Neonatal mortality rate reduction by improving geographic accessibility to perinatal care centers in Japan.

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Objectives: To assess reducing travel time to perinatal care centers, and to examine whether reducing travel time influences the neonatal mortality rate (NMR).

Methods: The travel time from a population centroid in each municipality to the nearest perinatal care center was measured using the Geographic Information System at two time points, 2002 and 2006. Areas with and without reductions in travel time were compared for changes in the NMR. The Difference-In-Difference Estimation was used to examine whether the NMR decreased in areas with reducing travel times.

Results: The median travel time was reduced from 66.99 minutes in 2002 to 39.09 minutes in 2006, and the mean NMR decreased from 1.72 (2002) to 1.33 (2006). The travel time showed great disparities. Of the areas that in 2002 had travel times longer than 60 minutes, by 2006 some areas that had improved accessibility by reducing travel time also had significant reductions in the NMR compared with regions that did not reduce travel time by 2006.

Conclusions: Reducing travel time to perinatal care centers by reconsidering the location of such centers is an effective strategy to reduce the NMR in Japan.

Keywords: perinatal care center, geographic accessibility, neonatal mortality rate, regional disparity

Introduction

The number of obstetricians in Japan decreased from 11,264 in 1996 to 10,074 in 2006, a decline of 10.6%, with a marked decrease starting in 2002 (a decline of 8.7% between 2002 and 2006).¹ From 1996 to 2006, the number of childbirths in Japan decreased by 9.4%,² while the number of obstetricians per 10,000 childbirths decreased slightly from 93.4 to 92.2. However, the number of women who gave birth after age 35 jumped from 9.8% in 1996 to 17.7% in 2006, and the rate of low-birth-weight neonates (less than 2,500 grams) increased from 7.5% to 9.6% during the same period.² These facts indicate an increase in high-risk pregnancies which caused a heavier workload for obstetricians in Japan. Thus, the shortage of obstetricians has become a problem,³ made worse by regional disparities in perinatal care resources in Japan.⁴,⁵ In light of this shortage of resources, effective action is needed to ensure adequate availability of perinatal care services.⁶

The uneven distribution of neonatal and pediatric care resources has been discussed in other countries, including the United States.⁷,⁸ The distribution of resources has been shown to influence medical outcomes in neonatal and pediatric care.⁹¹¹ Fewer physicians and obstetrician-gynecologists delivering babies has been predicted to lead to an increased mortality rate.⁹ Women from communities in which fewer deliveries occurred at their local medical facilities tended to have a greater proportion of birth-associated complications, a higher rate of prematurity, and higher neonatal care costs.¹⁰ Newborns in regions with the lowest supply of neonatologists had a higher relative risk of death than those in other regions.¹¹ Therefore,
inadequate availability of perinatal care services seems to cause worse perinatal outcomes.

The amount and distribution of resources have been associated with geographical accessibility to neonatal and pediatric care.12,13 One study reported that maternity facility closures had a negative impact on the geographic accessibility of pregnant women to obstetrical care in metropolitan areas in France.15 In the United States, there tended to be fewer medical providers in less populated areas, and poorer patients were less likely to seek medical care.13 Children living in these areas also needed to travel further for pediatric subspecialty care.13 Few studies on the association between geographic accessibility and medical outcomes in perinatal care have been conducted in Japan.

The Ministry of Health, Labor, and Welfare (MHLW) has been tackling this issue since 1996 by improving the system of perinatal care in Japan. To make effective use of perinatal care resources, the MHLW objectives were to establish a system of general and regional perinatal care centers. Both types of centers accept high-risk pregnant women and newborns with serious conditions, and offer advanced perinatal care; however, general perinatal care centers are better equipped for special care.14 This MHLW policy is intended to ensure that pregnant women have checkups in primary care clinics and are transferred to perinatal care centers only as necessary. The policy seemed to provide better coordination between primary clinics and perinatal care centers. Moreover, in 2005 the MHLW declared a policy of concentrating resources in advanced perinatal care facilities.16

