The Utility of Multimodality Imaging in a Patient with Ebstein Anomaly

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INTRODUCTION

Ebstein anomaly (EA), a congenital heart disease with an anatomic malformation of the tricuspid valve (TV) and right ventricular (RV) myopathy, can present in both children and adults. There is incomplete delamination of the TV from the RV endocardium, resulting in adherence of components of the TV to the RV wall. This usually manifests as apical displacement of the septal leaflet hinge point but can also involve the anterior and posterior leaflets, resulting in the formation of an atrialized portion of the RV that is thin and dilated. The apical displacement of the septal leaflet by at least 8 mm/m^2 is the most sensitive and specific echocardiographic finding for the diagnosis of EA and is often best seen in the apical 4-chamber view.[1] There is vast anatomic heterogeneity in EA due to varying degrees of delamination of the TV and RV atrialization, which can cause a leftward shift of the interventricular septum and can compromise the left ventricular (LV) geometry and hemodynamics, all of which can contribute to a patient's clinical decline. There is also frequent association with other congenital cardiac lesions such as patent foramen ovale, atrial septal defect, mitral valve prolapse, pulmonic stenosis, and pulmonary artery hypoplasia.[2] In addition to these structural lesions, there is a high incidence of tachyarrhythmias, especially related to accessory atrioventricular (AV) pathways.[3] Complex TV and ventricular anatomy and associated lesions can make traditional transthoracic imaging views challenging to interpret and utilize for clinical decision-making. Therefore, multimodality imaging with transthoracic echocardiography (TTE), transesophageal echocardiography (TEE), and cardiovascular magnetic resonance imaging (CMR) or contrast-enhanced cardiac computed tomography is important in the assessment of EA to assess the anatomic and functional status of the TV and right ventricle (RV), identify associated lesions, and plan for operative repair. Even after repair, multimodality imaging is an important tool in the follow-up of these patients for continued surveillance of the repaired or replaced TV and assessment of ventricular function.

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CASE PRESENTATION

A 57-year-old woman with a history of breast cancer now in remission after chemotherapy presented with progressive dyspnea on exertion and palpitations. They were told as a teenager that they had a heart murmur, but they never required any cardiac intervention. The patient has 3 adult children and reported no complications or heart failure symptoms during any of their pregnancies. Although the patient plays golf weekly, they had noted an increase in dyspnea when climbing stairs and when bending down to tie their shoes. They had noted palpitations for several years and were started on beta adrenergic blockade by a prior provider. The patient denied syncope, lightheadedness, dizziness, orthopnea, paroxysmal nocturnal dyspnea, and lower extremity edema.

On exam the patient's blood pressure was 116/72 mm Hg, heart rate was 63 beats per minute, and resting oxygen saturation was 99% on room air. They appeared stated age and were in no distress. There was a holosystolic murmur on exam heard across the precordium without gallops. There was no jugular venous distension or edema. The lungs were clear bilaterally. An electrocardiogram showed low-voltage complexes, normal sinus rhythm with left-axis deviation, and right bundle branch block (Figure 1). There was no delta wave. A TTE was performed; the LV was small and compressed with normal systolic function, and the RV was atrialized with severe (30 mm/m^2, normal <8 mm/m^2) apical displacement of the septal leaflet of the TV (Figure 2, Videos 1 and 2). There was at least moderate tricuspid regurgitation (TR) and an estimated RV systolic pressure of 22 mm Hg. Severe RV dysfunction was seen, and no atrial septal defect was noted on color-flow Doppler. Holter monitor was prescribed given the history of palpitations, and it showed rare premature ventricular contractions. Of note, the patient did not report any symptoms while wearing the Holter monitor. Given the patient's progressive symptoms, an exercise stress test was performed, during which the patient was noted to have a peak exercise oxygen saturation of 99% on room air, suggesting that they did not have intracardiac shunting. However, during testing the patient developed symptomatic ventricular tachycardia at 120 bpm with no associated hypotension that spontaneously converted to sinus rhythm (Figure 1). It was noted that the patient developed their symptom of dyspnea with low levels of exertion before they developed ventricular tachycardia. They were admitted to the hospital given the arrhythmia in the setting of EA. The patient underwent an electrophysiology study, which demonstrated normal sinus and AV node function. Atrioventricular reentrant tachycardia was induced, and the accessory pathway was ablated. Upon follow-up they noted that their palpitations had resolved since ablation.

