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ORIGINAL ARTICLE

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Arrhythmia after cone repair for Ebstein anomaly: The Mayo Clinic experience in 143 young patients

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Abstract

Background: The increased incidence of preoperative and postoperative arrhythmia in Ebstein anomaly (EA) prompted some clinicians to perform an electrophysiology study (EPS) in all patients prior to surgery for EA. The cone repair (CR) is the current surgical option of choice for most young patients with EA but the effect of the CR on arrhythmia is not well established.

Objectives: To assess the burden of arrhythmia in young patients after CR and to assess the utility of selective preoperative EPS.

Materials and Methods: A retrospective review of all patients <21 years of age with EA who had a CR at Mayo Clinic from June 2007 to December 2015 was performed. Surveys were mailed and telephone calls were made to all individuals to assess antiarrhythmic medication use and EP/device procedures performed after CR.

Results: There were 143 patients; median age, 10 years (0.1–20.9 years). Thirty-five (24%) patients had a preoperative EPS of which 26 (18%) had a preoperative ablation. Indications for EPS were Wolff–Parkinson–White (WPW), documented arrhythmia, or suspected arrhythmia. Posthospital discharge data were available for 140 (98%) patients. Mean follow-up was 2.9 years (0.1–9.2 years). At follow-up, 7 (5%) patients were receiving antiarrhythmic medications. After CR, only 3 (2%) patients who did not have a preoperative EPS have required an ablation.

Conclusions: The risk of arrhythmia after CR for EA in young patients is very low when a preoperative EPS is limited to those with WPW, known arrhythmia, or suspected arrhythmia. In smaller patients, it may be reasonable to defer the EPS.

KEYWORDS

ablation, arrhythmia, cone repair, Ebstein anomaly, electrophysiology study, pediatric

1 | INTRODUCTION

Ebstein anomaly (EA) results from the failure of proper delamination of the tricuspid valve leaflets from the right ventricle (RV) myocardium.[1] In addition to the tricuspid valve abnormalities, there is invariably some degree of RV (and occasionally left ventricle) myocardial dysfunction. The severity of EA occurs on a spectrum that results in varying degrees of tricuspid regurgitation, atrial dilation, RV dilation, and dysfunction. These effects have the potential to create substrates that can give rise to atrial arrhythmia, ventricular arrhythmia, and a greater incidence of Wolff–Parkinson–White (WPW) syndrome.[2]

The current approach to intervention on the tricuspid valve in EA is the cone repair (CR) as first described by da Silva and adapted by Dearani to provide a more physiologic repair than prior techniques.[3,4] Successful CR has been reported to be as high as 98% in young patients with EA who presented for surgery.[5] This has led to earlier valve repair in many patients. Prior to the CR, tricuspid valve surgery for EA often was delayed until patients were symptomatic or reached

adulthood. In those patients, valve replacement was needed in more than 60% of cases.[6] Delaying repair exposed patients to hemodynamic abnormalities often for decades. The deleterious effect this had on their underlying arrhythmia substrate is unknown.

The greater risk of arrhythmia in the EA population combined with the potential for postoperative surgical changes to make catheter-based arrhythmia intervention more difficult has prompted many clinicians to perform a preoperative electrophysiology study (EPS) in all patients with EA. Furthermore, in 2014, the group from Boston Children's Hospital published data, suggesting that a more aggressive preoperative assessment would be reasonable in all patients with EA.[7] However, what is not clear from the current literature is the effect of earlier CR in young patients on arrhythmia substrate and what the best strategy is for preoperative arrhythmia assessment and/or treatment in these patients. Herein, we present the data from the approach used at Mayo Clinic Rochester with the aim to assess the utility of selective preoperative EPS and to describe the burden of arrhythmia in young patients undergoing CR.

2 | MATERIALS AND METHODS

2.1 | Patient population

The Mayo Foundation Institutional Review Board approved this study. Electronic medical records were reviewed for all patients of <21 years of age with the diagnosis of EA who underwent CR at Mayo Clinic Rochester between June 2007 and December 2015. Data collected included demographics, history of arrhythmia, use of antiarrhythmic medications, surgical procedure details, and details of any EPS/ablations or cardiac rhythm device placement before, during, or after surgery. A follow-up survey was mailed to all patients after CR. If the survey was not returned, a second survey was mailed. A telephone call was attempted for all patients not returning the survey.

