Radiofrequency ablation on veno-arterial extracorporeal life support in treatment of very sick infants with incessant tachymyopathy

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Aims
To evaluate the use of extracorporeal membrane oxygenation (ECMO) in supporting infants who require radiofrequency ablation (RFA) for incessant tachyarrhythmias, with particular emphasis on modifications required to standard ablation techniques.

Methods and results
Three cases of RFA carried out in infancy on ECMO support were reviewed retrospectively. Two infants with permanent junctional reciprocating tachycardia (PJRT) and one with ventricular tachycardia (VT) presented in a low cardiac output state, owing to cardiomyopathy caused by incessant tachycardia. In each case antiarrhythmic drug therapy caused haemodynamic collapse, requiring emergency ECMO support. Drug therapy on ECMO was not successful. In one patient, the tachycardia was controlled on ECMO with antiarrhythmic drugs, but recurred following ECMO decannulation. Each patient had a successful RFA on ECMO support. Power delivery was low during ablation lesions. In the PJRT cases power as low as 3–5 Watts was effective. In the VT ablation, an irrigated tip RFA catheter was required when cooling remained poor even after temporarily stopping ECMO flow.

Conclusion
Extracorporeal membrane oxygenation provides a haemodynamically stable and safe platform for antiarrhythmic drug therapy and RFA in infants with incessant tachyarrhythmias. Once ECMO has been commenced, if the tachyarrhythmia remains difficult to control with antiarrhythmic drugs, RFA should be strongly considered, to avoid the risk of tachycardia recurrence following ECMO decannulation. Power delivery during ablation lesions may be low because of inadequate cooling of the catheter tip. Reducing or stopping flow in the ECMO circuit may not provide adequate cooling and an irrigated tip catheter may be required.

Keywords
Infancy • Incessant tachycardia • Tachymyopathy • Cardiomyopathy • Radiofrequency ablation • Extracorporeal membrane oxygenation

Introduction
In infants with incessant tachyarrhythmias it may prove impossible to give effective doses of antiarrhythmic drugs because their negatively inotropic effect, in the setting of already critically compromised ventricular function, may result in haemodynamic collapse. We describe three young children with tachyarrhythmias, where extracorporeal membrane oxygenator support was used to establish haemodynamic stability following cardiac arrest during antiarrhythmic drug therapy. All underwent successful radiofrequency ablation while on extracorporeal circulatory support.

Case 1
An 11-week-old 3.8 kg girl presented with signs of heart failure and shock. Her electrocardiogram (ECG) showed narrow complex long RP tachycardia with a heart rate of 224/min. Deeply negative P waves in the inferior leads indicated permanent junctional reciprocating tachycardia (Figure 1). Echocardiography showed a severely dilated poorly contracting left ventricle, with no congenital heart abnormality.

Adenosine terminated the arrhythmia, but tachycardia reinitiated immediately. The arrhythmia persisted after a 5 mg/kg loading dose of...
amiodarone, amiodarone infusion at 10 mcg/kg/min for 10 h and a 500 mcg/kg loading dose of esmolol followed by an esmolol infusion at 25 mcg/kg/min. During a second 5 mg/kg loading dose of amiodarone, tachycardia terminated, but this was followed by profound bradycardia and loss of cardiac output. The amiodarone and esmolol were stopped and external cardiac massage was carried out. The tachyarrhythmia recommenced at the same time as cardiac output returned. Venoarterial extracorporeal membrane oxygenator support was commenced, using the right carotid artery and jugular vein. Thereafter, sinus rhythm could not be maintained despite amiodarone 35 mcg/kg/min and flecainide 2 mg/kg. The patient developed severe pulmonary oedema secondary to left ventricular dysfunction, exacerbated by the increased afterload caused by the extracorporeal membrane oxygenator.

