The current trends of mortality following congenital heart surgery: the Japan Congenital Cardiovascular Surgery Database

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Abstract

OBJECTIVES: Whereas surgical outcomes of congenital heart surgery have improved during the past two decades, there are still measurable postoperative mortalities in this field. This study is aimed at evaluating the current situation of mortality following congenital heart surgery.

METHODS: Data on all registered 28 810 patients in The Japan Congenital Cardiovascular Surgery Database (JCCVSD) between 2008 and 2012 were analysed, except for patients with degenerative cardiomyopathy including dilated, restrictive and hypertrophic cardiomyopathy, and pathologically or histologically malignant cardiac tumours. The number of registered cases increased every year, and reached ~9000 cases in 2012. The median age at surgery was 0.8 years (range, 0–82). More than half of the patients (54%) who underwent surgery were <1 year old, and 6.0% of all patients were over 18 years old (adults). In this study, all mortalities within 90 days after the operation and mortality at discharge beyond 90 days of hospitalization were defined as ‘90-day and in-hospital mortality’.

RESULTS: The 30-, 90-day and in-hospital mortality rates were 2.3, 3.5 and 4.5%, respectively. The mean and median durations from surgery to death were 61 ± 89 and 28 days (range, 0–717), respectively. Whereas 658 mortalities (51%) occurred within 30 days of surgery, 265 (21%) occurred later than 90 days after surgery. A total of 3630 patients (13%) were hospitalized for more than 90 days after the operation; of those, 3365 patients survived at discharge (93%). Cardiac problems were the most frequent causes of death after the surgery at any point in time, and 7.1 per 1000 patients died at over 30 days after the operation due to solely cardiac.

CONCLUSIONS: The investigation of JCCVSD revealed that about a half of mortalities occurred later than 30 days; hence 90-day and in-hospital mortality would be a good discriminator that accurately represented the current situation of mortality following congenital heart surgery. Mortalities long after the operation due to post-cardiotomy heart failure without any other lethal complications were still not rare.

Keywords: Congenital heart disease • Surgery • Database • Extracorporeal membrane oxygenation

INTRODUCTION

Whereas a great improvement in the surgical outcomes of congenital heart surgery has been achieved during the past two decades, there are still measurable postoperative mortalities in this field. In addition, for the further evolution of surgical procedures or treatments for each anatomical group, therapeutic options such as left ventricular assist devices, heart transplantation and cardiac regenerative therapy must be offered to rescue patients falling victim to postoperative heart failure.

The Japan Congenital Cardiovascular Surgery Database (JCCVSD), which is the nationwide congenital heart surgery database registry system, was established in 2008 [1]. The accuracy of follow-up outcomes was confirmed by a site audit [2], and now >90% of congenital heart operations performed in Japan are enrolled in the database. Utilizing this database, we have reviewed the timing, cause and trends of death after congenital heart surgery in Japan in order to assess the current situation and the necessity of further treatment options for post-cardiotomy heart failure.

MATERIALS AND METHODS

Japanese Cardiovascular Surgery Database Organization Committee granted permission to access and analyse the data collected in the JCCVSD with a waiver of informed consent.

Of the patients registered on the JCCVSD between 2008 and 2012, 28 810 patients were selected as study subjects, mainly by fundamental diagnosis (Supplementary material, File S1) [3]. Patients with myocardial degenerative disease including dilated,
restrictive and hypertrophic cardiomyopathy, a cardiac tumour or complications after heart transplantation were excluded from this study (Supplementary material, File S2).

The characteristics of the 28,810 enrolled patients are summarized in Table 1. The number of admitted institutions was 17 in 2008, 68 in 2009, 93 in 2010, 102 in 2011 and 111 in 2012; thus, the number of registered cases increased every year and reached ~9000 cases in 2012. The median age at surgery was 0.8 years (range, 0–82). More than half of the patients (54%) who underwent surgery were <1 year old, and 6.0% of all patients were over 18 years old (adults). The surgery was electively scheduled for 84.6% of the patients, 11.3% of the cases were scheduled urgently and 4.1% were emergently performed.

Definitive surgery was defined as the last surgery that was planned according to each anatomical property, and so it included not only complete biventricular repair, but also partial biventricular repair or Fontan operations with or without fenestration. The prevalence rates of the definitive operation with cardiopulmonary bypass (CPB), the palliative operation with CPB, the definitive operation without CPB and the palliative operation without CPB were 64, 13, 7.0 and 15%, respectively.