Figure 1 shows the number of perinatal care centers from 1996 to 2008. A list of all perinatal care centers is available on the website of the Japan Association of Obstetricians and Gynecologists. (http://www.jaog.or.jp/japanese/jigyo/JYOSEI/center.htm, accessed on June 12, 2009) In Japan, perinatal care centers are certified by prefectures, therefore the researchers telephoned prefectural government offices to confirm the date when each perinatal care center was certified. Such certification data is public information and does not contain any personal information. Based on the data obtained from these telephone calls, the researchers determined the inter-annual change in the number of perinatal care centers. The number of perinatal care centers has been increasing steadily over time in Japan.

Figure 2 shows the inter-annual change in the neonatal mortality rate in Japan.2 Neonatal mortality rate and perinatal mortality rate are principal indicators for evaluating perinatal outcome. In 2007, the Japanese government compiled a report on the current state of maternal and child health which pointed out significant regional disparities in NMR in Japan.16 The report also noted that some areas had persistently worse levels of NMR and that few adequate analyses on the cause had been conducted.16 For this reason, this study used the NMR as a basis for evaluating perinatal outcome instead of the perinatal mortality rate.

The impact of MHLW policies has not been fully examined. Therefore, this study evaluated the effects of increasing perinatal care centers throughout Japan from the viewpoint of geographic accessibility, and examined whether it affected the medical outcomes of childbirths. The objectives of this study were: (a) to assess reductions in travel time to perinatal care centers from 2002 to 2006 using Geographic Information System (GIS) software, (b) to identify the neonatal mortality rate (NMR) over the same period, and (c) to examine the association between reductions in travel time and reductions of NMR.

Materials and Methods

Unit of areas

The MHLW has categorized the medical service areas in Japan into three units: the municipality, the Medical Service Area (MSA), and the prefecture. There were 2,366 municipalities in 2005.17 Each city in Japan with a population of more than one million, or at least 700,000 and expecting to reach one million in the near future, was subdivided into administrative wards. These wards were considered as municipalities in this study. An MSA is an area unit set up by each prefecture, and is composed of several neighboring municipalities that cooperate to meet one another’s medical needs. There were 358 MSAs based on the classification data in 2006.1 There are 47 prefectures in Japan.

The population size in municipalities ranges from 208 to 841,165; that of the MSAs ranges from 23,696 to 2,628,811; and that of prefectures ranges from 208 to 841,165; that of the MSAs ranges from 23,696 to 2,628,811.17 Each city in Japan with a population of more than one million, or at least 700,000 and expecting to reach one million in the near future, was subdivided into administrative wards. These wards were considered as municipalities in this study. An MSA is an area unit set up by each prefecture, and is composed of several neighboring municipalities that cooperate to meet one another’s medical needs. There were 358 MSAs based on the classification data in 2006.1 There are 47 prefectures in Japan.

The datasets by MSAs on 2002 and 2006 were both built using the classification of MSAs in 2006. The initial data in 2002 and 2006 on the variables used in this
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Figure 1: Inter-annual change in the number of perinatal care centers in Japan
General perinatal care centers and regional perinatal care centers both accept high-risk pregnant women and newborns with serious conditions, and offer advanced perinatal care. However, general perinatal care centers are better equipped for special care. The researchers obtained the data on the number of perinatal care centers from the website of the Japan Association of Obstetricians and Gynecologists. Information on the date when each center was certified was obtained directly from prefectural government offices.

Figure 2: Inter-annual change in the neonatal mortality rate (NMR) in Japan
The data on the neonatal mortality rate was obtained from Vital Statistics in 1996-2008 by the Ministry of Health, Labor and Welfare.
study except travel time were counted by municipalities according to the classification in 2002 and 2006 respectively. The initial data on travel time were based on the classification in 2005 for both 2002 and 2006, because the data on the population centroid of each municipality, which are crucial for measuring the travel time, were available only in 2005. Using the same classification for measuring the travel time, the researchers examined the inter-annual change in the travel time, regardless of the impact of changes in the classification of municipalities. Even though the classification of municipalities changed in 2006, the data by municipalities at each time point can be recounted according to the classification of MSAs in 2006. Thus, no problems occurred in building the datasets both on 2002 and 2006. This process of building the datasets enabled comparison analysis between the same area units in 2002 and 2006.

