Cardiac Arrest in Infants After Congenital Heart Surgery

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Background—The survival rate to discharge after a cardiac arrest in a patient in the pediatric intensive care unit is reported to be as low as 7%. The survival rates and markers for survival strictly regarding infants with cardiac arrest after congenital heart surgery are unknown.

Methods and Results—Infants in our pediatric cardiac intensive care unit database were identified who had a postoperative cardiac arrest between January 1994 and June 1998. Parameters from the perioperative, prearrest, and resuscitation periods were analyzed for these patients. Comparisons were made between survivors and nonsurvivors. Of 575 infants who underwent congenital heart surgery, 34 (6%) sustained a documented cardiac arrest; of these, 14 (41%) survived to discharge. Perioperative parameters, ventricular physiology, and primary rhythm at the time of arrest did not influence outcome. Prearrest blood pressure was lower in nonsurvivors than in survivors \( (P<0.001) \). A high level of inotropic support prearrest was associated with death \( (P=0.06) \). Survivors had a shorter duration of resuscitation \( (P<0.001) \) and higher minimal arterial pH \( (P<0.02) \) and received a smaller total dose of medication during the resuscitation. Although survivors had an overall shorter duration of resuscitation, 5 of 22 patients (23%) survived to discharge despite resuscitation of >30 minutes.

Conclusions—The outcome of cardiac arrest in infants after congenital heart surgery was better than that for pediatric intensive care unit populations as a whole. Univentricular physiology did not increase the risk of death after cardiac arrest. Infants with more hemodynamic compromise before the arrest as demonstrated with lower mean arterial blood pressure and higher inotropic support were less likely to survive. The use of predetermined resuscitation end points in this subpopulation may not be justified. (Circulation. 1999;100[suppl II]:II-194–II-199.)

Key Words: heart defects, congenital ■ cardiopulmonary resuscitation ■ pediatrics ■ surgery

Cardiac arrest in the general pediatric intensive care unit population is an uncommon event with a dismal outcome. During the past 15 years, the reported incidence of patients requiring cardiopulmonary resuscitation in a pediatric intensive care unit has been between 1.5% and 6% of all admissions.\(^1\)\(^-\)\(^3\) The overall reported survival rate for these children is between 8.8% and 31%, and the survival rate for children <1 year old is 15%.\(^1\)\(^-\)\(^3\) The few reports that distinguish between cause of arrest portray an even more discouraging outcome for patients sustaining a cardiac arrest compared with those who have a pure respiratory event. The survival rate for cardiac and respiratory arrest for patients in the general pediatric intensive care unit has been reported to be 7% and 33%, respectively.\(^3\) When resuscitation is prolonged, the prognosis is even poorer. The reported survival rate for resuscitation duration of >15 and >30 minutes is 0% to 12.2% and 0% to 5.6%, respectively.\(^1\)\(^-\)\(^3\) The current literature suggests that the outcome of cardiac arrest is extremely poor among patients in the general pediatric intensive care unit population.

Studies concerning resuscitation in the pediatric intensive care unit include few patients who sustained a cardiac arrest after congenital heart surgery, and markers for survival in this subpopulation are poorly documented. A recent multi-institutional study demonstrated a 17.6% survival rate in 34 children with congenital heart disease who had sustained a postoperative cardiac arrest.\(^1\) Another recent investigation involving children of all ages showed that both prolonged duration of cardiopulmonary bypass and elevated early postoperative serum lactate levels were markers of major adverse events, including cardiac arrest.\(^4\) However, no reports are available for survival or markers of survival strictly regarding infants who had cardiac arrest after congenital heart surgery.

The objectives of this study were to describe the survival rates and other outcomes in infants with cardiac arrest after congenital heart surgery in a pediatric cardiac intensive care unit (PCICU) and to determine markers for survival and death in this patient population.