The decision to perform a preoperative EPS was at the discretion of treating the team of physicians involved and in some cases it was done prior to referral to the Mayo Clinic. However, the general approach was to perform a preoperative EPS in patients with WPW, known arrhythmia, or suspected arrhythmia. In general, the EPS was electively deferred in smaller patients whose arrhythmia was well controlled preoperatively. The EPS protocols varied from provider to provider but all patients were assessed for inducible atrial arrhythmias, reentrant SVT, and the presence of an accessory pathway. The exact protocol used to assess for ventricular arrhythmias was not always known nor was the ventricular stimulation protocol consistent between the providers. An ablation was attempted if a suitable substrate was noted.

Cone repair was performed by a single surgeon as described previously.[4] The decision to perform an intraoperative Maze procedure, right reduction atrioplasty, bidirectional Glenn, and/or plication of the atrialized RV was made around the time of the operation based on multiple factors such as history of atrial arrhythmias, the degree of atrial and ventricular dilation, the degree of ventricular dysfunction, and appearance of the myocardium of the atrialized RV.

2.2 | Statistical analysis

Basic descriptive statistics were performed. Continuous variables are reported as median and range. Categorical variables are reported as counts and percentage.

3 | RESULTS

3.1 | Patient characteristics

A total of 143 patients with EA <21 years of age had a CR at Mayo Clinic Rochester between June 2007 and December 2015. The median age at the time of CR was 10.0 (0.1–20.9) years and 54% were male. Forty-four patients (31%) had an arrhythmia prior to CR (Table 1).

3.2 | Intraoperative procedures

During CR, 20 (14%) patients had a right atrial maze procedure, 130 (91%) patients had a right reduction atrioplasty, and 94 (66%) patients had plication of the atrialized RV. Forty-nine (34%) patients had a bidirectional Glenn either prior to or at the time of CR.

3.3 | Electrophysiology studies

Thirty-five (24%) patients had a preoperative EPS, resulting in 26 (18%) patients undergoing ablation and 9 (6%) patients had a negative EPS (Figure 1). Thirty-three arrhythmia substrates were targeted for catheter ablation in the 26 patients undergoing preoperative ablation: 2 atrial tachycardias, 1 ventricular tachycardia, 5 AV nodal reentrant tachycardias, and 25 accessory pathways. Of the 9 patients with a negative EPS, 3 had a history of intermittent WPW, 1 patient had a poorly conducting antegrade only accessory pathway with no inducible SVT which was not targeted for ablation, and 5 had no history of arrhythmia nor clinical concern for arrhythmia but rather were studied empirically based on the physician's discretion.

Thirteen patients who had an indication for a preoperative EPS were electively deferred at the discretion of the treating physicians. Two patients were adolescents who went on to have ablations after CR; 1 with a history of intermittent WPW who had a concealed

TABLE 1 Preoperative patients' characteristics

Number of patients: n	143
Median age, years (range)	10.0 (0.1–20.9)
Male, n (%)	77 (54%)
Preoperative arrhythmia: n (%)	44 (31%)
SVT, n (%)	24 (17%)
WPW with SVT, n (%)	15 (10%)
WPW without SVT, n (%)	15 (10%)
Ectopic atrial tachycardia, n (%)	2 (1%)
Atrial flutter/IART, n (%)	1 (1%)
Ventricular tachycardia/fibrillation, n (%)	2 (1%)

Abbreviations: IART, intraatrial reentrant tachycardia; SVT, supraventricular tachycardia; WPW, Wolff–Parkinson–White.

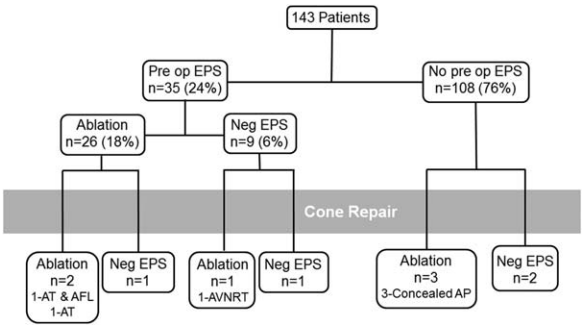

FIGURE 1 EPS before and after CR. Data displayed above the grey bar labeled "Cone Repair" were before CR and data below the grey bar labeled "Cone Repair" were after CR. Abbreviations: AFL, atrial flutter; AP, accessory pathway; AT, atrial tachycardia; AVNRT, atrioventricular nodal reentry tachycardia; EPS, electrophysiology study; Neg, negative

accessory pathway ablation and 1 with a history of SVT who also had a concealed accessory pathway. One EPS was electively deferred because the patient required preoperative ECMO following an out of hospital arrest. This patient had an epicardial ICD placed at the time of CR. The remaining 10 patients whose EPS were electively deferred were done due to small size (Table 2). These 10 patients' ages ranged from 5 days to 4 years and their weights ranged from 2.5 to 17 kg. Eight of the 10 patients were taking antiarrhythmic medication at the time of CR and 9/10 had documented arrhythmia prior to CR (8 with SVT and 1 with AT). At a median follow-up of 4.5 (1.7–7.8) years in these 10 patients, only 1 remains on antiarrhythmic medications, none have had an ablation, and all are alive.