Radiofrequency ablation was undertaken one week after presentation. A 5 French Mariner 4 mm tip ablation catheter (Medtronic Inc.) was used to map the tricuspid valve annulus in tachycardia. Earliest atrial activation was in a posteroseptal position at the mouth of the coronary sinus. Tachycardia terminated during radiofrequency applications at 50 and 60°C at this site, but could be easily reinduced. A third lesion in a slightly more medial position at 70°C, delivering a power of 10 W, for 30 s, terminated tachycardia immediately. A 30 s ‘bonus’ lesion was delivered at the same site. Thereafter tachycardia could not be induced.

The patient was weaned from extracorporeal membrane oxygenator support after 2 days, but continued to require intensive care owing to pulmonary haemorrhage. The tachyarrhythmia recurred after 9 days and was successfully ablated 22 days after the first procedure, with three further lesions delivered on the atrioventricular valve ring just posterior to the mouth of the coronary sinus. There was no further recurrence on 5 year follow-up.

**Case 2**

A 14-month-old 13 kg boy presented with a history of pallor and reduced tone. His ECG showed broad complex tachycardia with a heart rate of 320/min, a left bundle branch block morphology and an inferior QRS axis. Ventricular tachycardia was suspected when 400 mcg/kg of adenosine failed to terminate the arrhythmia. A 5 French endocardial temporary pacemaker lead was passed down...
the oesophagus and connected to one of the praecordial leads on an ECG to generate a unipolar signal showing atrial activation. The atrial ECG showed 2:1 ventriculoatrial block, with an atrial rate of 160 per min, confirming the diagnosis of ventricular tachycardia (Figure 2). Echocardiography demonstrated normal cardiac structure, impaired function, but no ventricular dilation.

Tachycardia persisted after a 5 mg/kg loading dose of amiodarone and direct current (DC) cardioversion up to 30 Joules. External cardiac massage was required after a loading dose of esmolol resulted in temporary loss of cardiac output. Venoarterial extracorporeal membrane oxygenator support was initiated via the right carotid artery and jugular vein.

After a further amiodarone loading dose of 5 mg/kg, the tachyarrhythmia converted to a junctional rhythm with a rate of 150–180 per min, but this quickly degenerated to ventricular tachycardia then ventricular fibrillation. Ventricular fibrillation persisted despite calcium chloride, magnesium sulphate, 50 Joule DC cardioversion and amiodarone 15 mcg/kg/min. The rhythm converted to ventricular tachycardia only after a 1 mg/kg bolus of lignocaine, lignocaine 0.9 mg/kg/h and further DC cardioversion. Following a 2 mg/kg bolus of flecainide the heart fibrillated again. Although DC cardioversion then restored sinus rhythm, flecainide was stopped as there was electromechanical dissociation.

After 4 days in junctional rhythm, treated only with amiodarone 12 mcg/kg/min, the child was decannulated from extracorporeal support, with reconstruction of the carotid artery. However, 7 h after decannulation, ventricular arrhythmias recommenced, sometimes with loss of cardiac output requiring cardiopulmonary resuscitation. For a further 36 h there were recurrent salvos of ventricular tachycardia resistant to all drug therapy, cooling to 35°C and DC cardioversion. Extracorporeal membrane oxygenator support was therefore recommenced, with re cannulation of the right carotid artery and jugular vein.

Radiofrequency ablation was undertaken 9 days after presentation. All antiarrhythmic drugs were stopped one day before the procedure. A 5 French Marinr ablation catheter was introduced via the right femoral vein. Left femoral venous access was used for a 5 French decapolar catheter in the coronary sinus and a 4 French quadripolar catheter in the His position. Frequent ventricular ectopy with a morphology similar to the ventricular tachycardia was mapped conventionally and using electroanatomical imaging (Ensite NavX, St Jude Medical). Earliest ventricular activation was in the anterosuperior right ventricular outflow tract (Figure 3).
Radiofrequency ablation proved ineffective as power delivery was limited to 8 W because the Marinr catheter quickly reached its temperature limit. This problem continued, even when extracorporeal support was temporarily stopped to increase flow through the right side of the heart to allow better cooling of the catheter tip. The ablation catheter was therefore changed to a 7 French Celsius B curve irrigated 4 mm tip catheter (Biosense Webster). Ablation at the same site achieved a power of 30 W and resulted in acceleration then termination of the tachycardia. Radiofrequency lesions were delivered for a total of 150 s.

