# Ebstein Anomaly in the Adult Patient

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**KEYWORDS**

• Ebstein anomaly • Tricuspid valve • Cone repair • Pregnancy • Accessory pathway

**KEY POINTS**

- Ebstein anomaly is a congenital malformation involving primarily apical displacement of the tricuspid valve and right ventricular myopathy.
- Typical presenting symptoms in the adult patient are palpitations, exertional limitation, and cyanosis.
- Echocardiography is the key imaging modality for diagnosis and demonstrates tricuspid valve findings, including apical displacement of the septal leaflet and tethering of the valve to the right ventricular myocardium.
- Tricuspid valve repair is the ideal operative approach and should be considered when there is exertional limitation, cyanosis, and/or progressive right ventricular dilation or dysfunction.
- Pregnancy generally is well tolerated, with risk of right heart failure, arrhythmia, prematurity, and congenital heart disease in the offspring.

## INTRODUCTION

Ebstein anomaly was first described by Wilhelm Ebstein in 1866 in a 19 year old with cardiac cachexia and cyanosis.[1] It is a rare form of congenital heart disease involving primarily the tricuspid valve and right ventricle. It has a wide spectrum of anatomic involvement and clinical presentation. This article focuses on the presentation and management of the adult with Ebstein anomaly.

## EPIDEMIOLOGY

Ebstein anomaly is estimated to occur at a rate of 0.17 to 0.72 per 10,000 live births and has no correlation with gender or race.[2,3] An association with maternal age and multiple gestation pregnancy has been observed in some epidemiologic series but not in others.[2–4] Antenatal exposure to lithium historically has been believed to be a cause of Ebstein anomaly[5]; however, the impact of lithium exposure more recently has been challenged.[6,7]

Ebstein anomaly has been observed to occur at higher rates in some families, including identical twins, suggesting there may be a genetic etiology in a minority of cases.[4,8,9] Mutations in genes encoding sarcomere proteins, including MYH7 and $\alpha$-tropomyosin, have been identified in other affected patients, providing a possible genetic link between Ebstein anomaly and occasionally co-occurring left ventricular noncompaction.[10,11] Most cases of Ebstein anomaly, however, are without identifiable genetic explanation.

## ANATOMY

Ebstein anomaly primarily is characterized by abnormalities of both the tricuspid valve and the right ventricle. There is a wide spectrum of tricuspid valve anatomic derangements possible, and attention to valve morphology is critical to optimally planning surgical intervention and patient management.

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### *Tricuspid Valve*

Formation of the tricuspid valve in utero requires delamination of the valve leaflets, or separation of the leaflet tissue from the underlying myocardium. The tricuspid valve leaflets in Ebstein anomaly demonstrate varying degrees of failure of delamination, leaving them adherent to the right ventricle.[12] The septal and posterior leaflets typically are affected most severely, sometimes with little functional tissue present.[12] The anterior leaflet can be large and sail-like or tethered by fibrous tissue with reduced mobility.[12] Very mobile anterior leaflets often lack appropriate chordal attachment, whereas tethered leaflets may have insertion directly to a papillary muscle or the myocardium.[13] Fenestrations often are present in the anterior leaflet, contributing to tricuspid regurgitation.[14]

In addition to abnormality in the shape and size of the leaflets, the annular attachment of the septal and posterior leaflets is displaced apically, with the point of maximal displacement at the commissure of these 2 leaflets.[13] The functional tricuspid valve orifice thereby is shifted anteroapically toward the right ventricular outflow tract.[12] In most cases, there is severe tricuspid regurgitation related to inability of the abnormal tricuspid leaflets to effectively coapt.[12] Rarely, excessive attachment of the anterior leaflet directly to the myocardium results in tricuspid stenosis or even an imperforate tricuspid valve.[13]

### *Right Ventricle*

Displacement of the tricuspid valve results in 2 portions of the right ventricle. The inlet right ventricle, between the anatomic (nondisplaced) tricuspid annulus and the functional right ventricle, often is referred to as the atrialized right ventricle.[13] This portion tends to become very dilated and often dyskinetic.[12] The atrialized right ventricle receives the tricuspid regurgitation volume load and has to-and-fro flow with the anatomic right atrium, given the lack of a valve between these 2 structures. The resulting volume overload leads to progressive dilation of both chambers.[12] Pathologic specimens frequently demonstrate very thin walls in the atrialized right ventricle that are fibrotic and sometimes entirely lacking in muscular tissue.[13]

