Management of Pediatric Tachyarrhythmias on Mechanical Support

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Background—Pediatric patients with persistent arrhythmias may require mechanical cardiopulmonary support. We sought to classify the population, spectrum, and success of current treatment strategies.

Methods and Results—A multicenter retrospective chart review was undertaken at 11 sites. Inclusion criteria were (1) patients <21 years, (2) initiation of mechanical support for a primary diagnosis of arrhythmias, and (3) actively treated on mechanical support. A total of 39 patients were identified with a median age of 5.5 months and median weight of 6 kg. A total of 69% of patients were cannulated for supraventricular tachycardia with a median rate of 230 beats per minute. A total of 90% of patients were supported with extracorporeal membrane oxygenation for an average of 5 days. The remaining 10% were supported with ventricular assist devices for an average of 38 (20–60) days. A total of 95% of patients were treated with antiarrhythmics, with 43% requiring >1 antiarrhythmic. Amiodarone was the most frequently used medication alone or in combination. A total of 33% patients underwent electrophysiology study/transcatheter ablation. Radiofrequency ablation was successful in 9 patients on full flow extracorporeal membrane oxygenation with 3 radiofrequency-failures/conversion to cryoablation. One patient underwent primary cryoablation. A total of 15% of complications were related to electrophysiology study/ablation. At follow-up, 23 patients were alive, 8 expired, and 8 transplanted.

Conclusions—Younger patients were more likely to require support in the presented population. Most patients were treated with antiarrhythmics and one third required electrophysiology study/ablation. Radiofrequency ablation is feasible without altering extracorporeal membrane oxygenation flows. There was a low frequency of acute adverse events in patients undergoing electrophysiology study/ablation, while on extracorporeal membrane oxygenation. (Circ Arrhythm Electrophysiol. 2014;7:658-663.)

Key Words: ablation techniques ■ antiarrhythmic drugs ■ heart-assist device ■ pediatrics

Tachyarrhythmia-induced cardiogenic shock is a rare albeit life-threatening phenomenon. Mechanical support devices, including both extracorporeal membrane oxygenation (ECMO) and ventricular assist devices (VAD), have been successfully used to provide cardiac support to these fragile pediatric patients.1–4 Once these patients have been successfully placed on mechanical support, there have been case reports and case series of various treatment modalities offered to these patients. Some reports describe spontaneous termination of tachycardias,2 whereas others discuss medical1,3–5 and transcatheter approaches3,4,6 to terminate these tachycardias. Occasionally, these patients have no meaningful cardiac recovery leaving their only option to be orthotopic heart transplantation.7

Clinical Perspective on p 663

Current pediatric experience and survival data for mechanical support are also evolving rapidly. Pediatric cardiac ECMO data demonstrate survival rates of 38% to 56%.8–10 The most current data for patients supported with VADs demonstrate that 75% survived to heart transplantation or recovery.11

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*Pediatric and Congenital Electrophysiology Society study participants are provided as an Appendix.

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The objective of this study is to understand the patient population who receives mechanical support for persistent, hemodynamically compromising tachyarrhythmias and to determine the spectrum and success of the current treatment strategies to treat these arrhythmias, including both medical and transcatheter therapies, as well as clinical outcomes.

Methods
A multicenter retrospective chart review was undertaken at 11 centers in North America. Approval for the study was obtained through the institutional review board at each participating center. Patients treated between January 2004 and June 2012 were included in this study. Other inclusion criteria for the study were (1) patients <21 years of age, (2) initiation of mechanical support (either ECMO or VAD) for a primary diagnosis of arrhythmias, and (3) actively treated for tachyarrhythmias, while on mechanical support. Patients were excluded if they did not receive treatment for their arrhythmia, while on mechanical support. Charts were reviewed at each participating site by a site-specific investigator, and data were collected including patient demographic data, details of tachyarrhythmias, therapeutic interventions (including medical and transcatheter interventions), complications, and long-term outcomes. Data collection forms were generated by the primary institution and forwarded to participating institutions. The data collection forms included data in the following categories: (1) patient demographics, (2) arrhythmia (mechanism of arrhythmia(s), cycle length, etc), (3) antiarrhythmic information (number and kind of antiarrhythmics/patient), (4) ablation information (including substrate, location of ablation, ablation energy source, etc), and (5) outcomes.