**Variables**

The variables used in this study were the travel time, the NMR (per 1,000 childbirths), and other factors expected to affect the NMR, as well as the number of births, the number of obstetricians (per 10,000 childbirths), and the rate of low-birth-weight neonates.

The NMR, the number of births and the rate of low-birth-weight neonates were obtained from Vital Statistics in 2002 and 2006. The number of obstetricians was obtained from the Survey of Physicians, Dentists and Pharmacists in 2002 and 2006.

**Analysis**

(1) Travel time measurements and Empirical Bayes estimation of NMR

This study measured the travel time from a population centroid in each municipality to the nearest perinatal care center using road network analysis with GIS software. For geographically finer measurements of the travel time, a population centroid of municipalities was used. Municipalities consisting of isolated islands were excluded from the analysis because travel from these smaller islands to the main island is not based on roads only. The sample size of the measurements was 2,294 municipalities, which included 97.0% of the municipalities in 2005. The median travel time by MSA was used for analysis. The reason for using the median value was that a non-normal distribution was expected for the travel time. This study examined 346 MSAs (96.6% of the total MSAs), excluding MSAs that consisted of isolated islands.

The researchers measured the travel time at two time points, 2002 and 2006, using data on the numbers and locations of perinatal care centers at each time point, and then examined inter-annual changes from 2002 to 2006 in terms of the geographic accessibility to perinatal care centers. The same road network data in the GIS software were set up both in 2002 and 2006 because only the effect of increasing the number of perinatal care centers was being evaluated. As mentioned above, general perinatal care centers were better equipped to handle special obstetrical care than regional perinatal care centers. However, since there are fewer general perinatal care centers, in some areas the regional perinatal care centers also provided most of the advanced obstetrical care. Under these local conditions, this study regarded these two types of centers equally as providers of emergency medical facilities for obstetrical patients.

In this study, the medical outcomes of childbirths were evaluated based on the NMR per 1,000 childbirths in each MSA. When using population-based mortality rates, the mortality rate in areas with a relatively small population is biased. A slight change in the number of deaths can drastically impact the mortality rate, which is known as a “small area estimation” error. To avoid this problem, the researchers adjusted the mortality rate by Empirical Bayes estimation approach. Bayesian statistics is concerned with statistical estimation where prior knowledge or beliefs about parameters of interest, as well as observed data, are taken into account when estimating their values. This study supposed that the true and unknown neonatal mortality rate in each area is \( \Theta_i \). For calculating the Empirical Bayes estimate of \( \Theta_i \), an estimate of the mean value \( \gamma_i \) and the variance value \( \phi_i \) of the prior distribution for \( \Theta_i \) are needed. Based on the method by Bailey and Gatrell, this study performed Empirical Bayes estimation of the NMR according to the following procedure:

\[
\hat{\Theta}_i = w_i r_i + (1 - w_i) \gamma_i
\]

where

\[
w_i = \frac{\phi_i}{\phi_i + \gamma_i / n_i}
\]
One obvious reduction is to assume that the prior means and variances for all areas are the same. That is, \( \gamma_i = \gamma \) and \( \phi_i = \phi \). Using the method of moments, \( \gamma \) are estimated by the pooled mean of the observed rates, that is:

\[
\hat{\gamma} = \frac{\sum y_i}{\sum n_i}
\]

and then \( \phi \) are estimated based upon a weighted sample variance of observed rates about this mean as:

\[
\hat{\phi} = \frac{\sum n_i (r_i - \hat{\gamma})^2}{\sum n_i} - \frac{\hat{\gamma}}{\bar{n}}
\]

where \( \bar{n} \) is the average population across all the areas. With the estimates \( \hat{\gamma} \) and \( \hat{\phi} \), \( w_i \) are then estimated as:

\[
\hat{w}_i = \frac{\hat{\phi}}{\hat{\phi} + \hat{\gamma}/n_i}
\]

and therefore the Empirical Bayes estimates of the neonatal mortality rates are:

\[
\hat{\Theta}_i = \hat{\gamma} + \frac{\hat{\phi} (r_i - \hat{\gamma})}{\hat{\phi} + \hat{\gamma}/n_i}
\]

