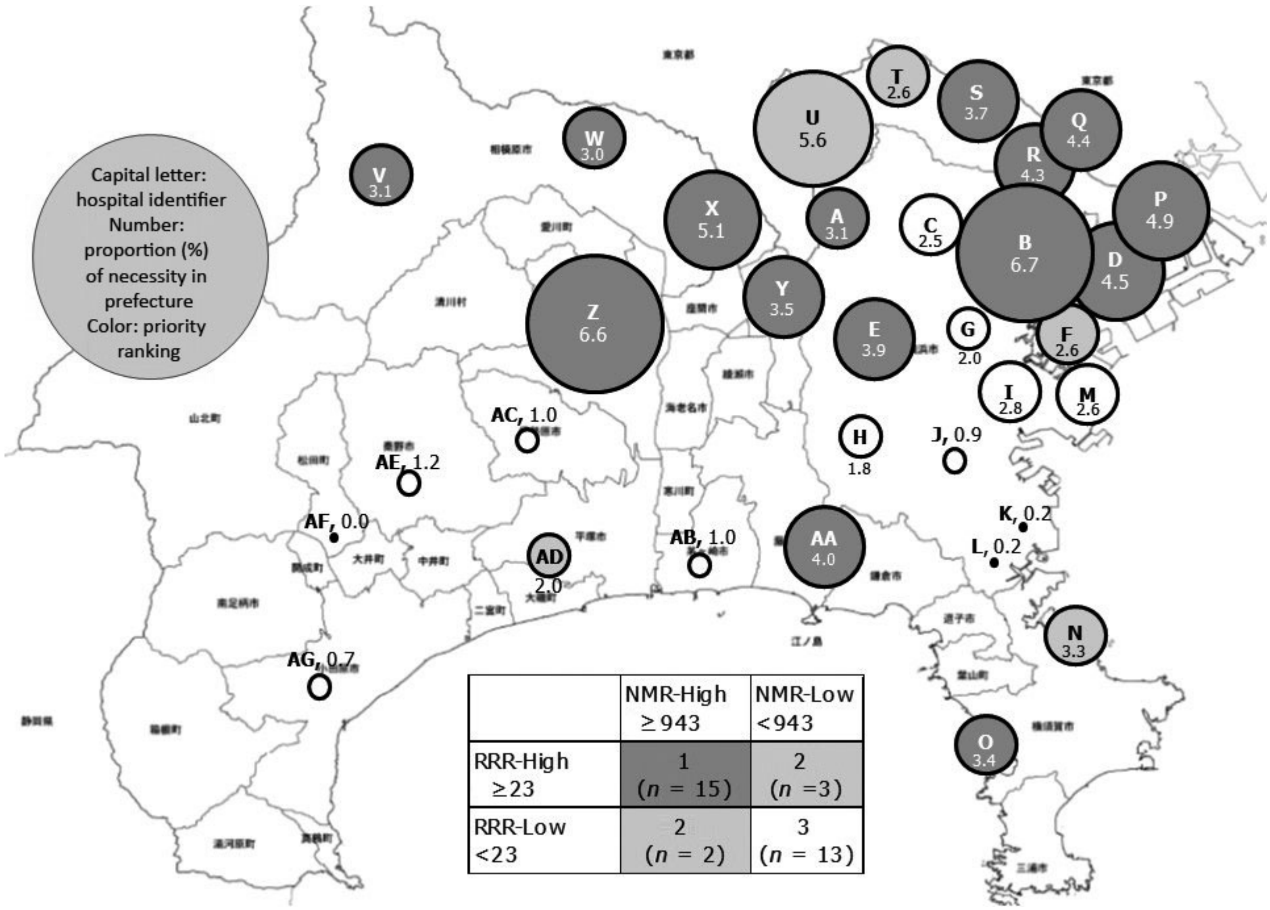

Fig. 1. Distribution of need for medical resources (NMR%) in Kanagawa Prefecture, Japan, and classification of medical care support in the event of a disaster. RRR, medical risk/resource ratio.

support, making it possible to examine prioritization for medical support.

In the classification of prioritization for medical support, disaster base hospitals with both RRR and NMR higher than the median value were deemed as being priority 1, those with either RRR or NMR higher than the median value as priority 2, and those with either RRR or NMR lower than the median value as priority 3. There were 15 hospitals with priority 1, five with priority 2, and 13 with priority 3 (Fig. 1).

DISCUSSION

THIS STUDY REVEALED that the imbalance in medical care demand and supply at the time of a disaster can be quantified based on RRR, and the need for medical support can be quantified through NMR. We also showed that it is possible to classify hospitals that need medical support based on a combination of RRR and NMR.