The functional right ventricle typically is smaller than normal and sometimes contains only the right ventricular outflow tract.[12] Although its function is better than the atrialized right ventricle, there is an inherent myopathy in patients with Ebstein anomaly, such that even the functional right ventricle may be enlarged and have declining function over time.[15] In the setting of severe right ventricular enlargement, the ventricular septum can be pushed left-ward, causing left ventricular compression, which may contribute to impairment of left ventricular function.[12]

### *Associated Defects*

The most common associated congenital anomaly is atrial septal defect and patent foramen ovale, occurring in more than 80% of patients.[16] Ventricular septal defects and pulmonary stenosis also are observed.[16] Left heart disease of some form occurs in a significant number of patients, in 1 series close to 40%.[17] This includes findings consistent with left ventricular noncompaction (most common, with a potential genetic link, described previously), abnormalities of left ventricular systolic or diastolic function, and left-sided valve disease, including mitral valve prolapse and bicuspid aortic valve.[17] Left-sided valve disease has been observed to occur at rates above the general population, suggesting a nonrandom association. Accessory conduction pathways occur frequently in Ebstein anomaly, in 5% to 25% of patients,[18] and Wolff-Parkinson-White syndrome is associated more commonly with Ebstein anomaly than any other form of congenital heart disease.[19]

## CLINICAL MANIFESTATIONS

### *Symptoms*

Although often diagnosed by prenatal ultrasound or in early childhood, many patients present with a new diagnosis of Ebstein anomaly in adulthood. Palpitations are a common presenting symptom. One series of adults with unoperated Ebstein anomaly demonstrated arrhythmia in 51% at the time of presentation.[20] Some adult patients report symptoms of heart failure, including dyspnea, fatigue, and lower extremity edema.[12] Exercise intolerance can occur due to reduced right ventricular function and severe tricuspid regurgitation or related to exercise-induced cyanosis from right-to-left shunting across the atrial septum. Paradoxic embolism through an atrial septal defect or patent foramen ovale also can occur, especially in the setting of severe tricuspid regurgitation, and present as stroke or transient ischemic attack, brain abscess, or myocardial infarction.[21]

### *Physical Examination*

The physical examination, like the clinical presentation, is dictated in large part by the severity of pathology. Young children with severe disease present with signs of heart failure and severe cyanosis.[12] Adults generally have a milder

phenotype than children and less profound symptoms. Careful attention to the physical examination can provide clues to the diagnosis.

Despite the presence of severe tricuspid regurgitation in most cases, the jugular venous pulse typically is normal, without prominent V wave. This is related to the very large right atrium and atrialized right ventricle accommodating tricuspid regurgitation without transmitting pressure to the jugular vein.[22] Failure of the right ventricle may lead to rise in the mean jugular venous pressure, but a prominent V wave and systolic pulsation of the liver are not expected.[23] Additionally, despite significant right ventricular enlargement, the parasternal impulse of the right ventricle typically is subtle.[22]

On auscultation, the first heart sound usually is split with delayed tricuspid valve closure (T1), due to both a right bundle branch block and the large anterior leaflet, which takes longer to fully close.[23] T1 typically is loud, related to increased tension in the anterior leaflet as it reaches its fully closed position; this often is referred to as the sail sound.[23,24] If the anterior leaflet is very mobile, there can be multiple closure sounds that mimic ejection clicks.[12] The second heart sound is split, again due to right bundle branch block. There often is a third and/or fourth heart sound present.[23]

Tricuspid regurgitation results in a holosystolic murmur at the lower left sternal border that increases with inspiration. Paradoxically, many adults have a very soft or absent systolic murmur due to severe regurgitation with rapid equalization of pressure across the tricuspid valve. A diastolic murmur of increased flow across the tricuspid valve occasionally can be appreciated,[24] although clinically this is heard infrequently in adult patients.

