Risk Stratification and Outcome of Cardiac Surgery for Patients With Body Weight <2,500 g in an Asian Center

Jeng-Wei Chen, MD; Yih-Sharng Chen, MD, PhD; Chung-I Chang, MD; Ing-Sh Chiu, MD, PhD; Nai-Kuan Chou, MD, PhD; Hsing-Hao Huang, MD; Chi-Hsiang Huang, MD; Shu-Chien Huang, MD, PhD

Background: Cardiac surgery performed in patients with low body weight is a challenge for surgeons. Currently, such outcomes are mainly reported from European or North American centers. In this study, we review our cardiac surgery experience with neonates and infants weighing <2,500 g.

Methods and Results: We included patients with a body weight <2,500 g who received cardiac surgery between January 2008 and December 2012. The survival outcome was compared to that of patients with large body weight, and then the Risk Adjusted Classification for Congenital Heart Surgery (RACHS-1) categorization was used for operative risk stratification. In the 1,245 index operations, 53 patients (4.3%) were <2,500 g. The mean body weight was 2,232 g (range 1,320–2,500 g). The hospital mortality rate was 20.7% (11/53). Most (85%) of the procedures were in RACHS-1 category ≥3. The risk ratio was significantly higher in RACHS-1 category 3 (relative risk [RR]:6.2; 95% confidence interval [CI]:1.6–23.9) and 4 (RR:4.6; 95% CI:1.4–15.0), respectively, while it was not significantly different in category 2 (RR:1.02; 95% CI:1.01–1.02) and category 6 (RR:2.9; 95% CI:0.36–13.3).

Conclusions: Cardiac surgery performed on infants with low body weight is generally a complex procedure, but the results are acceptable. The risk was higher than that for patients with higher body weight in RACHS-1 category 3 and 4. Further investigation to improve the outcome of this high-risk group is needed. (Circ J 2014; 78: 393–398)

Key Words: Congenital heart disease; Mortality; Surgery

Patients of low body weight with congenital heart defects are difficult to manage. The small body size increases the technical difficulty, risk of cardiopulmonary bypass (CPB), requires a relatively large amount of blood for priming, and the immature organ systems also complicate postoperative care. Low body weight is generally considered as a risk factor for mortality in cardiac surgery. Whether the surgery should be delayed until body weight increases or performed despite the low body weight is a clinical dilemma. Previous studies have found that the overall in-hospital mortality rate for body weight <2,500 g is 15–24%. In recent years, we adopted an aggressive approach for cardiac surgery in patients with low body weight. In this study, we review our experience with cardiac surgery for neonates and infants weighing <2,500 g and their CPB management and outcome. We also compare outcome to that reports from the Society of Thoracic Surgeons Congenital Heart Database with risk stratification using Risk Adjusted Classification for Congenital Heart Surgery (RACHS-1) categorization.

Methods

Patients

Records of patients with body weight <2,500 g who received cardiac surgery between January 2008 and December 2012 at National Taiwan University Hospital were retrieved from the University’s registry of cardiac surgery and CPB. Patients who underwent simple ligation of patent ductus arteriosus were excluded. We adopted an “all-comer” policy in which surgery was provided to all patients with congenital cardiac defects when operation was suggested, regardless of body weight. Preoperative data, diagnosis, surgical procedure, CPB management, and clinical outcome were collected by retrospective chart review.

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Departments of Surgery (J.-W.C., Y.-S.C., C.-I.C., I.-S.C., N.-K.C., S.-C.H.), Anesthesiology (H.-H.H., C.-H.H.), National Taiwan University Hospital, National Taiwan University College of Medicine, Taipei, Taiwan

Mailing address: Shu-Chien Huang, MD, Department of Surgery, National Taiwan University Hospital, 7 Chung-Shan South Road, Taipei 100, Taiwan. E-mail: cvshuang@gmail.com


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was compared between patients with a body weight ≤ 2,500 g and >2,500 g. Given that there were no RACHS-1 category 1 procedures performed in patients with low body weight, we compared only patients with RACHS-1 categories 2–6. When comparing the present results to international standards, we used the report from the Society of Thoracic Surgeons Congenital Heart Database as a reference.