Prevalence of patients by risk adjustment in the congenital heart surgery system (RACHS) ([4], Supplementary material, File S3) categories were as follows: risk category 1 in 13% of patients, category 2 in 33%, category 3 in 34%, category 4 in 7.7%, category 5 in 0.1% and category 6 in 2.6% of patients.

### Definition of 90-day and in-hospital mortality

The database forced medical practitioners to enter the discharge date within 90 days after the last surgery and the life prognosis at postoperative day 90, so that mortality up to and including postoperative day 90 was completely recorded. If patients were in the hospital for more than 90 days after the operation, the entering of the discharge date and life prognosis was voluntary. However, 3616 of 28,810 patients (13%) were in the hospital beyond postoperative day 90, and the life prognoses at discharge were recorded for all patients.

In addition, only 3.1% of all mortalities occurred after discharge. All these patients were discharged within 90 days after the last operation and their death was identified by the confirmation of life prognosis at 90 days after the last surgery. Therefore, in this study, all mortalities within 90 days after the operation and mortality at discharge beyond 90 days of hospitalization were defined as ‘90-day and in-hospital mortality’.

### Definition of the cause of death

The cause of death was determined by the treating physicians according to their clinical impressions when considering the postoperative course, which was objectively assessed according to the clinical chart of the intensive care unit, operative records, echocardiograms, catheterizations and clinical summaries. Then, the principal clinical issue contributing to the patient’s death was determined as the cause of death, which was not necessarily the same as the preterminal event occurring immediately before death. Because the identification of the sole cause of death was usually difficult, all possible causes [i.e. (i) cardiac, (ii) lung, (iii) infection, (iv) central nervous system damage, (v) renal and other issues] could be concomitantly recorded.

### Post-cardiotomy extracorporeal membrane oxygenation cannulation

Extracorporeal membrane oxygenation (ECMO) cannulation and decannulation have been added as surgical procedures since 2010. During the study period, paediatric left ventricular assist systems were not available, and there had been only 2 donors under 15 years of age for paediatric heart transplantation, nevertheless, the Organ Transplant Law in Japan was revised and enforced in 2010.

### Study methods

Evaluated variables in this study were as follows: (a) timing and cause of death after surgery; (b) differences in mortality rates by generation, surgical year, RACHS risk category and operation type; and (c) prognostic outcomes for post-cardiotomy ECMO support.

Preoperative risk factors that were required to be entered into the database are listed in the Supplemental Material. Risk factor analysis was conducted using the Pearson’s χ² test and data were...
analysed using the JMP software version 10 (SAS Institute, Cary, NC), USA. Differences were considered statistically significant when the P-value was <0.05.

RESULTS

Timing and cause of death after surgery

Of all the 28,810 patients enrolled in the database, 1293 mortalities (4.5%) were identified (Fig. 1). The 30-day and 90-day mortality rates were 2.3 and 3.5%, respectively. Forty of the mortalities (3.1%) occurred after discharge. The mean and median durations from the last operation to death were 61 ± 89 days and 28 days (range, 0–717), respectively. Whereas 658 mortalities (51%) were observed within 30 days of the last surgery, 352 (27%) were from 30 days to 90 days, and 265 (21%) were observed more than 90 days after the last surgery.

The causes of death after surgery were often multifactorial (Table 2). Of all 1293 mortalities, 546 mortalities (42%) were related solely to cardiac issues; thus any other lethal problems such as lung issues, infections, central nervous system damage or renal issues were not related. Solely lung issues was the second most frequent cause of death, which included acute respiratory distress syndrome, pulmonary hypertension crisis or persistent pulmonary hypertension without such problems as left heart issues, pulmonary bleeding or thromboembolism, and so on. Infection was the sole cause of death in 99 patients (7.7%), and central nervous system damage was the sole cause of death in 41 patients (3.2%). Table 2 also demonstrates the different trends in the causes of death by displaying the timing of death. Although cardiac issues were the most common causes of death during the entire period, the prevalence of mortalities caused by cardiac issues decreased as time passed, and mortalities caused by infection increased.