The prior distribution for \( \Theta_i \) in all the Empirical Bayes estimates discussed above is "aspatial"; that is, the prior mean and variance is assumed equal over all areas. An alternative would be to require the adjusted estimate for an area to be shrunk towards a "neighborhood" rather than a global mean. This would be more sensible, since the Empirical Bayes estimates presented above are invariant to the spatial configuration of areas and this does not seem intuitively reasonable. The researchers can achieve this by simply modifying the prior distribution for \( \Theta_i \) to allow for a mean and variance which are related to a "neighborhood" of \( i \), rather than being constant for all areas. In this study, such a neighborhood was defined on the basis of MSAs sharing a common boundary. This process of estimation can be performed using the "Local Empirical Bayes Estimator" function in the R package "spdep". Therefore this function was used in this study.

(2) Assessment of impact of reducing travel time on the NMR

To examine the impact of changes in the travel time to perinatal care centers in each MSA on the adjusted NMR from 2002 to 2006, 346 MSAs were stratified into two groups. Mori et al. reported that taking longer than 60 minutes to transport sick neonates increased the incidence of neonatal death.\(^{22}\) Therefore, for the stratification, this study set the reference point at 60 minutes in travel time in 2002 as follows: "< 60 min" and "\( \geq 60 \) min." Moreover, these two groups were further categorized into two subgroups based on whether the travel time was reduced from 2002 to 2006. This study examined whether the travel time was reduced. It was meaningful to evaluate whether obstetrical patients in each MSA benefitted from the policy that increased the number of perinatal care centers. Therefore, the groups were categorized as follows: "improved," which indicated areas with a reduction in the travel time according to the policy of increasing perinatal care centers; and "non-improved," which indicated areas without a reduction in the travel time according to the policy. Because the same road network data was used in 2002 and 2006, only the effect of the policy of increasing perinatal care centers was evaluated. In each stratified group (< 60 min or \( \geq 60 \) min), the increase-decrease ratio of the NMR was compared between the "improved" and "non-improved" groups. The increase-decrease ratio of the NMR was calculated by dividing the value of the NMR in 2006 by that in 2002 for each MSA. In each of the four groups (< 60 min and the improved, < 60 min and the non-improved, \( \geq 60 \) min and the improved, \( \geq 60 \) min and the non-improved), the NMR was compared between 2002 and 2006. Statistical significance was assessed using an unpaired \( t \)-test for intergroup comparisons, and a paired \( t \)-test for inter-annual changes within each group. In addition, this study used a non-linear model, LOESS (locally-weighted scatter plot smoothing), to more closely examine the association between reductions in travel time and changes in the adjusted NMR. The details of the LOESS modeling used in this study were adopted from Cleveland and Devlin,\(^{23}\) and Fan and Gijbels.\(^{24}\)

To directly evaluate the effects of reducing the travel time on the NMR, this study used the Difference-In-Difference (DID) estimation, which is a method for evaluating the impact of a certain policy using two cross-sectional data sets collected before and after the implementation of the policy.\(^{25}\) In DID estimation, one first identifies the group affected by a certain policy
and the one not affected. The differences between these two groups are then compared before and after the implementation of the policy. In this study, the group affected by a certain policy means the “improved” group, which indicated areas with a reduction in the travel time according to the policy of increasing perinatal care centers, whereas the one not affected means the “non-improved” group, which indicated areas without a reduction in the travel time according to the policy. The DID estimations in this study are modeled based on Wooldridge as follows:

\[ y = \beta_0 + \beta_1 dT + \beta_2 d^2 + \beta_3 dTXd^2 + \beta_4 Z + \varepsilon \]