Following the procedure the patient remained in sinus rhythm and was successfully decannulated from extracorporeal support after 2 days. Cardiac function normalized within 24 h of ablation. There was no recurrence of tachycardia on 6 years follow-up.

Case 3

A 6-week-old 4.1 kg baby presented with a 2 weeks history of poor feeding and reduced activity. There were signs of heart failure and low cardiac output. His ECG demonstrated narrow complex long RP tachycardia with a heart rate of 220/min. Deeply negative P waves in leads II, III, and aVF indicated permanent junctional reciprocating tachycardia. Direct current cardioversion terminated the tachycardia. Echocardiography in sinus rhythm demonstrated a dilated poorly functioning left ventricle, with no congenital heart abnormality. Tachycardia recurred after a few hours despite treatment with propranolol and digoxin.

A 5 mg/kg loading dose of amiodarone did not terminate the arrhythmia. Owing to our previous experience with patient 1, the possibility of sudden haemodynamic collapse following further doses of amiodarone was recognized. An extracorporeal membrane oxygenator circuit was therefore primed before giving a second 5 mg/kg loading dose of amiodarone over 30 min.

Tachycardia recommenced following cannulation and continued even after an 8 mcg/kg loading dose of digoxin, esmolol 200 mcg/kg/min and amiodarone 5 mg/kg followed by an infusion of 15 mcg/kg/min. Direct current cardioversion on this combination of drugs restored sinus rhythm. However, tachycardia recurred 2 days later when the esmolol dose was weaned to 50 mcg/kg/min and the amiodarone to 5 mcg/kg/min.

Radiofrequency ablation was carried out 3 days after presentation. A 4 French quadripolar catheter was placed in the right ventricular apex and the tricuspid valve annulus was mapped in tachycardia with a 5 French Marinr ablation catheter. Earliest atrial activation was just posterior to the mouth of the coronary sinus. Three 30 s ablation lesions were delivered in this area, with a maximum temperature of 50°C and power of 3–5 W. Tachycardia terminated during the first burn, but could be easily reinduced. Although tachycardia could not be reinduced after the second burn, ventricular pacing showed that pathway conduction persisted. Ventriculoatrial block was achieved 0.7 s after commencing the third radiofrequency lesion, a little lateral to the first ablation site (Figure 4).
Table 1 Technical data for the ablation procedures

<table>
<thead>
<tr>
<th>Patient</th>
<th>Tachycardia</th>
<th>Radiofrequency catheter</th>
<th>Tip size (mm)</th>
<th>Tip temperature</th>
<th>Power (W)</th>
<th>Acute success</th>
<th>Recurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PJRT</td>
<td>5F Marinr</td>
<td>4</td>
<td>70°C</td>
<td>10</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>VT</td>
<td>5F Marinr then upsized to 7F Celsius irrigated tip (^a)</td>
<td>4</td>
<td>–</td>
<td>30</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>PJRT</td>
<td>5F Marinr</td>
<td>4</td>
<td>50°C</td>
<td>3–5</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

PJRT, permanent junctional reciprocating tachycardia; VT, ventricular tachycardia.
\(^a\)The temperature of the irrigated tip catheter was not documented.

The patient was successfully weaned from extracorporeal support and decannulated 2 days after the ablation. Cardiac function had recovered completely 6 days after the procedure. There was no tachycardia recurrence on 19 months follow-up (Table 1).

**Discussion**

Although most tachyarrhythmias that present in infancy can be readily controlled with antiarrhythmic drugs, there may be no therapeutic window for drug treatment in some patients with tachycardiomypathy, as drug doses that are adequate to control the arrhythmia may also cause haemodynamic collapse.\(^1\) In these circumstances, extracorporeal membrane oxygenator support provides a stable platform to allow drugs to be given in higher doses or ablation to be carried out.\(^2–6\)

The combination of a beta blocker and loading doses of amiodarone was particularly poorly tolerated in the three cases presented. Our strategy for infants with incessant tachyarrhythmias and cardiomyopathy has therefore changed. In retrospect, the decision to give a second loading dose of amiodarone in case 3 was incorrect. We now use amiodarone as a single agent, without a loading dose, gradually increasing the infusion rate to avoid suddenly compromising cardiac output.