## DIAGNOSTIC FEATURES

### *Electrocardiogram*

The electrocardiogram (ECG) of a patient with Ebstein anomaly can reveal multiple abnormal findings (**Fig. 1**), including the following:

- Right atrial enlargement, with the so-called Himalayan P waves[22]
- Right bundle branch block, often with fragmented QRS complexes (a second QRS complex attached to the related to infra-Hisian conduction disturbance and abnormal activation of the atrialized right ventricle[25]
- PR prolongation, resulting from atrial dilation and delayed intra-atrial conduction[26]
- Low-voltage QRS in right-sided chest leads, secondary to generalized right ventricular myopathy[27]
- Supraventricular tachycardia and atrial arrhythmias

Apical displacement of the septal tricuspid valve leaflet results in discontinuity of the central fibrous body and septal atrioventricular (AV) ring.[23] This disruption of the AV connection creates the potential for accessory pathways.[25] In these cases, pathologic specimens demonstrate muscular tissue that passes through the fibrous tissue at the hinge of the tricuspid leaflet, thereby forming a bridge from the atrial wall to the ventricular

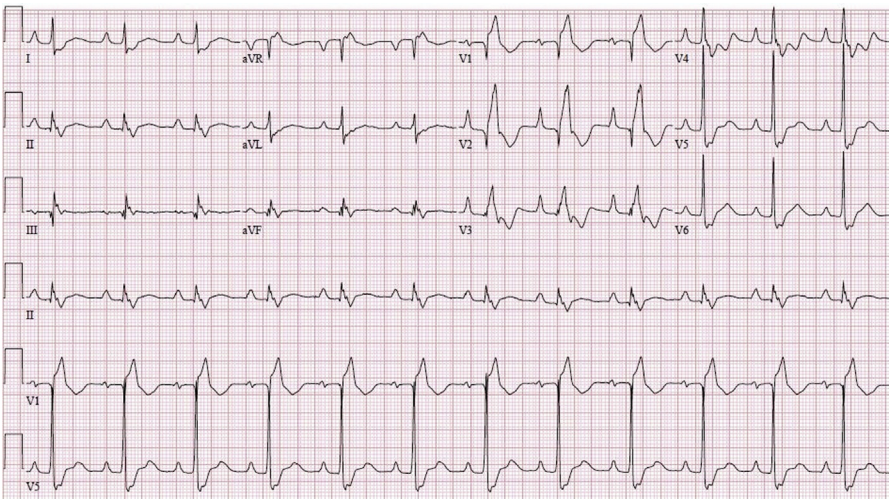


**Fig. 1.** ECG of a 43-year-old man with Ebstein anomaly, demonstrating right atrial enlargement (as seen by the tall, peaked P waves), first-degree AV block (PR interval 224 ms), and right bundle branch block with fragmented QRS complex (fragmentation defined as >2 notches in the R or S wave in 2 contiguous leads). (*From* Das MK, Zipes DP. Fragmented QRS: a predictor of mortality and sudden cardiac death. *Heart Rhythm.* 2009;6(3 Suppl):S8-14.)

myocardium.[28] In Ebstein patients with reentrant tachycardia, 30% are found to have more than 1 accessory pathway.[18] Electrographically, patients with accessory pathways may demonstrate evidence of preexcitation, with left bundle branch block and predominant S wave in the right precordial leads (Fig. 2).[25] In other cases, preexcitation can be subtle, with short PR interval and loss of the typical right bundle branch block.[18]

In addition to accessory pathway–mediated tachycardia, patients with Ebstein anomaly have a high incidence of atrial arrhythmias. ECG in these cases may reveal atrial fibrillation, typical atrial flutter, atrial tachycardia (incisional, after repair), or, less commonly, AV nodal reentrant tachycardia.[18,19] Although relatively uncommon, sudden death related to ventricular arrhythmias recently has been recognized to occur in this patient population more frequently than realized previously.[29] It is important to differentiate wide complex tachycardia related to aberrantly conducted atrial fibrillation from ventricular tachycardia.[18]

### *Chest Radiograph*

Chest radiograph findings vary depending on the severity of disease. In cases of significant right heart enlargement, chest radiograph demonstrates right atrial enlargement and marked cardiomegaly with a globular contour[22] (Fig. 3). The great arteries generally are small with a subtle aortic shadow, creating a narrow vascular pedicle.[22,23]

### *Echocardiogram*

Transthoracic echocardiography is the test of choice for the evaluation of a patient with suspected Ebstein anomaly. Echocardiogram can confirm the diagnosis, assess the severity of disease, and identify other associated anomalies. The echocardiographic diagnosis of Ebstein anomaly involves demonstrating apical displacement of the septal leaflet, which is best assessed in an apical 4-chamber view (Fig. 4D). Calculation of the displacement index involves measuring the distance between the mitral and septal tricuspid hinge points, which then is indexed to body surface area. A displacement index greater than 8 mm/m$^2$ has been demonstrated to be a sensitive predictor of Ebstein anomaly.[30]