### Statistical Analysis

SPSS 20.0 for Windows was used for analysis. All data are as mean±SD or median (range). Differences between in-hospital survival and non-survival patients were analyzed using chi-squared or Fisher’s exact test for categorical variables and independent t-test for continuous variables. Multivariate logistic regression analysis was performed on variables considered risk factors for in-hospital mortality with P<0.05 on univariate analysis. A follow-up survival curve was plotted using the Kaplan-Meier method.

### Results

A total of 53 patients with body weight <2,500 g received cardiac surgery during the study period. There were 27 boys (51%) and 26 girls. The median age at surgery was 12 days (range, 0–73 days). The median body weight on the day of operation was 2,210 g (range, 1,320–2,500 g). The median gestational age was 38 weeks (range, 32–42 weeks), and 17 patients were premature. Six patients presented with extra-cardiac malformation, including tracheo-esophageal fistula (n=1), hiatus hernia (n=1), omphalocele (n=1), hepatoblastoma (n=1), hypospadias (n=1), and choanal atresia (n=1). Only 1 patient had a recog-

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**Table 1. Diagnosis and Operative Data by RACHS-1 Category**

<table>
<thead>
<tr>
<th>RACHS-1/Diagnosis</th>
<th>Procedure</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VSD</td>
<td>Total correction</td>
<td>7</td>
</tr>
<tr>
<td>TOF</td>
<td>Total correction</td>
<td>1</td>
</tr>
<tr>
<td><strong>Category 3</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarctation of aorta</td>
<td>Aortoplasty</td>
<td>3</td>
</tr>
<tr>
<td>VSD</td>
<td>PA banding</td>
<td>1</td>
</tr>
<tr>
<td>TOF</td>
<td>Shunt or RV-PA conduit</td>
<td>9</td>
</tr>
<tr>
<td>PA, IVS</td>
<td>RVOT reconstruction</td>
<td>1</td>
</tr>
<tr>
<td>PA, VSD</td>
<td>Palliative shunt</td>
<td>1</td>
</tr>
<tr>
<td>TGA/IVS</td>
<td>RVOT patch</td>
<td>1</td>
</tr>
<tr>
<td>Congenital mitral regurgitation</td>
<td>Mitral valvuloplasty</td>
<td>1</td>
</tr>
<tr>
<td>Right atrial capillary hemangioma</td>
<td>Tumor excision</td>
<td>1</td>
</tr>
<tr>
<td><strong>Category 4</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TGA/VSD</td>
<td>ASO+VSD repair</td>
<td>3</td>
</tr>
<tr>
<td>TAPVR</td>
<td>Total correction</td>
<td>8</td>
</tr>
<tr>
<td>Truncus arteriosus</td>
<td>Total correction</td>
<td>2</td>
</tr>
<tr>
<td>Interrupted aortic arch</td>
<td>Aortoplasty</td>
<td>3</td>
</tr>
<tr>
<td>Taussig-Bing anomaly</td>
<td>ASO+VSD repair+aortoplasty</td>
<td>1</td>
</tr>
<tr>
<td><strong>Category 6</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single ventricle</td>
<td>Norwood stage 1</td>
<td>8</td>
</tr>
<tr>
<td>Hypoplasia left heart syndrome (6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tricuspid atresia (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unbalanced atrioventricular defect (1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ASO, arterial switch operation; IVS, intact ventricular septum; PA, pulmonary atresia; RACHS-1, Risk Adjusted Classification for Congenital Heart Surgery; RVOT, right ventricular outlet truct; TAPVR, total anomalous pulmonary venous return; TGA, transposition of the great arteries; TOF, tetralogy of Fallot; VSD, ventricular septal defect.
Cardiac Surgery With Low Body Weight

In the present study, the in-hospital mortality rate was 20.7% (11/53 patients). Death occurred on average 9 days after operation (range, 1–24 days). The cause of in-hospital mortality was intractable heart failure in 9 patients; hemorrhagic stroke-related brain death in 1 patient; and fungal sepsis in 1 patient.