Methods

The PCICU database was reviewed for infants undergoing congenital heart surgery between January 1994 and June 1998. Patients were...
included in this study if they were ≤12 months old and sustained a documented cardiac arrest during the postoperative period. Cardiac arrest was defined as chest compressions or the absence of a palpable spontaneous pulse that was not resolved with only airway intervention. Resuscitation was attempted without the benefit of any mechanical ventricular support or extracorporeal membrane oxygenation (ECMO). Medical records, including patient charts, operative reports, and the laboratory database, were reviewed for perioperative, prearrest, and resuscitative data. The patients were then grouped into survivors and nonsurvivors for statistical comparisons. Survivors were defined as all patients who had a return of spontaneous circulation (ROSC) after a documented cardiac arrest and were subsequently discharged from the hospital; ROSC was defined as return of a spontaneous pulse detectable with palpation of a central artery. Nonsurvivors were subdivided into 3 groups: patients with no ROSC, patients with ROSC but who died <24 hours after the arrest, and patients with ROSC but who died >24 hours after the arrest and before discharge.

### Perioperative Parameters

Preoperative parameters included the patient’s age, weight, and primary cardiac diagnosis. Intraoperative parameters included the surgical procedure and resulting physiology. We classified patients as having biventricular physiology when the pulmonary and systemic circulations were in series with no hemodynamically significant shunts. All other patients were classified as having univentricular physiology. The cardiopulmonary bypass, aortic cross-clamp, and circulatory arrest durations were also analyzed.

### Prearrest Parameters

Prearrest physiological and laboratory parameters from the 12 hours before the arrest were recorded. The median values for these parameters were calculated and used for comparison. If the arrest occurred during the initial 12 postoperative hours, the median values of all prearrest values documented since admission to the intensive care unit were used. Prearrest physiological parameters included the heart rate and the mean arterial blood pressure (MAP). Prearrest laboratory parameters included the arterial and venous oxygen saturation, serum bicarbonate, arterial base deficit, total serum bilirubin, platelet count, and serum creatinine. Arteriovenous oxygen difference was calculated for each simultaneous pair of arterial and venous saturations recorded. In an effort to provide a quantified index of the patient’s condition, the dosages of inotropic infusions before arrest were used to derive an inotrope score, similar to previous descriptions. Dosages are expressed in micrograms per kilogram per minute. The score was obtained with the formula:

\[
[(\text{dopamine+dobutamine+amrinone})\times1]+[(\text{milrinone}\times20)\\+\{(\text{epinephrine+norepinephrine+isoproterenol})\times100]\]

### Resuscitation Parameters

The timing of the arrest was expressed in terms of the postoperative day on which it occurred. Only the initial postoperative arrest during a single patient admission was included for analysis. Arrests were considered separate events if ≥20 minutes elapsed between resuscitative efforts, including chest compressions, administration of arrest medications, and defibrillation/cardioversion. Parameters from the resuscitation period included the resuscitation duration, the lowest recorded arterial pH, and the total per-kilogram dosage of each resuscitation medication. The availability of central venous and arterial access, as well as epicardial pacing wires at the time of arrest, was recorded for all patients. The primary rhythm at the time of arrest was classified as ventricular fibrillation/pulseless ventricular tachycardia (VF/VT) or non-VF/VT. The latter category was subclassified as either bradycardia/asystole or pulseless electrical activity. The number of defibrillations and the total defibrillation energy were recorded for the patients with VF/VT.

### Medium-Term Outcome

For the patients who survived to discharge, medium-term outcome data were collected. The medical records were reviewed, and the families and primary physicians of survivors were contacted to determine the total length of hospital admission, disposition at discharge, and out-of-hospital survival. The disposition at discharge was separated into the following categories: to home (pre-event residence), to home with chronic nursing care (>6 months after discharge), or to a long-term rehabilitation facility.

### Statistical Analysis

Parameter values are reported as median with range. Comparisons between survivors and nonsurvivors were accomplished with the unpaired Student’s t test, the Fisher exact test, or χ² analysis. A value of $P<0.05$ was considered statistically significant.

### Results

There were 575 infants who underwent congenital heart surgery between January 1994 and June 1998. The study population consisted of the 34 infants (6%) who sustained a documented cardiac arrest in the PCICU after surgery. Fourteen patients (41%) survived to discharge, and 20 patients (59%) died. Among the nonsurvivors, 11 (55%) had no ROSC, 3 (15%) had ROSC but died <24 hours after the arrest, and 6 (30%) had ROSC but died >24 hours after the arrest and before discharge.