3.4 | Follow-up

Posthospital discharge follow-up data were obtained for 140 (98%) patients. Seventy-two (50%) patients returned a survey or were contacted by phone. The median follow-up was 2.9 (0.1–9.4) years. After CR, 10 patients had an EPS (Figure 1). Five of these 10 patients also had a preoperative EPS. In the 5 patients who had a preoperative EPS, the postoperative EPS was subsequently negative in 2 patients. Three (2%) patients had ablation of 4 arrhythmia substrates that were not previously inducible: focal atrial tachycardia (n = 2), cavotricuspid isthmus atrial flutter (n = 1), and atypical AVNRT (n = 1). In the other 5 patients with no preoperative EPS, the postoperative EPS was negative in 2 patients, and 3 (2%) had an ablation of a concealed accessory pathway.

TABLE 2 Patients ≤17 kg with electively deferred EPS

Number of patients: n	10
Median age, years (range)	1.7 (0.1–4.2)
Median weight, kg (range)	11.1 (2.5–17)
Pre-CR:	
Taking antiarrhythmics pre-CR, n	8
History of SVT pre-CR, n	9
Post-CR	
Median follow-up post-CR, years (range)	4.5 (1.7–7.8)
Taking antiarrhythmics post-CR, n	1
Ablations post-CR, n	0
Death post-CR, n	0

Abbreviations: CR, cone repair; SVT, supraventricular tachycardia.

At last follow-up, 7 (5%) patients were taking antiarrhythmic medications. One patient had SVT and did not have a preoperative study. This patient was taking amiodarone and propranolol. Three patients were being treated with β-blockers for PVCs. Another 3 patients had atrial arrhythmias (atrial tachycardia, atrial flutter, or IART) and 2 were taking sotalol and 1 was receiving β-blocker therapy. No patients had ventricular tachycardia. No patients had known arrhythmia without therapy at follow-up. Two patients had cardiac rhythm devices. One had an ICD placed at the time of the CR for secondary prevention following an out of hospital arrest. This patient has had no VT and no device discharges at last follow-up of 4.5 years. One patient had a pacemaker placed 6 years after CR for sinus node dysfunction and 2:1 AV block.

There were 2 deaths; 1 early postoperative and 1 late. The early mortality occurred in a neonate with EA and pulmonary valve atresia who required ECMO postoperatively owing to poor ventricular function and succumbed to nonarrhythmic complications on postoperative day 6. The late death occurred in an adolescent who was the driver in a motor vehicle accident 2.8 years after CR. This patient had an EPS post-CR and underwent a successful ablation of a concealed accessory pathway. There was no ventricular arrhythmia observed or induced at the EPS.

4 | DISCUSSION

Several studies have documented an increased risk of atrial arrhythmia, ventricular arrhythmia, and WPW (15%–20%) in patients with EA.[2,6–10] Most studies include adult patients and therefore report arrhythmia in older patients who have been exposed to the hemodynamic abnormalities associated with EA for many years. Perhaps not surprisingly there appears to be a higher incidence of atrial arrhythmia both before and after tricuspid valve repair in these prior reports.[10] In addition, there was a higher incidence of ventricular arrhythmia and sudden death reported in these studies.[2,7,9] Our study was limited to patients <21 years of age at the time of CR which may in part account for why we found a much lower rate of atrial and ventricular arrhythmia both before and after CR than compared to other studies. This observation was also suggested by Oh et al.[2] who noted that patients with no preoperative arrhythmia or symptoms were considerable younger and rarely developed tachyarrhythmias postoperatively. Furthermore, Brown et al.[6] found that having an accessory pathway was actually associated with lower mortality. One purposed explanation for this finding was that patients with WPW came to medical attention sooner and were younger at the time of surgery.