The dependant variable \( y \) means the adjusted NMR in this model; \( dT \) is a dummy variable which is 1 for the group with a reduction in the travel time and 0 otherwise; \( d^2 \) is a dummy variable which is 1 for post policy-implementation and 0 otherwise; and \( dTXd^2 \) is the interaction term which is 1 for the group with a reduction in the travel time and post-policy implementation, and 0 otherwise. The standardized coefficient (\( \beta_3 \)) of the interaction term (\( dTXd^2 \)) indicates the policy effect on reducing the travel time, which is the number of interest in this model. \( Z \) represents other variables affecting the NMR, and the standardized coefficient \( \beta_4 \) indicates the effects of these variables: the number of births, the number of obstetricians (per 10,000 childbirths), and the rate of low-birth-weight neonates.

This study used R 2.10.0, SAS 9.1.3, and SPSS 12.0 software for the statistical analysis. Statistical significance was defined as \( P < 0.05 \) for all tests. Travel time was measured by GIS software (LogiSTAR, Pasco Corporation), and geographic distribution of the travel time and NMR was mapped by GIS software (MarketPlanner GIS, Pasco Corporation).

### Results

**Inter-annual change in the GIS-measured travel time and adjusted NMR**

The median travel time in the MSAs dropped from 66.99 minutes to 39.09 minutes between 2002 and 2006 (Table 1), a 41.6% reduction. The data on travel times were non-normally distributed in this as well as a previous study, therefore the median value was used for the travel time. The mean NMR by MSA decreased from 1.72 to 1.33 between 2002 and 2006 (Table 1). The mean increase-decrease ratio of the NMR was calculated by dividing the value of the NMR in 2006 by that in 2002 for each MSA.

### Table 1. Characteristics of the travel time and the neonatal mortality rate (NMR)

<table>
<thead>
<tr>
<th></th>
<th>Travel time</th>
<th>NMR a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2002</td>
<td>2006</td>
</tr>
<tr>
<td>N</td>
<td>346</td>
<td>346</td>
</tr>
<tr>
<td>Mean</td>
<td>81.85</td>
<td>52.46</td>
</tr>
<tr>
<td>SD</td>
<td>56.91</td>
<td>40.14</td>
</tr>
<tr>
<td>Median</td>
<td>66.99</td>
<td>39.09</td>
</tr>
<tr>
<td>Max</td>
<td>266.08</td>
<td>209.39</td>
</tr>
<tr>
<td>Min</td>
<td>7.45</td>
<td>5.20</td>
</tr>
<tr>
<td>25 percentile</td>
<td>38.92</td>
<td>26.54</td>
</tr>
<tr>
<td>75 percentile</td>
<td>107.29</td>
<td>63.19</td>
</tr>
</tbody>
</table>

NMR, neonatal mortality rate; SD, standard deviation

The travel time was measured from a population centroid in each municipality to the nearest perinatal care center. The median travel time by Medical Service Area (MSA) was calculated and used for the analysis. The NMR was adjusted by Empirical Bayes estimation. The increase-decrease ratio of the NMR was calculated by dividing the value of the NMR in 2006 by that in 2002 for each MSA.

Sources:

Figure 3: Geographic distribution of the median travel time by Medical Service Area (MSA)
The map shows the inter-annual change in the geographic distribution of the travel time from 2002 to 2006 in 346 MSAs, excluding MSAs that consisted of isolated islands.

Figure 4: Geographic distribution of the NMR by MSA
The map shows the inter-annual change in the geographic distribution of the NMR from 2002 to 2006 in 346 MSAs, excluding MSAs that consisted of isolated islands.
Impact of reducing the travel time on the NMR

In the ≥ 60-min group with travel times in 2002, there was a significant difference between the “non-improved” and “improved” subgroups for the mean increase-decrease ratio in the NMR (Table 2). In the “≥ 60 min and non-improved” subgroup, the increase-decrease ratio of the NMR showed an increase between 2002 and 2006 (mean=1.05). With regard to the inter-annual change in the NMR, all groups, except for the “≥ 60 min and non-improved” subgroup, had a significant reduction in their NMR from 2002 to 2006. Only in the “≥ 60 min and non-improved” subgroup was there no significant reduction in the NMR (Table 2).