### Perioperative Parameters

Perioperative values are shown in Table 1. All primary cardiac defects and the procedures that were performed to palliate or repair them are shown in Table 2. A similar number of patients underwent univentricular and biventricular procedures. None of the perioperative parameters, including postoperative physiology, influenced survival.

### Table 1. Perioperative Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>All Patients</th>
<th>Survivors (n=14)</th>
<th>Nonsurvivors (n=20)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, d (years)</td>
<td>9</td>
<td>9 (2–275)</td>
<td>8.5 (4–215)</td>
<td>0.72</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>3.2</td>
<td>3.1 (2.1–6.5)</td>
<td>3.4 (1.8–6.2)</td>
<td>0.81</td>
</tr>
<tr>
<td>Male:female, n</td>
<td>15:19</td>
<td>4:10</td>
<td>11:9</td>
<td>0.17</td>
</tr>
<tr>
<td>Univentricular:biventricular, n</td>
<td>18:16</td>
<td>8.6</td>
<td>10:10</td>
<td>0.41</td>
</tr>
<tr>
<td>CPB, min</td>
<td>148</td>
<td>123 (26–243)</td>
<td>156 (49–340)</td>
<td>0.13</td>
</tr>
<tr>
<td>Circulatory arrest, min</td>
<td>50</td>
<td>49 (0–102)</td>
<td>54 (0–113)</td>
<td>0.69</td>
</tr>
<tr>
<td>Aortic cross-clamp, min</td>
<td>63</td>
<td>51 (0–112)</td>
<td>65 (0–175)</td>
<td>0.10</td>
</tr>
</tbody>
</table>

CPB indicates cardiopulmonary bypass.

Values are median (range).
Prearrest Parameters

Prearrest values are shown in Table 3. Prearrest parameters suggest that compared with survivors, the nonsurvivors were more hemodynamically compromised immediately before the arrest. Nonsurvivors had a significantly lower prearrest MAP and a trend toward a higher inotropic score than survivors. Also, all patients with an inotropic score of >40 before arrest died (n=8). Other prearrest parameters, including mechanical ventilation, did not significantly influence survival.

Resuscitation Parameters

Resuscitation values are shown in Table 4. The median postoperative day of arrest for all patients was 5 days and did not differ between survivors and nonsurvivors. In general, arrests did not occur during the early postoperative period or as an unexpected late postoperative event in patients. Several parameters from the resuscitation period were markers of survival; these included the lowest recorded arterial pH, the total amount of epinephrine administered, and the total amount of bicarbonate administered.

The overall survival rate decreased as resuscitation duration increased. Seven of 26 patients (27%) survived after 15 minutes of resuscitation, 5 of 22 patients (23%) survived after 30 minutes, and 3 of 19 patients (16%) survived after 45 minutes. As expected, the resuscitation duration was longer for nonsurvivors than for survivors; however, prolonged resuscitation did not preclude survival. Resuscitative efforts lasted for >30 minutes in 5 of 14 survivors (36%).

The primary rhythm at arrest was VF/VT in 14 patients (41%) and non-VF/VT in 20 patients (59%). In the latter group, no patients had pulseless electrical activity as the primary documented arrest rhythm. Of the 18 infants with univentricular physiology, 6 (33%) had VF/VT and 12 (67%) had non-VF/VT. Of the 16 infants with biventricular physiology, 8 (50%) had VF/VT and 8 (50%) had non-VF/VT. Rhythm, regardless of ventricular physiology, did not influence survival. The defibrillation energy and the number of shocks for survivors versus nonsurvivors were 3.2 J/kg (range, 1.7 to 10.9 J/kg) versus 4.7 J/kg (range, 1.6 to 16.7 J/kg) and 2.3 shocks per patient, respectively.

Central venous access was available at the time of arrest in 11 of 14 survivors (79%) and 17 of 20 nonsurvivors (85%). In the latter group, no patients had pulseless electrical activity as the primary documented arrest rhythm. Of the 18 infants with univentricular physiology, 6 (33%) had VF/VT and 12 (67%) had non-VF/VT. Of the 16 infants with biventricular physiology, 8 (50%) had VF/VT and 8 (50%) had non-VF/VT. Rhythm, regardless of ventricular physiology, did not influence survival. The defibrillation energy and the number of shocks for survivors versus nonsurvivors were 3.2 J/kg (range, 1.7 to 10.9 J/kg) versus 4.7 J/kg (range, 1.6 to 16.7 J/kg) and 2.3 shocks per patient for both groups, respectively.