When comparing survivors to non-survivors, we found a statistically significant difference in body weight, corrected age, preoperative shock, extra-cardiac malformation or genetic disorder, CPB time, use of delay sternum closure, acute renal failure, and postoperative ECMO for circulation support. Multivariate analysis indicated that non-survivors had a lower body weight, lower corrected age, and more postoperative ECMO support (Table 2).

RACHS-1 Categorization and Mortality

The risk-adjusted mortality according to RACHS-1 categorization is summarized in Table 3. In this study, most of the procedures (84.9%) were high-risk procedures (RACHS ≥3). The mortality rate was significantly higher in patients with higher RACHS-1 categorization (P<0.0001).

Body Weight ≤2.5 kg vs. >2.5 kg

In the same period (2008–2012), excluding patent ductus arteriosus (PDA) ligation and RACHS-1 category, 1,152 patients with body weight >2.5 kg received congenital cardiac surgery at National Taiwan University Hospital. We compared the results of patients with low body weight to those of patients...
with body weight >2.5 kg. The mortality rate was significantly higher for the low birth weight group in category 3 (15% vs. 2.77%, P=0.024), and category 4 (29.4% vs. 8.33%, P=0.019). In category 2, the mortality rate was very low for both groups (0% vs. 0.42%, P=NS). In categories 5 and 6, the mortality rate was high for both groups (37.5% vs. 21.9%, P=0.537).

In a 5-year period, open heart surgery performed in patients <2,500 g was found to be associated with 20.7% mortality. The present results are similar to the reported STS database with adjustment according to RACHS-1 categorization. Early primary repair has become the preferred strategy for congenital heart disease in low birth weight infants. Waiting for increased body weight will prolong the duration in which infants can experience lower output or hypoxic status. This may increase morbidity and mortality due to the injury of a second organ, but infants with a low birth weight still have a high risk of death after surgery. The literature reported a mortality rate ranging from 15% to 24%. Although this result was acceptable given the poor prognosis, it is several fold higher when compared to common procedures in infants of normal body weight.

Many studies have been conducted to analyze high risk in cardiac surgery on infants with low body weight. The duration of CPB, prolonged circulation arrest time, postoperative low cardiac output, extra-cardiac congenital malformation, hypoplastic left heart syndrome and perioperative metabolic acidosis have been identified as significant risk factors for mortality. Some studies stated that age, prematurity, and weight at surgery did not influence early outcome, but infants with a low birth weight still have a high risk of death after surgery. The duration of aortic cross-clamp and circulation arrest was dependent upon the complexity of the procedure and could be shortened with increased surgical experience and improved technique. The statistical significance was possibly masked by other factors and the limited number of cases.

As reported by Ades et al, postoperative extracorporeal circulation support was associated with mortality in the present study. Ten patients in the present study needed ECMO support after cardiac surgery, and only 1 patient survived. Eight patients died on ECMO, and another 1 patient was weaned off ECMO successfully but died from uncontrolled fungemia and late mortality included sepsis (n=6), arrhythmia (n=1), and pulmonary vein obstruction despite repeated revision for pulmonary venous obstruction (n=1). The Kaplan-Meier survival curve is shown in Figure.

**Discussion**

STS, Society of Thoracic Surgery. Other abbreviations as in Tables 1, 3.

### Table 4. Comparison With STS Database (2007)*

<table>
<thead>
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<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mortality (%)</td>
<td>n</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>0</td>
<td>139</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>15</td>
<td>183</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>29.4</td>
<td>105</td>
</tr>
<tr>
<td>5+6</td>
<td>8</td>
<td>37.5</td>
<td>90</td>
</tr>
</tbody>
</table>

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[Figure. Kaplan-Meier survival curve for patients undergoing cardiac surgery with body weight <2,500 g.]