As a result of the LOESS model that confirms the change in the NMR among the stratified groups, the increase-decrease ratio of the NMR in the group with a reduction in travel time showed a decrease in their NMR between 2002 and 2006 (mean=0.83). In the group without a reduction in travel time, the increase-decrease ratio of the NMR showed a decrease in their NMR only in areas with travel times less than 60 minutes in 2002. However, in areas with travel times in 2002 of more than 60 minutes and without a reduction in travel time, the increase-decrease ratio of the NMR remained beyond one, which showed the increase in their NMR between 2002 and 2006 (Figure 5).

The DID estimation was performed only in the “≥ 60 min” group, since a significant difference in the NMR was observed only in this group as mentioned above. Table 3 shows the descriptive statistics of the variables used for the DID estimation.

The standardized coefficient of dTXd2 in Table 4 indicated the policy effect on reducing the travel time, and this value showed a negative significance (-0.30) in the result of this DID estimation model. This result denoted that in the group with a reduction in the travel time between 2002 and 2006, the NMR decreased significantly as compared with the group without a reduction in the travel time during the same period. In addition, the standardized coefficient of Number of obstetricians per 10,000 childbirths in Table 4 also showed a negative significance (-0.18). This result denoted that the number of obstetricians per 10,000 childbirths was significantly associated with a reduction in the NMR.

Discussion

Taking into consideration the features of the universal healthcare insurance system in Japan, it is necessary to improve the perinatal care system in order to provide pregnant women with appropriate access to advanced perinatal care, regardless of where they live. To cope with the lack of resources for perinatal care in Japan, the MHLW implemented system improvements in 1996, such as building perinatal care centers and concentrating resources in these centers. This study showed a reduction of approximately 28 minutes in travel time to access perinatal care centers from 2002 to 2006. The regional disparities in accessibility were partially resolved, but some areas still had poor accessibility, even in 2006.
Neonatal mortality and geographic accessibility

Table 3. Characteristics of the variables for the Difference-In-Difference (DID) estimation

<table>
<thead>
<tr>
<th></th>
<th>Year</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NMR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>1.80</td>
<td>0.66</td>
<td>0.40</td>
<td>4.29</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>1.37</td>
<td>0.57</td>
<td>0.00</td>
<td>4.10</td>
<td></td>
</tr>
<tr>
<td><strong>Number of childbirths</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>1827.81</td>
<td>1580.02</td>
<td>169.00</td>
<td>8077.00</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>1697.44</td>
<td>1531.75</td>
<td>141.00</td>
<td>7618.00</td>
<td></td>
</tr>
<tr>
<td><strong>Number of obstetricians per 10,000 childbirths</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>85.65</td>
<td>35.59</td>
<td>0.00</td>
<td>195.28</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>81.69</td>
<td>34.91</td>
<td>0.00</td>
<td>211.11</td>
<td></td>
</tr>
<tr>
<td><strong>Rate of low-birth-weight neonates</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>0.09</td>
<td>0.01</td>
<td>0.06</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>0.09</td>
<td>0.01</td>
<td>0.06</td>
<td>0.13</td>
<td></td>
</tr>
</tbody>
</table>

N=190

NMR, neonatal mortality rate; SD, standard deviation

The DID estimation was performed only in the “≥ 60 min” group, since a significant difference in the NMR was observed only in this group.