Table 3. Prearrest Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>All Patients</th>
<th>Survivors (n=14)</th>
<th>Nonsurvivors (n=20)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate, bpm</td>
<td>145</td>
<td>150 (128–188)</td>
<td>140 (125–185)</td>
<td>0.49</td>
</tr>
<tr>
<td>MAP, mm Hg</td>
<td>54</td>
<td>59 (43–72)</td>
<td>48 (40–62)</td>
<td>0.0003</td>
</tr>
<tr>
<td>Mechanical ventilation, n</td>
<td>29</td>
<td>11</td>
<td>18</td>
<td>0.63</td>
</tr>
<tr>
<td>AVO2 difference, % saturation</td>
<td>38</td>
<td>43 (18–58)</td>
<td>36 (18–69)</td>
<td>0.60</td>
</tr>
<tr>
<td>Serum HCO3 –, mEq/L</td>
<td>24</td>
<td>27 (9–36)</td>
<td>22 (14–32)</td>
<td>0.18</td>
</tr>
<tr>
<td>Arterial BE, mmol/L</td>
<td>0.1</td>
<td>0.9 (−17–15)</td>
<td>−0.8 (−5–8)</td>
<td>0.43</td>
</tr>
<tr>
<td>Total bilirubin, mg/dL</td>
<td>2.5</td>
<td>3.5 (0–17.4)</td>
<td>2.3 (0–24.4)</td>
<td>0.67</td>
</tr>
<tr>
<td>Platelet count, ×10^12/μL</td>
<td>77</td>
<td>77 (14–666)</td>
<td>75 (23–156)</td>
<td>0.19</td>
</tr>
<tr>
<td>Serum creatinine, mg/dL</td>
<td>0.7</td>
<td>0.6 (0.3–1.8)</td>
<td>0.75 (0.3–2.2)</td>
<td>0.18</td>
</tr>
<tr>
<td>Inotrope score</td>
<td>18</td>
<td>9 (0–40)</td>
<td>27 (0–400)</td>
<td>0.06</td>
</tr>
</tbody>
</table>

AVO2 indicates arteriovenous oxygen saturation difference; HCO3 –, bicarbonate; and BE, base excess.

Values are median (range).
the 5 patients without epicardial pacing wires at the time of their arrest, only 1 patient (20%) survived, whereas 2 patients died without ROSC, and 2 patients died >24 hours after ROSC.

**Medium-Term Outcome**

The median hospital length of stay was 35 days (range, 7 to 76 days). All 14 survivors were discharged home (pre-event residence), and no patients required home nursing care beyond the 6-month follow-up visit. During a median of 21-month follow-up (range, 6 to 43 months), 1 patient with truncus arteriosus died 30 months after her initial cardiac arrest. This death occurred after a second operation for a right ventricle–to–pulmonary artery conduit.