A CMR was obtained due to persistent symptoms and demonstrated severe EA with severe TR and a regurgitant fraction of 63% (Figure 3, Videos 3 and 4). The anterior leaflet was tethered to the free wall of the RV with multiple attachments, and the septal

VIDEO HIGHLIGHTS

Video 1: TTE, apical 4-chamber view of the LV, demonstrates small compressed LV due to severely enlarged atrialized portion of the RV. The LV systolic function appears normal by visual assessment.

Video 2: TTE, apical 4-chamber view of the RV, demonstrates severe apical displacement of the septal leaflet hinge point (30 mm/m^2). The RV function is challenging to estimate but appears moderately reduced visually.

Video 3: CMR imaging, 4-chamber view. The anterior leaflet has multiple attachments to the RV free wall. The septal leaflet is tethered to the septal wall, and the hinge point is severely apically displaced.

Video 4: CMR imaging, short-axis view of small and tethered septal leaflet and anterior leaflet of TV with multiple attachments to the anterior wall without coaptation causing severe TR jet. Large thin walled "atrialized" RV is seen. Small LV cavity is seen with normal function.

Video 5: CMR imaging view of anterior leaflet demonstrates attachment to the RV free wall through multiple tether points as well as a large mobile posterior leaflet. The RV inflow points toward the RV outflow instead of the RV apex.

View the video content online at www.cvcasejournal.com.

leaflet was small and tethered while the posterior leaflet was normal in size with unrestricted motion (Figure 4, Video 5). The RV systolic function was moderately reduced, with an RV ejection fraction of 39%. The LV was compressed and had normal systolic function, with an LV ejection fraction of 58%. The patient underwent right heart catheterization to evaluate hemodynamics, especially cardiac output, RV end-diastolic and right atrial (RA) pressure, and pulmonary vascular resistance for surgical planning. On right heart catheterization the RA pressure was 15 mm Hg, RV end-diastolic pressure was 15 mm Hg, and mean pulmonary artery pressure was 20 mm Hg with precapillary wedge pressure of 15 mm Hg. The FICK calculated cardiac output was 2.8 L/min, and cardiac index was 1.7 L/min/m^2. The calculated pulmonary vascular resistance was less than 2 Woods units. The patient is currently undergoing planning for TV repair.

DISCUSSION

Since severity in EA is varied, there is a wide clinical presentation of these patients. Those who survive to adulthood, especially prior to diagnosis, generally have less severe forms of the anomaly. However, while they often do well for many years, over time they are at risk for developing heart failure symptoms as well as arrhythmias as demonstrated by our patient case. Heart failure and arrhythmias are the leading causes of morbidity and mortality in the population of adult patients with EA.[4] Ebstein anomaly is associated with accessory pathways, especially those located along the posterior and septal border of the TV where the valve leaflets are most abnormal, which can increase the risk of malignant ventricular arrhythmias. Due to this, electrophysiologic evaluation is necessary in all patients with EA preoperatively. Patients with EA who are pregnant are especially at risk of developing these symptoms and complications during their pregnancy or peripartum. Within the population of pregnant patients with EA, there is also a higher risk of low birth weight and spontaneous abortion.[5]

On the basis of current guidelines, surgical repair or reoperation for adults with EA and significant TR is recommended when there are associated heart failure symptoms, worsening exercise capacity, and/or progressive RV systolic dysfunction.[6] Recent data show an 11% cumulative mortality for patients with mild EA, which is higher than that of the general population.[4,7] Those with complex EA have higher rates of mortality closer to 17%, and those with severe EA have higher rates of early mortality.[4] Overall, patients benefit from surgical intervention, with high survival rates reaching 70% to 80% up to 40 years postoperatively[4] and nearly 90% of patients having an improvement in their functional status postoperatively.[8] Given this, it is important to correctly identify the appropriate clinical window for surgical intervention, which can be difficult given the wide spectrum of disease.

Multimodality imaging is important in the initial assessment of patients with EA as well as in the surgical planning for valve repair or replacement. With multiple and more dense attachments of the anterior and septal leaflets, TV repair becomes challenging, so it is important to fully assess the anatomy and characterize the function of all TV leaflets. Echocardiography is often the first-line diagnostic tool used. Quantitative criteria for diagnosis of EA are the apical displacement of the septal leaflet hinge point at least 8 mm/m^2 or an absolute distance in AV valve offsetting by 20 mm in adults as seen in the apical 4-chamber view.[1,9] Sweeps in the 4-chamber view anteriorly and posteriorly and subcostal short- and long-axis sweeps can help evaluate for TV attachments.[10] In particular, it is important to identify the leaflet attachments, size, and mobility as this can have implications for surgical repair.