Statistical Analysis
Results are primarily limited to descriptive findings and are expressed as percentages with median values (first and third interquartile) for continuous variables. Where appropriate, statistical analyses were performed using Wilcoxon 2-sample test for unmatched samples with statistical significance set for \( P \leq 0.05 \). Binomial 95% confidence intervals are reported when relevant.

Results
Demographic Data
A total of 39 patients were collected from 11 participating centers across the United States and Canada. The median age of patients was 5.5 months (interquartile range [IQR], 0.85–50 months) with a median weight of 6 kg (IQR, 3.6–11.9 kg). A majority, 64% (25/39), of patients had a significant medical history, whether cardiac or noncardiac (Table). For those patients with a cardiac history, 50% (12/24) had a history of congenital heart disease. Previous congenital heart disease surgery was performed in 66% (8/12) of the patients with coronary heart disease, and 1 patient had a previous ECMO run. A fetal diagnosis of tachycardia had been made in 13% (5/39) patients.

Electrophysiological Properties
The average tachycardia rate was 230 beats per minute (IQR, 200–275 beats per minute; Table). The majority of patients, 69% (27/39), had supraventricular arrhythmias. The rest of the patients were split between junctional tachycardias in 10% (4/39) and ventricular arrhythmias in the last 21% (8/39).

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### Table. Patient Information

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<td>4 (10%)</td>
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<tr>
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<td>3 (11%)</td>
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<tr>
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<td>Treated with antiarrhythmic medications</td>
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<td>16 (43%)</td>
</tr>
<tr>
<td>Treated with a single antiarrhythmic agent</td>
<td>21 (57%)</td>
</tr>
<tr>
<td>AV nodal reentrant tachycardia</td>
<td>3 (11%)</td>
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<tr>
<td>Wolff–Parkinson–White</td>
<td>1 (4%)</td>
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<tr>
<td>Junctional tachycardias</td>
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<tr>
<td>Accessory pathway</td>
<td>8 (21%)</td>
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<tr>
<td>Permanent junctional reciprocating tachycardia</td>
<td>3 (11%)</td>
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<td></td>
</tr>
<tr>
<td>Noncardiac history</td>
<td>1 (4%)</td>
</tr>
</tbody>
</table>

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Details of Mechanical Support

VA ECMO was the modality of mechanical support in 90% (35/39) of cases (Figure). A total of 43% of patients were placed on ECMO emergently, while undergoing cardiopulmonary resuscitation. The median time on ECMO was 5 days (IQR, 3–7 days). A total of 17% (6/35) expired while on ECMO or had redirection of care and expired. The remaining 83% (29/35) of patients were successfully decannulated from ECMO. A total of 26% (8/29) of patients who were successfully decannulated from ECMO had significant complications.

The remaining 10% (4/39) of patients received VADs, with 25% (1/4 patients) receiving biventricular assist and 75% (3/4 patients) receiving left ventricular assist only. The median time on VAD was 38.5 days (IQR, 26–52 days) and all (100%) were successfully separated from mechanical support. The majority, 75% (3/4), went on to orthotopic heart transplant and 25% (1/4) had cardiac recovery and was successfully separated from VAD. There were no documented complications in this group.

Patients supported with ECMO were younger than those supported with VAD, 3.5 months (IQR, 146–168 months) versus 156 months (IQR, 0.6–14 months) (P<0.05), and were smaller, 5.1 kg (IQR, 3.5–8.4 kg) versus 43 kg (IQR, 28–58 kg; P<0.05). Those patients supported with ECMO spent less time on mechanical support when compared with patients with VAD, 5 (IQR 3–7 days) days versus 38.5 (IQR 26–52 days) days (P<0.05).

Antiarhythmic Medications

The vast majority, 95% (37/39), of patients were treated with antiarrhythmic medication, while on mechanical support. Specifically, 21 (21/37; 57%) patients were treated with a single agent, 9 (9/37; 24%) patients were treated with 2 antiarrhythmic agents, 6 (6/37; 16%) patients were treated with 3 antiarrhythmic agents, and 1 (1/37; 3%) patient was treated with 4 antiarrhythmic agents. The most commonly used single antiarrhythmic was amiodarone (81%; 17/21). Other agents used in isolation included: esmolol (2/21 patients; 9.5%), adenosine (1/21; 4.5%), and lidocaine (1/21; 4.5%). All patients who were treated with multiple agents were treated with amiodarone in conjunction with other agents, including esmolol, lidocaine, digoxin, flecainide, procainamide, propafenone, metoprolol, propranolol, and adenosine (Table).