The decision to carry out radiofrequency ablation of a tachyarrhythmia in infancy involves carefully weighing up the likelihood of procedural success, the potential for procedural complications, the likelihood of drug therapy controlling the tachycardia, the chance of spontaneous tachycardia resolution as the child grows older and the probability that complications will occur as a result of prolonged drug therapy and intensive care.

In the largest reported series of infant ablations 88% of tachycardia substrates were eliminated, with a 5% major complication rate and a 0.7% mortality rate.\(^7\) Despite these promising results, ablation is still usually reserved for cases where medical therapy has failed, as complication rates are higher in older children, there is a danger that lesions on the atrioventricular valve ring will cause coronary artery damage\(^8\) and ablation lesions in the ventricle may enlarge as the child grows.\(^9\) However, this may not be the lowest risk strategy as prolonged intensive care may also result in morbidity, such as the pulmonary haemorrhage that occurred in case 1.

Ablation was carried out in case 1 as the tachycardia proved resistant to high-dose amiodarone. In case 2, ablation was undertaken because the tachycardia recurred when extracorporeal support was withdrawn. There is a strong argument for ablation in all cases where extracorporeal support has been instituted and control of the tachycardia cannot be readily achieved with drugs, to avoid the risk of tachycardia recurrence following decannulation, as extracorporeal support is difficult to reinstitute when one carotid artery and jugular vein have already been ligated.\(^2–9\) Ablation was performed in case 3 because doses of antiarrhythmic drugs that were effective in controlling the tachyarrhythmia also caused heart rate slowing to 70/min, which was inadequate to provide sufficient cardiac output for the child to be weaned off extracorporeal support.

Certain alterations to ablation technique were necessary because of the extracorporeal support. Firstly, it was not possible to use the jugular venous approach for vascular access as the superior caval vein was occupied by the venous cannula. Secondly, on extracorporeal support there was minimal flow through the heart, which reduced local convective cooling of the radiofrequency catheter tip. As radiofrequency application is temperature limited, this resulted in low power delivery and reduced thermal injury. Although reducing or stopping extracorporeal flow during radiofrequency applications is a potential solution for this problem, this was only attempted in case 2 and proved ineffective, possibly because low flow persisted owing to poor cardiac function. In these circumstances, an irrigated tip catheter delivered successful higher energy lesions, but we do not advocate its routine use where a standard ablation catheter achieves success, as low-energy burns may also achieve a permanent result. We speculate that low-energy burns may be effective in infants because low-volume lesions may still destroy ablation targets that are much closer to the endocardium in a small heart. Although recurrence rates may well be reduced by using an irrigated tip, we contend that it is more important to avoid the increased risk of cardiac perforation, pericardial effusion, damage to cardiac structures and long-term pro-arrhythmia that is likely to be associated with larger volume deeper lesions. However, operators should be prepared to perform repeat procedures promptly as recurrence rates may be high with temperature limited low power lesions. Thirdly, although it has been suggested that reducing the duration of burns may reduce complication rates,\(^10\) we did not reduce the duration of application below 30 s, as we were concerned that shorter applications would increase recurrence rates, in circumstances where there was potential for haemodynamic decompensation if recurrence occurred after withdrawing extracorporeal support.
Conclusion

Extracorporeal membrane oxygenation is effective in treating haemodynamic collapse secondary to antiarrhythmic drug treatment. It provides a haemodynamically stable and safe platform for radiofrequency ablation of incessant tachycardia in infancy. It can be argued that ablation should be electively performed in those cases requiring extracorporeal membrane oxygenator support when the tachyarrhythmia remains difficult to control with drugs, as ablation in infancy has high success rates and the risk of tachycardia recurrence following decannulation should be avoided.

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References