Ebstein anomaly is not just a TV issue and is truly a cardiomyopathy, so functional assessment of the RV and TV also needs to be performed prior to surgical intervention. Assessment of TR by TTE alone is difficult in this patient population for a myriad of reasons. For example, leaflet orientation is not the same in patients with EA compared with those without EA, there may be multiple jets of TR, and flow can be laminar in nature due to relatively normal RV systolic pressure in the majority of patients.[1] Imaging with TEE can be useful in analyzing the valve directly in different views (especially transgastric views), but subsequent imaging with CMR, as suggested in the guidelines,[6] provides quantifiable data to fill in gaps from echocardiography. With CMR, accurate quantitative assessment of TR severity can be accomplished along with quantitative assessment of RV size and function as was seen in our patient case. To accurately obtain RV volumes, an axial stack series may need to be utilized instead of relying solely on the short-axis stack because in this patient population the RV inflow can be rotated and angulated toward the RV outflow instead of the RV apex. In addition, detailed images of the TV leaflets can also be acquired, allowing for further characterization of the anterior leaflet motion, size, and attachments.

Several classification systems have been developed to describe the wide spectrum of severity so that the appropriate surgical technique can be chosen. A commonly used system to determine severity is the Celermajer index, which uses the ratio of the functional RA to the sum of the remaining chambers. The functional RA is composed of the anatomic RA and atrialized portion of the RV. If this index is greater than 1.0, it is a poor prognostic factor. This index was originally developed for use in echocardiography but in recent years has been