Only 2/39 (5%) patients were not treated with antiarrhythmics, while on mechanical support. Both of these patients were treated with antiarrhythmic medications before the initiation of mechanical support and had bradycardic arrests.

Figure. Flow chart demonstrating patient clinical courses and outcomes. ECMO indicates extracorporeal membrane oxygenation; OHT, orthotopic heart transplant; and VAD, ventricular assist device.
secondary to antiarrhythmic administration. Both of these patients proceeded directly to the electrophysiology laboratory once on mechanical support.

**Electrophysiology Studies and Transcatheter Ablation**

Of the 39 patients in this study, 13 (13/39; 33%) patients underwent electrophysiology study (EPS) with transcatheter ablation, while on ECMO support. Eleven of 13 patients were treated with antiarrhythmics on support before proceeding for ablation. No patients with VAD underwent EPS/ablation. The average duration from time of initiation of mechanical support to EPS/ablation was 63±53 hours. Pediatric electrophysiologists performing these cases used an average number of intravascular access points 1.5±0.6, and the average number of pacing catheters was 2±0.7. There were a total of 25 ablation targets, with an average of 2.4±2 electrophysiological substrates per patient. Four patients had multiple tachycardia substrates. Right-sided accessory pathways were the most common supraventricular tachycardia mechanism, and left ventricular tachycardias were the most common ventricular tachycardia mechanism (Table).

**Ablation Energy Source**

The majority of patients, 9/13 (69%), underwent EPS and ablation using radiofrequency energy only. There were no alterations to mechanical support flows documented during these cases. The substrates that underwent successful radiofrequency ablation alone included accessory pathways, atrioventricular node reentry tachycardia (AVNRT)/slow pathway modification, AV node ablation, and ventricular tachycardias. One patient (8%) underwent primary cryoablation. This patient had a left atrial appendage ectopic atrial tachycardia and the operator elected to use cryoablation for safety purposes primarily.

The remaining 3 patients (23%) had a combination of radiofrequency ablation plus cryoablation. All 3 patients were started with radiofrequency energy but were unsuccessful in ablating the target foci, which included a right atrial appendage focus, AVNRT/slow pathway modification, and AV node ablation. In these 3 patients, an attempt was made to improve lesion formation and tip cooling by decreasing ECMO flow rate in increase blood flow through the heart. However, there was no improvement in lesion formation or thermodynamics with this strategy. All 3 of these patients were converted to cryoablation and underwent successful ablations. All 13 patients had acutely successful ablations.

One patient (1/39; 3%) underwent an EPS only because this patient had noninducible tachycardia in the laboratory. The remaining 25 patients (25/39; 64%) did not undergo EPS or transcatheter ablation.

**Adjunct Procedures**

Of the 14 patients who went to the cardiac catheterization laboratory (CCL), 6 patients (43%) had an associated procedure, while in the CCL. The associated procedures included 5 hemodynamic catheterizations, 2 right ventricular endomyocardial biopsies, and 2 static balloon atrial septostomies. The remaining 8 patients (57%) went to the CCL for an EPS±transcatheter ablation alone.

**Complications From EPS/Transcatheter Ablation**

There was 1 complication directly attributable to the EPS/ablation. This patient developed complete heart block during cryoablation of a slow pathway for AVNRT. In this patient, there was return of normal AVN conduction in the CCL. In a second patient, there was 1 complication that was possible attributable to the EPS/ablation. This patient developed mitral valve damage leading to significant mitral regurgitation and eventually requiring mitral valve replacement. This patient underwent ablation of a right posteroseptal accessory pathway, and during the same procedure they underwent static balloon atrial septostomy. Considering this latter outcome to be a complication, EPS/ablation results in a complication rate of 15% for those patients on mechanical support who underwent EPS/transcatheter ablation.