Although some clinicians perform a preoperative EPS routinely in all patients with EA, at Mayo Clinic Rochester we have adopted a strategy

in young patients of selective EPS. Our data suggest that by limiting EPS to patients with WPW, known arrhythmia, or those suspected of having arrhythmia based on the history that one can identify and treat nearly all the individuals with underlying arrhythmia. Only 2% of our patients who did not undergo a preoperative EPS went on to have an ablation after CR. When examining these patients more closely, one could argue that 2 of the 3 patients in our study who went on to have an ablation after CR were adolescents that met our criteria for a preoperative EPS and perhaps should have had an ablation preoperatively. Additionally, in the 6 patients who did undergo an ablation after CR, all 7 arrhythmia substrates were successfully ablated despite the postoperative changes: 2 atrial tachycardias, 1 atrial flutter, 3 right-sided concealed accessory pathways, and 1 AV node reentry tachycardia. It is also worth noting that 3 of these 6 patients who had an ablation after CR did not have their arrhythmia (atrial flutter, atrial tachycardia, and AV node reentry tachycardia) induced on their preoperative EP study further emphasizing the limited utility of routine preoperative studies. Furthermore, the number of patients treated medically for arrhythmia at follow-up is also very low at 5%. This includes 1 patient being treated for atrial tachycardia who had a preoperative and postoperative EPS with no inducible arrhythmia and 3 patients treated at the discretion of their provider for PVCs in which the necessity of treatment may be debatable.

Another interesting finding from our data was that in the 10 smaller patients ($\leq$17 kg) for whom a preoperative EPS was electively deferred, despite having an indication based on our criteria, there was a very low incidence of arrhythmia at a median follow-up of 4.5 (1.7–7.8) years. None of these patients have required an ablation postoperatively. Only 1 patient is taking antiarrhythmic medication at the time of last follow-up 1.7 years after CR. This finding of resolution of arrhythmia that presents at a young age is well documented in other patient populations.[11–14] Although the length of follow-up in these patients is insufficient to declare them free of arrhythmia long term, these data suggest that electively deferring ablation in small patients is a reasonable approach particularly, given the increased risk of procedural complications in this population.[15–18]

Ventricular tachycardia and sudden death in EA patients after TV repair is well documented. In one study by Oh et al.[2] published in the pre-CR era, 12% of patients had documented preoperative VT and 10% died suddenly from VF in the hospital or from presumed arrhythmia as an outpatient. In a more contemporary study done in patients undergoing CR, Shivapour et al.[7] noted 2 sudden deaths out of 74 patients prompting further investigation into the need for more aggressive preoperative arrhythmia assessment. However, it should be noted that, while the median patient age in that study (12.1 years) was similar to our study (10 years), older patients were also included and ranged in age up to 56.2 years making direct comparison to our data difficult. In our patient population, there were 2 deaths, 1 early, and 1 late. The early mortality was a nonarrhythmic complication in a neonate on ECMO postoperatively. The etiology of the late mortality is unclear as it was teenage patient who died as the driver in a single car accident and could have been arrhythmogenic. This patient did, however, have an EPS within a year of death and did not have any inducible ventricular arrhythmia. As this was a retrospective review and included EPS data performed by multiple providers the ventricular stimulation protocol used varied and may have been more or less aggressive from patient to patient. Despite this, preoperatively, there were only 2 patients with ventricular arrhythmia 1 of which had an ablation for ventricular tachycardia and 1 of which presented with cardiac arrest and had a defibrillator placed at the time of CR. Furthermore, we found no patients being treated for ventricular tachycardia either medically or with catheter ablation post-CR at follow-up. It is also worth noting that the one patient with an ICD has not had any ICD discharges or documented ventricular arrhythmia. This low incidence of ventricular arrhythmia and sudden death in our cohort of patients differs from that of prior studies. Again, perhaps this is because our study was limited to younger patients and the previous studies have included older patients. Another factor contributing to our outcomes may be that in 66% of patients had plication of the atrialized RV at the time of CR and it is possible this minimized the risk of ventricular tachycardia and sudden death.

5 | LIMITATIONS

This is a retrospective review and decisions about EPS and intraoperative procedures were made by the treating team of physicians which varied by case and hence no protocol was strictly utilized to determine the need for procedures. Additionally, follow-up was limited to $<$10 years after CR. During long-term follow-up, the risk of arrhythmia may increase.

6 | CONCLUSIONS

The development of the CR has allowed for earlier surgical repair in a greater number of young patients with EA. In young patients with EA undergoing CR, a preoperative EPS can be limited to those with WPW, known arrhythmia, or suspected arrhythmia. In smaller patients, it may be reasonable to defer the EPS despite having a clear indication. When taking the above approach, the risk of arrhythmia after CR at follow-up is very low.

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CONFLICT OF INTEREST

None.

AUTHOR CONTRIBUTIONS

All authors read and approved the final version of the manuscript.
Concept/design: Wackel, Johnson, Cetta
Data collection: Wackel, Sessions, Holst, Johnson
Data analysis/interpretation: Wackel, Cetta
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