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sepsis. We believed poor heart function after operation was the major cause of mortality.\textsuperscript{25–27} ADES et al reported 83\% mortality in infants with low birth weight who had postoperative ECMO support,\textsuperscript{28} and SEO et al reported 100\% mortality.\textsuperscript{4} In the present study, prolonged CPB time was associated with postoperative ECMO support (P < 0.001), but use of DHCA, duration of aortic cross-clamp, and preoperative shock status were not associated with postoperative ECMO support (P = 1.0, 0.141 and 0.73, respectively). This indicates that the complexity of the procedure, and intraoperative difficulty could be reflected in prolonged bypass time, which would then necessitate postoperative ECMO support. The ECMO results were poor in the present low body weight group, and were also poor in the literature.

Acute renal failure was also associated with higher mortality in this study. BLINDER et al also found that acute kidney injury is common in infants after cardiac surgery and was associated with higher morbidity and mortality.\textsuperscript{28} For acute kidney injury that has reached stage III, the odds ratio for mortality was 9.46 (95\% confidence interval [CI]: 2.91–30.7). Of the present 22 patients with postoperative acute kidney injury, 11 patients (50\%) survived and were successfully weaned off dialysis. Patients whose renal function did not improve died. This suggests that avoiding injury of a second organ is important in reducing the risk of mortality.

In previous studies, extra-cardiac malformations and genetic disorders have been reported as significant risk factors.\textsuperscript{19} The reported prevalence was from 25\% to 35\%. In the present series, however, the incidence was relatively low, only 13.2\% (7/53 patients), and all patients with extra-cardiac malformation and genetic disorders survived. We believe this is related to the parents’ selection bias. In Taiwan, prenatal diagnosis is advanced and highly accurate. Prenatal echocardiography and advanced genetic testing might reduce the incidence of complex combined cardiac and extra-cardiac malformation, but we do not have detailed prenatal diagnosis data.

During the study period, more patients with a high RACHS-1 categorization (≥3) were noted in the lower body weight group at National Taiwan University Hospital (84.9\% vs. 57.1\% in body weight (BW) > 2.5 kg; P < 0.001). This trend was similar to the STS data published by CURZON et al (Tables 4).\textsuperscript{6}

In the present study, in category 2, the mortality approached zero despite a lower body weight. This suggests that in simple procedures (such as ventriculot septal defect or tetralogy of Fallot), early surgical treatment is warranted. The mortality rate was significantly higher in RACHS-1 categories 3 and 4, which we believe is related to the technical difficulty of the surgery in patients with smaller bodies, as well as due to poor preoperative conditions associated with complex congenital heart disease.

In the present RACHS-1 category 6 patients, low weight was associated with 37.5\% mortality, while for patients with a larger body weight it was 17.2\% (risk ratio, 2.888; 95\% CI: 0.626–13.326). Although the difference was not statistically significant, the present result is similar to that obtained in the Pediatric Heart Network Single Ventricle Reconstruction (PHN SVR) trial. In the largest series the early mortality was 16\% and low body weight was associated with a 2.1-fold increase in odds ratio of mortality.\textsuperscript{29,30} Consistent with other reported series, hypoplastic left heart syndrome (HLHS) was associated with high mortality in low body weight, and Norwood stage one palliation (SIP) performed on patients with low body weight was associated with more than double the risk.\textsuperscript{6,21,24} More effort is needed to improve outcome in this group.

### Study Limitations

We recognize the limitations of this retrospective, single-center study. The number of subjects was small, and patient diagnosis and operative method were complex and heterogeneous. The efficacy of the statistical analysis was limited by the relatively smaller number of cases included in the study.

### Conclusions

Cardiac surgery performed on infants with low body weight is generally a complex procedure. The risk was higher than for infants with a larger body weight in RACHS-1 categories 3 and 4. Given the poor nature of the disease course for congenital cardiac defects, cardiac surgery could be performed with acceptable results, but further investigation to improve the outcome of this high-risk group is needed.

### Acknowledgments

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