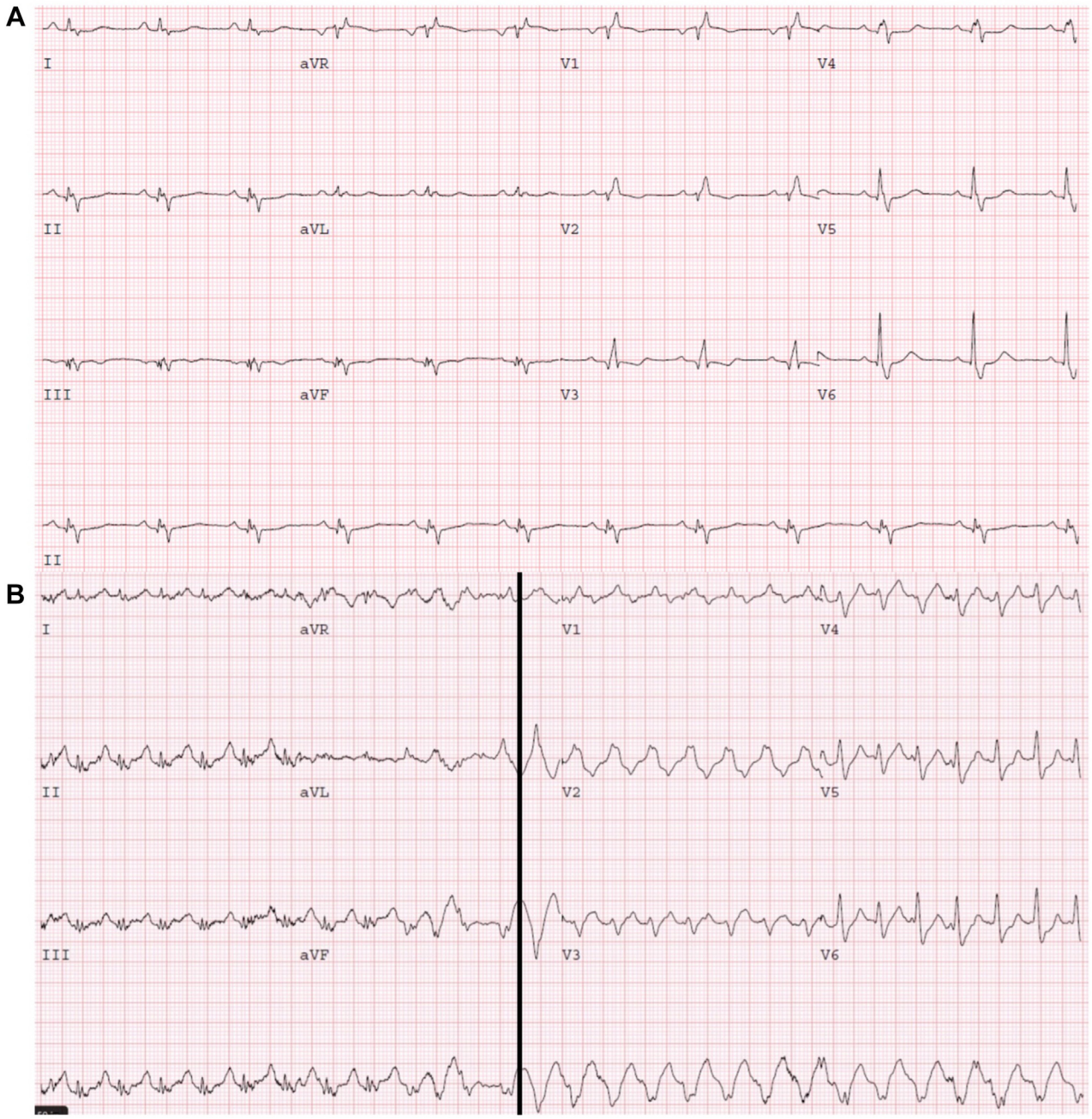

Figure 1 **(A)** Baseline electrocardiogram with normal sinus rhythm and right bundle branch block and **(B)** stress electrocardiogram with development of sustained monomorphic ventricular tachycardia 5 minutes into exercise (*black line*).

applied to CMR as well since CMR can provide accurate quantitative data. Another commonly used system is the Carpentier classification system, which uses anatomic features of the TV to classify differing degrees of valve malformation from class A to D.[11] Class A patients, who have moderate apical displacement with preserved leaflet mobility, require only minimal mobilization of the leaflets without need for plication of the small atrialized RV.[11] On the other end of the spectrum, in class D, the leaflets are adherent to the RV except in the infundibular area, and there is a large atrialized RV, which is severely dysfunctional. Some patients with class D anomaly may not be a candidate for certain surgical repairs.[10,11] These features, as well as features necessary for other classification systems such as the Celermajer index, require both qualitative and quantitative data derived from both echocardiography and CMR.

There are several surgical options available for this patient population. Single-ventricle repair is generally performed in children with severe EA with a severely dysfunctional RV when a biventricular repair is not possible. Surgical intervention in the adult population generally

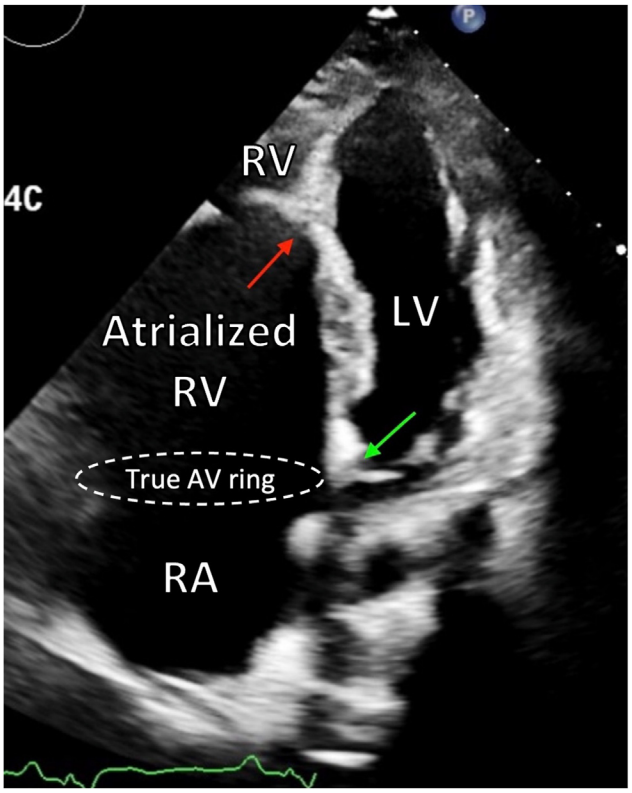

Figure 2 TTE, apical 4-chamber (4C) view at end systole with 50 mm (30 mm/m^2) apical displacement of the septal leaflet hinge point (*red arrow*) in relation to the left AV valve (*green arrow*).