**Outcomes/Current Status**

Median to long-term outcomes (>30 days) for these patients demonstrated that 59% (23/39; 95% confidence interval, 0.42–0.74) were alive at the time of data collection. One patient had a recurrence of ectopic atrial tachycardia after decannulation from ECMO and underwent a repeat radiofrequency ablation. (Of note, this patient had an initially successful cryoablation on ECMO for a right atrial appendage ectopic atrial tachycardia.) There were 5 patients who had complications postmechanical support. The most common complication, seen in 2 patients, was thrombosis requiring medical therapy with thrombolytics (sites of thrombosis included left and right internal jugular veins and left subclavian vein). Another patient developed hypoxic encephalopathy and developmental delay. The next patient had mitral valve damage and required mitral valve repair×3 followed eventually by mitral valve replacement. Finally, a patient developed gastric perforation (from a nasogastric tube) requiring an emergent laparotomy.

An additional 20.5% (8/39; 95% confidence interval, 0.09–0.36) patients were alive after undergoing orthotopic heart transplantation. Half of these patients (50%; 4/8; 95% confidence interval, 0.15–0.84) were transplanted directly from mechanical support (3 from VADs and 1 from ECMO), and the remaining 4 patients were transplanted after decannulation or separation from mechanical support. The diagnoses for the 4 patients transplanted directly from mechanical support included: fetal supraventricular tachycardia complicated by severe hydrops, dilated cardiomyopathy (2 patients and 1 with a genetic anomaly), and congenital heart disease (tetralogy of Fallot). The diagnoses for the late transplants included hysiocytoid cardiomyopathy (2 patients), Becker muscular dystrophy, and dilated cardiomyopathy secondary to congenital heart disease.

The final 20.5% (8/39; 95% confidence interval, 0.09–0.36) of patients had expired at time of follow-up. Six patients expired while on mechanical support or had redirection of care because of fatal intracranial hemorrhage (5 patients) or multiorgan failure (1 patient). One patient had a sudden cardiac arrest after an orthotopic heart transplantation. And finally, the last patient was a postoperative patient with tetralogy of Fallot who had an out-of-hospital sudden cardiac arrest.
Discussion

This study represents the largest study to date investigating the active management of pediatric patients with tachyarrhythmias on mechanical support. There are several novel findings from this article. First, most patients who underwent mechanical support because of hemodynamically compromising tachycardias were young, with a majority of patients having a medical history (either cardiac or noncardiac). ECMO was the most commonly used form of mechanical support. The most common arrhythmia mechanism was supraventricular arrhythmias. Antiarrhythmics were used in the vast majority of patients, with amiodarone being the most commonly used antiarrhythmic both as a single agent and as combination therapy. Only one third of patients who required mechanical support required an EPS/ablation, usually after 2 to 3 days on mechanical support. Interestingly, pediatric electrophysiologists seem to perform these procedures commonly using minimally invasive techniques, using as few intracardiac catheters and vascular access points as possible. This is likely attributable to the small patient size and potential complication rate.

Radiofrequency ablation was the most common energy source used in these cases, with no alteration of flow on mechanical support needed to ensure adequate lesion formation. For a minority of patients who had inadequate lesion formation, there was a change in energy source from radiofrequency ablation to cryoablation. In these patients, radiofrequency was attempted both at maximal flows on mechanical support and at lower flows. It did not seem that decreasing the supported cardiac output by decreasing flows and allowing potentially for more convective cooling allowed for better lesion formation. Rarely, cryoablation was used as the primary modality for ablation. For those patients who did go the CCL for EPS/ablation, just under half of the patients also underwent an adjunct cardiac catheterization procedure as well. There were few complications directly attributable to EPS/ablation. The 1 complication that was directly attributable (transient complete heart block) was fully reversed, while the patient was in the CCL. The second complication was possibly attributable to EPS/ablation. Long-term outcomes were less promising, with 59% of patients doing relatively well at time of follow-up. A total of 20.5% of patients had undergone successful orthotopic heart transplantation (4 directly from mechanical support and 4 late transplants), and 20.5% of patients expired at follow-up (6 on mechanical support and 2 later deaths).

There are several findings from this study that have important implications. First, antiarrhythmic therapy is commonly used in these ill patients. Amiodarone was the most frequently used antiarrhythmic. A case report by Kendrick et al in 2006 interestingly discussed a case of a neonate status post tetralogy of Fallot repair, who developed postoperative junctional ectopic tachycardia and required ECMO support. The infant was treated with larger than usual doses of amiodarone to achieve clinical effect and therapeutic serum concentrations. This group concluded that the delivery of amiodarone to patients on ECMO is complicated by larger blood volumes, circuit changes, and binding to the circuit, and that this group may require larger than usual doses of amiodarone. The data collection for this study was unable to assess accurately whether larger doses of amiodarone were necessary in patients on mechanical support. However, it is an important consideration during clinical practice.