Differences in mortality rate by preoperative variables

The differences between the number of patients and mortality rates by generation are shown in Fig. 2A. The postoperative mortality rate of surgery in the neonatal period was 12% (547/4760) and exhibited the highest rate of all four generations (P < 0.001). On the other hand, postoperative mortality rates of surgery in children over 1 year of age (1.6%, 188/11,523) and adults over 18 years of age (2.4%, 42,173) were significantly lower when compared with the other three generations.

The chronological changes of the enrolled patient number and mortality rate by surgical year are shown in Fig. 2B. The number of enrolled patients increased yearly, whereas the mortality rate varied each year, ranging from 4.2 to 5.9%. In 2012, 376 of the 9361 patients enrolled were deceased and the mortality rate was 4.2%, which was almost the same trend as in 2011.

The differences between the numbers of patients and the mortality rates by RACHS risk category are shown in Fig. 3. The risk grade category and the mortality rate had a statistically strongly positive, linear correlation (R² = 0.951, P < 0.001), except for risk category 5, where the repair of truncus arteriosus and an interrupted aortic arch was performed. There were only 16 patients who received these procedures during the entire study period.

The differences between the numbers of patients and the mortality rates by surgical situation and type are shown in Fig. 4. Whether CPB was required or not, the mortality rate of palliative surgery was significantly higher than that of definitive surgery (800/8259 = 9.7% vs 493/22,526 = 2.2%, P < 0.001). With regard to the former, the mortality rate of palliative surgery with CPB was significantly higher than that of the same surgery without CPB (416/3833 = 10% vs 384/4426 = 8.7%, P < 0.001) (Fig. 4A). With regard to surgical situation, emergency surgery resulted in a mortality rate of >20% (255/1194 = 21.4%), while that of elective surgery was 2.8% (682/24,360) (Fig. 4B).

Prognostic outcomes of post-cardiotomy extracorporeal membrane oxygenation cannulation

Between 2010 and 2012, 108 of the registered 24,425 patients (0.4%) required ECMO cannulation during the perioperative period. Of those, 41 patients survived to discharge after successful ECMO decannulation (38%). The mean and median durations

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**Table 2:** Causes of death after surgery (multiple reasons allowed)

<table>
<thead>
<tr>
<th>Mortality</th>
<th>All</th>
<th>Beyond 30 days</th>
<th>Beyond 90 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>1293</td>
<td>617</td>
<td>265</td>
</tr>
<tr>
<td>Cause of death</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac</td>
<td>776 (60.0)</td>
<td>329 (53.3)</td>
<td>121 (45.7)</td>
</tr>
<tr>
<td>Cardiac-only</td>
<td>546 (42.2)</td>
<td>205 (33.2)</td>
<td>72 (27.2)</td>
</tr>
<tr>
<td>Lung</td>
<td>376 (29.1)</td>
<td>199 (32.3)</td>
<td>85 (32.1)</td>
</tr>
<tr>
<td>Lung-only</td>
<td>169 (13.0)</td>
<td>90 (14.6)</td>
<td>48 (18.1)</td>
</tr>
<tr>
<td>Infection</td>
<td>225 (17.4)</td>
<td>155 (25.1)</td>
<td>73 (27.5)</td>
</tr>
<tr>
<td>Infection-only</td>
<td>99 (7.7)</td>
<td>62 (10.0)</td>
<td>29 (10.9)</td>
</tr>
<tr>
<td>CNS damage</td>
<td>85 (6.6)</td>
<td>31 (5.0)</td>
<td>11 (4.2)</td>
</tr>
<tr>
<td>CNS damage-only</td>
<td>41 (3.2)</td>
<td>7 (1.1)</td>
<td>1 (0.4)</td>
</tr>
<tr>
<td>Renal</td>
<td>7 (0.5)</td>
<td>6 (1.0)</td>
<td>5 (1.9)</td>
</tr>
<tr>
<td>Others</td>
<td>237 (18.3)</td>
<td>142 (23.0)</td>
<td>70 (26.4)</td>
</tr>
</tbody>
</table>

CNS: central nervous system.
from ECMO cannulation to death in the remaining 67 patients were 42.8 ± 66.2 days and 18 days (range, 0–299), respectively.