Sources:


Figure 5: Scatter plot of the Increase-Decrease ratio of the NMR versus the travel time in 2002 by MSA. Each point in the figure denotes an MSA. Using the LOESS method, the regression curves show the relationship between the increase-decrease ratio of the NMR and the travel time in 2002 for each category of “improved” and “non-improved” in the travel time. The thin broken lines above and below the middle lines indicate a 95% confidence interval. The vertical line depicts the 60-minute-travel time threshold used in this study.
The MSAs that had a longer travel time in 2002 and did not reduce it by 2006 showed no reduction in their NMR. A reduction in travel time to perinatal care centers seemed to be associated with a lower NMR. Receiving tertiary obstetrical care is associated with a lower neonatal mortality rate among low-birthweight neonates.\(^{27,28}\) Therefore, it is essential to transfer complicated delivery cases to facilities with tertiary obstetrical care. The duration of inter-facility transportation affected neonatal mortality; as already mentioned, taking longer than 60 minutes to transport sick neonates increased incidences of neonatal death.\(^{22}\) If a 60-minute travel time is regarded as a threshold, then those regions with travel times longer than 60 minutes must close the gap between this threshold and their current travel times. A decrease in the regional disparities in the travel time, which were confirmed in this study, should further reduce the NMR.

As the results showed, increasing the number of obstetricians per 10,000 childbirths would also contribute to a reduction in the NMR. However, increasing the number of obstetricians can take many years, and hence reducing the travel time should take priority to improve the perinatal care system.

To shorten the travel time, the standard approach is to build new perinatal care centers and concentrate perinatal care resources into these centers.\(^{15}\) However, this concentration of resources may lead to closures of small maternity facilities.\(^{12}\) Therefore, women with normal deliveries would be needlessly forced to use advanced perinatal care facilities. In such situations, it would be difficult to permanently reserve enough beds for possible high-risk deliveries in these facilities. Therefore, at a time of scarce resources, an effective method for shortening the travel time would be to reorganize the locations of some existing centers. In areas with good accessibility where there is an excess of centers in an MSA, reallocation of some centers to areas with poor accessibility should be considered. The optimum location of perinatal care centers should be examined in terms of geographic accessibility.

The results of this study provide valuable and useful insight for policy makers who are in charge of improving the perinatal care delivery system in Japan. This study has several limitations. Travel times in this study were measured by GIS because official data on actual transport times for maternal and obstetrical patients specifically are not available in Japan. Actual transport times should be compared with the results of this study. The effect of improvements in the road network was not taken into account in this study when evaluating the travel time in 2002 and 2006; only the number of perinatal care centers was evaluated. Further research would be desirable to evaluate the impact of road network factors on measuring the travel time.

In addition, in the group of MSAs with travel times less than 60 minutes in 2002, even those without a reduction in the travel time had significant reductions of the NMR. This result suggests that there may be factors affecting the reduction of NMR other than travel time and several variables used in this study. Other
possible factors are pediatricians who specialize in neonatology and the availability of Neonatal Intensive Care Units (NICUs). In previous studies, the supply of neonatologists was associated with neonatal mortality. However, Socioeconomic variables, such as income, were also not considered in this study. It has been reported that growing income inequality in Japan may lead to an increase in the level of Japanese who are at health risk. It is difficult to know the status of pediatricians expert in neonatology because only data on the total number of pediatricians are available in Japan. The total number of NICUs was 2,122 in 2002, and 2,341 in 2005, however, the data on NICUs by MSAs are not available in Japan, either. For these reasons, this study cannot take these factors into account for the analysis.

Socioeconomic variables, such as income, were also not considered in this study. It has been reported that growing income inequality in Japan may lead to an increase in the level of Japanese who are at health risk in the future. However, equality of income does not seem to be related to medical outcomes at this point in Japan, which currently has a universal healthcare insurance system. Therefore, the impact of income was not examined in this study. Taking into consideration these limitations, further research will be required to improve the perinatal care system in Japan.

Acknowledgements

The authors gratefully acknowledge Ms. Sawako Okamoto, MS, and Dr. Makiko Arima from the Tokyo Medical and Dental University for critical comments on the manuscript; Drs. Chieko Mitaka, Motohiro Shimizu and Daisuke Ikeda from the Tokyo Medical and Dental University, and Dr. Ayano Kunimitsu from the Ministry of Health, Labor and Welfare for advice on the perinatal care system in Japan; and Ms. Clara Marin for editing in English.

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