A minority of patients, 33%, required EPS and transcatheter ablation. Many, but not all of these patients, had been treated with antiarrhythmics, while on mechanical support. However, because of persistent arrhythmias, this group of patients required transcatheter intervention. There has been no systematic study of this in the past although there have been a smattering of cases reported in the literature. In 2011, a case series by Dyamenahalli et al described the use of ECMO for intractable arrhythmias and complete congenital heart block. In this series of 9 patients, there were 7 patients with tachyarrhythmias and 2 patients with complete congenital AV block. Ablations were performed in 2 patients (29%), and either rate or rhythm control was achieved in all patients with tachycardia. All patients survived to hospital discharge, with 1 late death and the remaining 8 patients all having good overall and neurological outcomes. Although this patient population is smaller than the group described in this article, the same general principles apply. That is, majority of patients are able to achieve rate or rhythm control with antiarrhythmics, and only a minority of patients required EPS/ablation to achieve rhythm control.

There are limited data available about complication rates for those patients who underwent EPS/transcatheter ablation. The experience of the Boston group with cardiac catheterizations on patients supported by ECMO in 2002 is noteworthy. They described 54 patients undergoing 60 catheterizations in this patient population. Complications were limited to 3% and consisted of cardiac perforation in neonatal cases. There were no bleeding complications noted, and no reports of transport-related complications of the ECMO circuit to or from the CCL. Overall, 72% of patients were able to be decannulated, 48% survived to hospital discharge, and 43% were alive at follow-up (average 35 months). Within their 54 patients, there were 2 newborns who underwent a total of 3 EPS/transcatheter ablations. Both patients had severe Ebstein anomaly and refractory supraventricular tachycardia (1 had Mahaim-mediated supraventricular tachycardia). Although both patients were able to be weaned from mechanical support, only 1 patient survived to hospital discharge. In our population of patients who underwent EPS/transcatheter ablation, the complication rate was 15%, higher than that reported in the Boston/catheterization experience. This difference may be magnified because of our relatively smaller patient numbers, as well as the different underlying diagnoses.

Limitations

The study design was a retrospective chart review and as such has the associated biases of retrospective studies. There was no standardization of treatment for these patients among the 11 institutions. Also, we had relatively small patient numbers, despite being a multicenter study spanning 8 years. There were data points that we were not able to obtain accurately, particularly in regards to patients treated with antiarrhythmic medications (doses and quantity of boluses; doses and duration of continuous infusions). We were unable to capture the clinical details for when and why patients were taken to the EP laboratory versus continued medical treatment with antiarrhythmics. Finally, duration from arrhythmia control to decannulation was not ascertained.
Conclusions

Often when mechanical support is instituted in pediatric patients with intractable tachycardias, there is associated cardiac defect or cardiomyopathy. The most common arrhythmic mechanism is supraventricular tachycardia. The majority of patients are managed with medication, with amiodarone being the most frequently used antiarrhythmic. Given that a significant proportion of patients had resolution of tachycardia using intravenous antiarrhythmics, this would be a reasonable course of action before transcatheter ablation. Radiofrequency ablations are needed in one third of patients and are technically feasible without modifying flows on mechanical support. If there is inadequate lesion formation with radiofrequency ablation on full ECMO flows, then it is reasonable to change the ablation energy source to cryoablation. Finally, the significant risk of adverse events was attributable to mechanical support with less risk attributable to EPS/transcatheter ablation, while on mechanical support.

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Disclosures

None.

References


Appendix

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CLINICAL PERSPECTIVE

To date, there have been no systematic studies of patients with tachyarrhythmias on mechanical support. Quantifying the patient population and implemented treatment plans will allow clinicians to understand which treatments have historically provided the best result for this cohort of patients. By identifying the trends set forth from this data, clinicians can learn the value of antiarrhythmic and ablation therapies. In addition, physicians will be better prepared to deal with possible complications that may arise during the course of treatment of these patients. Finally, the statistical data gathered from this study will help focus the development of future studies aimed at improving the survival and recovery rates of tachyarrhythmia patients on mechanical support.
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