**DISCUSSION**

The Japanese Association for Thoracic Surgery Committee has reported the results of thoracic and cardiovascular surgery, including congenital heart surgery, annually since 1986, and is famous for the establishment on a national scale of the annual statistics overview because of the high response rate to the survey [5]. On the other hand, an individual case registration system, according to the authorized nomenclature for the diagnosis and surgical procedure, was mandated to compare the outcomes accurately with other nationwide or international databases [6]. Although each category based on a risk-adjusted tool did not match, 30-day, 90-day, and in-hospital mortality rates after congenital heart surgery in Japan were 2.3, 3.5 and 4.5%, respectively, during the past 5 years, which compared favourably with the Congenital Heart Surgery Database of the Society of Thoracic Surgeons, the European Association for Cardio-thoracic Surgery or a combination of the two [7–9]. The number of operations and post-operative mortality rates have currently stabilized at ≈9000 cases per year and <5.0% during the last 2 years, respectively.

Two specific medical situations of Japan were demonstrated in this study. First, 111 institutions performed ≈7000 congenital open heart surgeries using CPB in 2012. There are <10 institutions in Japan where >200 congenital open heart surgeries were annually performed; thus, the other 5000 cases were carried out at the remaining 100 institutions. Although this database system cannot allow for a more detailed investigation of the relationship between the case volumes, case complexities and mortality rates of each institution, it is noteworthy that the overall nationwide surgical outcomes were acceptable even if such a large amount of small programmes exist [10].

Although a case-matched comparison study could not be conducted because of the different definitions of operative mortality, another unique situation in Japan is the long duration from...
operation to death [11–13]. Indeed, half of all mortalities were observed 30 days after surgery, and the median duration from operation to death was 28 days. With full medical cost coverage of patients born with congenital heart disease until 18 years of age, by the support of disabled children from the public health care system in Japan, parents and caregivers can make the greatest efforts possible to cure all children. As a result, extended intensive care continues for patients with post-cardiotomy complications, and a considerable number of patients are finally cured and discharged from the hospital long after surgery. In fact, out of the 3630 patients (13%) hospitalized for more than 90 days after the operation, 3365 patients survived at discharge (93%).

Cardiac problems were the most frequent cause of death after surgery at any point in time, and 7.1 per 1000 patients died after postoperative day 30 due solely to cardiac problems, which means that there are still some patients who died owing to post-cardiotomy heart failure without any other lethal complications after long-term intensive care. Except for some medically developed countries, advanced therapeutic options such as heart transplantation or long-term use of ventricular assistance devices are not available for post-cardiotomy heart failure in the paediatric population [14]. Patients who developed post-cardiotomy heart failure were treated with conventional therapy methods like medication, catheterization or surgical intervention, and temporary extracorporeal membrane oxygenation support with limited therapeutic effects. Finally, the Organ Transplant Law in Japan was revised and enforced in 2010, which legally and ethically allowed for paediatric heart transplantation. Donations from brain-death cadavers under 15 years old are now possible without written declaration of the donors themselves. Although there have only been two donors so far, an increase is expected [15]. In addition, an investigator-initiated trial of the EXCOR® paediatric ventricular assist device (Berlin Heart, Inc., Berlin, Germany) is now ongoing in Japan for bridge-to-heart transplants or recovery use [16, 17].

Study limitations

Limitations of this study were as follows. At first, the number of enrolled institutions significantly increased during the studied 5 years; therefore, only a small percentage of institutions reported their data during a part of the early study period. Even in the later study period, however, ~90% of all congenital heart surgeries was reported to this database. Second, a registry of post-cardiotomy complications, and a considerable number of patients are finally cured and discharged from the hospital long after surgery. In fact, out of the 3630 patients (13%) hospitalized for more than 90 days after the operation, 3365 patients survived at discharge (93%).

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With the large number of data in this database system, more detailed information about specific diagnosis-operative procedure is expected to be analysed. Also, further scientific analysis of the discrepancy between 30-day mortality and 90-day and in-hospital mortality by each diagnosis and procedure in addition to the RACHS score is mandatory.

In conclusion, significant discrepancy between 30-day mortality and 90-day and in-hospital mortality was demonstrated from analysis of the JCCSD. Patients who died long after the operation due to post-cardiotomy heart failure without any other complications are not rare.

SUPPLEMENTARY MATERIAL

Supplementary material is available at ICVTS online.

Conflict of interest: none declared.

REFERENCES