focuses on a 2-ventricle repair with TV repair or replacement. Most modern repairs revolve around the cone reconstruction, where delaminated valve tissue is used to create a cone of tricuspid leaflet tissue that is reattached at the true TV annulus such that leaflet tissue coapts to leaflet tissue, although more conventional monocuspid techniques are still used.[8,12] The RV is also plicated to reduce the size of the functional RV and TV annulus.[8,12] Replacement of the TV can be performed instead of a repair but is generally reserved for older patients when repair is not feasible or satisfactory.[1,12] In patients with a small RV with severe dysfunction, preserved LV function, and normal pulmonary vascular resistance, a cavopulmonary connection (Glenn shunt) can also be performed to offload the RV for what is commonly called a one and a half ventricular repair.[12] Late outcomes of operative intervention are good overall, but these patients can develop valve deterioration as well as heart failure and arrhythmias, which may require reoperation or even consideration of transplant, particularly if there is LV dysfunction.[8,12] Both echocardiography and CMR or cardiac computed tomography provide useful information on the postoperative evaluation of these patients including function of the repaired or replaced TV, RV, and LV function.

CONCLUSION

There is a wide spectrum of disease in patients with EA, making medical management as well as surgical planning difficult. Multimodality imaging plays an important role in diagnosis, follow-up, surgical planning, and postsurgical care of patients with EA.

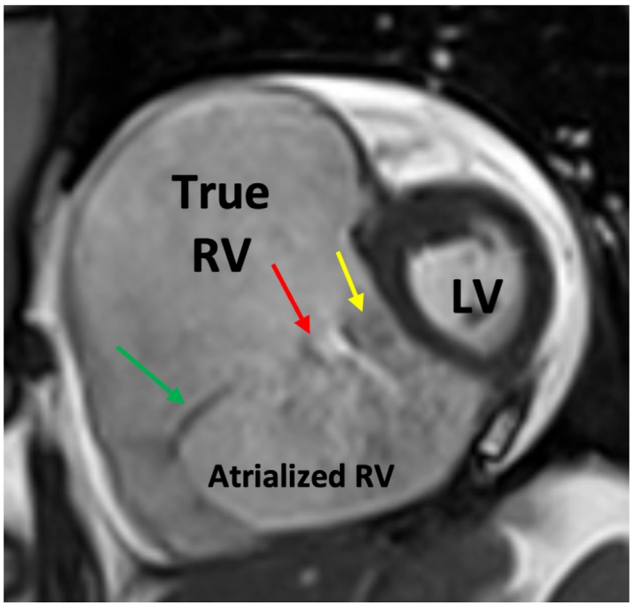

Figure 3 CMR imaging short-axis view of TV in systole with severe TR jet (*red arrow*) due to lack of coaptation of small septal (*yellow arrow*) and tethered anterior leaflets (*green arrow*).

ETHICS STATEMENT

The authors declare that the work described has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

CONSENT STATEMENT

Complete written informed consent was obtained from the patient (or appropriate parent, guardian, or power of attorney) for the publication of this study and accompanying images.

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DISCLOSURE STATEMENT

The authors report no conflicts of interest.

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SUPPLEMENTARY DATA

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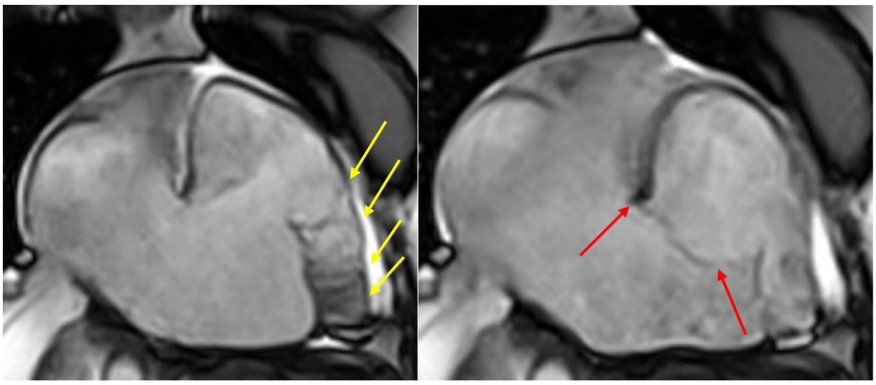

Figure 4 CMR imaging with view of multiple attachment points (*yellow arrows*) between anterior leaflet in diastole (*left*) and RV free wall and large mobile posterior leaflet in systole (between *red arrows*, *right*).

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