A surge in capacity requirements occurs in a hospital's emergency department and intensive care unit when thousands are injured in disasters that cover wide areas, such as earthquakes. The effective use of medical care resources is important to cater to the greatest number of affected people.[4] Although several reports have been released on indicators for assessing damage due to disasters, the majority of them comprise the opinions of experts or are drawn from observational studies and retrospective studies. The nature of a disaster makes it difficult to undertake quality research on them.[5] At present, there are no standard indicators to evaluate the imbalance in medical care demand and supply in hospitals based on disaster prediction. Hence, this study suggests that RRR be considered as an indicator. This indicator allows quantified predictions to be made concerning the imbalance in medical support caused by the occurrence of a disaster. From this, we found that the majority of the disaster base hospitals in Kanagawa Prefecture are likely to face an imbalance in medical care demand and supply. In addition, a similar trend was also found with respect to moderately and seriously injured persons. The RRR can be considered to be a new medical care demand–supply indicator that can quantify the imbalance in medical care demand and supply at disaster base hospitals, enabling a distribution across the area to be visualized. This study uses the number of empty beds at the time of a disaster as a measure of the RRR. The reason for this is that the number of empty hospital beds reflects the medical resources, such as corresponding staff and equipment at each hospital, and provides a representative value of medical resources.

Furthermore, the calculation of NMR allows a quantification of the extent of medical support per disaster base hospital, thus enabling a comparison across regions. To cope with critically ill persons, the intensive care unit must be expanded by two or three times its current size.[6] Based on this proposal, we defined the number of empty hospital beds required to restore the RRR to 2 as the NMR. Even with the same RRR value, the amount of medical care support required could be different. For example, even if the same RRR = 20, the situation would be different between 400/20 and 800/40. When calculating NMR, it becomes 180 at 400/20 and it becomes 360 at 800/40. Thus, we believe that it is important to calculate the NMR to clarify the difference in the amount of medical care support required.

Combining NMR and RRR, we can arrive at the number of hospitals required for providing adequate medical support. This study shows that hospitals with high RRR and NMR also have a high medical care demand–supply imbalance. This implies that the extent of medical support required to rectify it is also high. To ensure that medical services reach the majority of those injured, developing medical support as a top priority or as priority 1 is important. Hospitals with low RRR and NMR had a lower imbalance in medical care demand and supply. The extent of required medical support was also lower, which enables a degree of disaster response at one's own facilities. This category was defined as priority 3. For hospitals with either high RRR or NMR, it was not clear whether the hospital with high RRR (high medical support demand–supply imbalance) or the one with high NMR (large need for medical support) should be high in priority in terms of support provided. In this study, both are considered to be priority 2. Based on this priority classification and the NMR% of the region, it was possible to consider an appropriate medical support distribution plan.

With regard to future research directions, it would be worthwhile to further examine the imbalance in medical care demand and supply and medical support in other regions using methods similar to those used in this study. It is possible to develop a disaster plan for these other regions by taking this quantitative evaluation as the base data. We believe that this can be applied for establishing collaboration and transportation bases outside the region for effective use of medical resources. By calculating the RRR and NMR of all disaster base hospitals in the area affected by one earthquake, it is possible to classify the imbalance in medical demand and supply and the amount of support required for the entire afflicted area. Based on that data, we will be able to consider disaster response beyond the boundaries of administrative district. In addition, for specific cases, such as pediatric care, burn trauma, and external injury, we propose collaboration among hospitals.[6] Using the prediction of the number of injured for these specific cases, the RRR and NMR can be calculated and used as important data for plans and proposals.

This study includes the following limitations. First, the number of injured persons per disaster base hospital has been set without considering access to the hospital or hospitals other than disaster base hospitals and was simply assumed to be equal to the predicted number of injured persons in the region. Second, the indicators of medical care resources and number of empty beds have been calculated by assuming the bed occupancy rate to be 85%. As the bed occupancy rate for each disaster base hospital differs, examining data based more on reality (such as the yearly average of the bed occupancy rate) is important. The third limitation is the method used to calculate the revised estimate of the number of those injured. Future research should focus on aspects that should be part of the number of people in need of care and on setting the level of medical care demand at 1.5 times. Fourth, the calculation of Disaster-Induced Demand and Supply for Medical Care and the Capacity to Supply Disaster Medical Care we used were based on the concept of surge capacity[5] and our previous findings.[3] As we devised them as new tools, we might need to further test their validity and reliability in a future study. Finally, the different cut-off values might affect our results. We used medians for the cut-offs for RRR and NMR in order to categorize, and the medians would be adequate with this estimation values and under expectedly a non-normal distribution.

DISCLOSURE

Approval of the research protocol: N/A.
Informed consent: N/A.
Registry and the registration no. of the study/trial: N/A.
Animal Studies: N/A.
Conflict of interest: None.

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