**Discussion**

The outcome of infants receiving cardiopulmonary resuscitation after congenital heart surgery is better than the reported outcome in the general pediatric intensive care unit population. The survival rate in this study was 41% compared with the previously reported survival rates of 8.8% to 31% for all children and 15% for infants in the general pediatric intensive care unit population.1–3 When cardiac arrest is specifically addressed, the survival rate in this series was 41% compared with the survival rate of 7% reported by Bos et al1 in 1992 for pediatric intensive care patients. A likely explanation for the disparity in survival rates is that the populations are inherently different. Cardiac arrest after congenital heart surgery is usually an acute event in a patient with otherwise healthy organ systems rather than the end result in a chronically ill patient at the end stage of the disease. This statement is supported by the prearrest laboratory values of our patients. However, our results revealed that in the initial hours before the arrest, a lower MAP and significant inotrope support were associated with survival. Not surprisingly, these findings indicate that patients who are more hemodynamically compromised immediately before an arrest are more likely to die. Slonim et al1 reported on 205 children who had a cardiac arrest in a general pediatric intensive care unit; 14 of these patients had multiorgan dysfunction, and only 2 of 14 survived. This poor survival rate is similar to our finding that only 1 of 4 patients with multiorgan dysfunction survived. Another difference between the general pediatric intensive care unit population and our population is the relative incidence of arrest before arrival at in the pediatric intensive care unit. In the report of Slonim et al,1 33 patients sustained an arrest before arrival in the intensive care unit, and none of these patients survived after an additional arrest while in the pediatric intensive care unit. Only 1 of our patients had a preoperative arrest; this patient died after a subsequent postoperative arrest. An additional explanation for the differences in survival rates may be the relative availability of central venous access, arterial lines, and pacing wires in postoperative patients. Central venous access in our patients facilitated the rapid delivery of resuscitative medications and volume, as well as the immediate escalation of inotropic infusions. Arterial access was used to determine the adequacy of chest compressions through monitoring of the arterial tracing amplitude. In addition, arterial access allowed the frequent identification of arterial blood gas and serum electrolyte disturbances. The epicardial pacing wires were used to maintain atrioventricular synchrony and appropriate chronotropy during and immediately after the resuscitation in more than half of the infants. The influence on survival cannot be proved, but epicardial pacing was considered clinically useful for the majority of those in whom it was available. Previous reports do not comment on these factors; therefore, it is difficult to make further conclusions regarding these issues.

The differences in survival rates seen in this series and in patients in the general pediatric population remained true as resuscitation duration increased. The survival rate in our population versus the general pediatric intensive care unit population was 27% versus 0% to 12.2% after 15 minutes and 23% versus 0% to 5.6% after 30 minutes.1–3 In addition, we found a 16% survival rate after 45 minutes. These differences may again be related to the inherent characteristics of the 2 patient populations. In addition, our institutional philosophy is to avoid predetermined end points for resuscitation. This latter explanation may have contributed to the improved survival rate and outcome regardless of the resuscitation duration in this subgroup of patients. Although it was not surprising that shorter resuscitation duration, higher minimum pH, and lower dose of arrest medications were significantly associated with survival, the fact that some survivors had extreme values of these parameters indicates that survival rates can be improved if persistent efforts are made (Table 5).

**TABLE 4. Resuscitation Parameters**

<table>
<thead>
<tr>
<th>Resuscitation Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of arrest, postoperative d</td>
<td>5</td>
</tr>
<tr>
<td>Lowest arterial pH</td>
<td>7.20</td>
</tr>
<tr>
<td>Epinephrine dose, mg/kg</td>
<td>0.07</td>
</tr>
<tr>
<td>Bicarbonate dose, mEq/kg</td>
<td>4.2</td>
</tr>
<tr>
<td>Resuscitation duration, min</td>
<td>50</td>
</tr>
<tr>
<td>VF/VT:non-VF/VT, n</td>
<td>14:20</td>
</tr>
</tbody>
</table>

**TABLE 5. Extreme Resuscitation Values in Survivors**

<table>
<thead>
<tr>
<th>Resuscitation Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resuscitation duration</td>
<td>110 min</td>
</tr>
<tr>
<td>Lowest arterial pH</td>
<td>6.87</td>
</tr>
<tr>
<td>Epinephrine dose</td>
<td>0.28 mg/kg</td>
</tr>
<tr>
<td>Bicarbonate dose</td>
<td>15 mEq/kg</td>
</tr>
</tbody>
</table>
The 41% survival rate in this study was also significantly better than that in the few previous reports of cardiac arrest after congenital heart surgery. In 1986, Gillis et al.\textsuperscript{8} reported a 14% survival rate in 14 patients who sustained a cardiac arrest after congenital heart surgery. In 1997, Slomim et al.\textsuperscript{9} reported a 17.6% survival rate in 34 children with congenital heart disease who had sustained a postoperative cardiac arrest. However, exact comparisons are difficult because our study included only infants, whereas these studies included all pediatric age groups.

ECMO as a means of resuscitation for those who do not respond rapidly to other resuscitative measures was not available in our institution during the study period. However, 3 infants who initially had ROSC, after a median resuscitation duration of 73 minutes, were later placed on ECMO due to poor hemodynamics. One patient died <24 hours and 2 patients died >24 hours after the arrest. The poor outcome in these patients is similar to that of 7 patients in the study of Duncan et al.,\textsuperscript{9} who had delayed the placement of patients on ECMO, after a median resuscitation duration of 90 minutes; only 2 patients (28.6%) survived to discharge. Duncan et al.\textsuperscript{9} further reported that rapid-deployment ECMO, after a median resuscitation duration of 55 minutes, facilitated survival in 4 of 7 infants (57%) who sustained a cardiac arrest after congenital heart surgery.

Surprisingly, we found that univentricular physiology during the arrest was not a significant risk factor for death. These patients are expected to be more hemodynamically compromised both preoperatively and postoperatively. They have less myocardial reserve and would be expected to more readily experience ischemia. The nonpulsatile and low-flow state during cardiac arrest is more likely to predispose patients to thrombosis, which can be devastating in patients with shunts. In addition, once arrest occurs in patients with univentricular palliation, the resultant pathophysiological changes, such as increased systemic vascular resistance, further complicate management. Despite these theoretical considerations, univentricular physiology did not contribute to an increased mortality rate. Contrary to our expectations, we found that univentricular patients may have had even better hemodynamics going into the arrest compared with biventricular patients. The univentricular patients had a trend toward a lower prearrest inotrope score compared with biventricular patients (13; range, 0 to 100 versus 27.5; range, 0 to 400; \(P=0.08\)). Therefore, the severity of prearrest illness in the biventricular patients may have offset the disadvantages of arrest management in the univentricular patients.

Another unexpected finding in our study was the relatively high incidence of VF/VT arrest. We found an incidence of 41% for VF/VT compared with previous reports of 3% ( \(<8\) years) to 19% ( \(<20\) years).\textsuperscript{10,11} The primary rhythm reported for cardiac arrest in children is typically bradycardia that progresses to asystole or pulseless electrical activity.\textsuperscript{12,13} Therefore, the pediatric advanced life support recommendations focus on early airway manipulations and the initiation of chest compressions rather than early activation of emergency medical services and, thus, defibrillation.\textsuperscript{14} Our results suggest that the sequence of resuscitation may have to be different for this subpopulation of patients. The true prevalence of VF/VT during pediatric cardiac arrest remains unknown, and there are few data on primary rhythm at arrest for children in the intensive care unit. A possible explanation for this higher incidence of VF/VT is that the infants in our patient population had congenital heart disease, underwent congenital heart surgery, and thus were exposed to poor hemodynamics, ventriculotomies, and myocardial ischemia during cardiopulmonary bypass and hypothermic circulatory arrest. These exposures may have predisposed our patients to VF/VT. Furthermore, patients who responded to airway interventions only were excluded from the study group. These patients, as well as any patient sustaining a pure respiratory event, are more likely to have non-VF/VT as the primary arrest rhythm.\textsuperscript{12}

**Study Limitations**

The limitations of this study are most importantly related to the inherent problems of a historical cohort study design: the inconsistent nature of information in medical records and, therefore, the possibility of patients sustaining an arrest and not being identified or of parameters not being accurately documented. The small number and heterogeneity of patients in this series may have affected the statistical power of the study and made comparisons difficult. Comparisons with the literature and applications of our data are also limited because we included only infants.

**Conclusions**

Cardiac arrest survival rates in infants after congenital heart surgery were better than those for the general pediatric intensive care unit population as a whole. Univentricular physiology did not increase the risk of death after cardiac arrest. Infants with more hemodynamic compromise before arrest as demonstrated by lower MAP and higher inotropic support were less likely to survive. Infants with prearrest inotrope scores of \(>40\) did not survive their arrest. The incidence of VF/VT was significantly higher than that in previous reports, suggesting that the pediatric advanced life support recommendations for this subpopulation may have to be modified. Survival was less likely as resuscitation duration increased, but a resuscitation time of \(>30\) minutes did not necessitate poor outcome. Predetermined end points of resuscitation may lead to premature cessation with lower survival rates. Neurological and developmental evaluations of long-term survivors are warranted.

**References**


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