In addition to apical displacement, echocardiography in Ebstein anomaly demonstrates evidence of failure of delamination of the tricuspid valve leaflets. Leaflet tethering, defined as 3 or more attachments to the ventricular wall that impede leaflet motion, is expected and usually affects the septal and inferior leaflets more than the anterior leaflet.[15,31] In severely affected valves, there may be little mobility of the septal and inferior leaflet. It is important to use multiple echo imaging windows to completely assess the tricuspid valve anatomy (Fig. 4). The anterior and septal leaflets often are viewed best in the apical 4-chamber view, whereas the inferior leaflet may be better assessed using an right ventricular inflow view.[15] Due to distortion of valve anatomy, nonstandard imaging planes may be needed to adequately

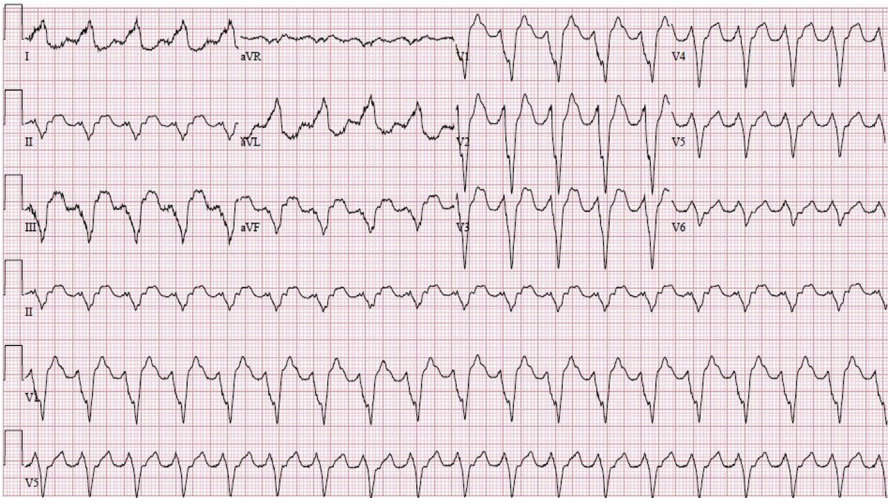


**Fig. 2.** ECG of a 16-year-old girl with Ebstein anomaly, Wolff-Parkinson-White syndrome, and prior pathway ablation, presenting with palpitations. ECG demonstrates wide complex tachycardia with left bundle branch block morphology and prominent S wave in the right precordial leads. The patient was found to be in supraventricular tachycardia.

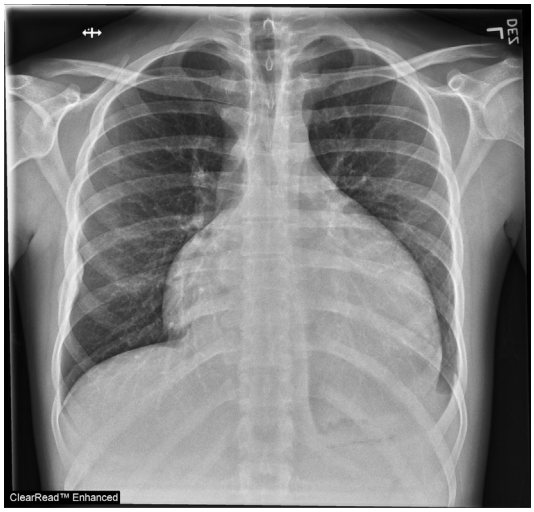


**Fig. 3.** Chest radiograph of a 19-year-old man with Ebstein anomaly demonstrating marked cardiomegaly with clear lung fields and subtle aortic shadow.

assess all 3 valve leaflets. When anticipating surgical repair of the tricuspid valve, thorough visualization and description of all 3 leaflets are important to allow for appropriate surgical planning.[14]

The demonstration and quantification of tricuspid regurgitation can be challenging. Distorted valve anatomy means that the origin of the regurgitant jet may be very near the apex in an apical 4-chamber view, and therefore can be missed by placing the color Doppler box closer to the anatomic annulus. There often are multiple jets of tricuspid regurgitation and they may be oriented inferiorly, because the valve orifice frequently is angled toward the right ventricular outflow tract.[15] In this case, regurgitation may be best demonstrated in the parasternal short axis or subcostal view.[15] Quantification methods used for other forms of tricuspid regurgitation are less helpful in cases of Ebstein anomaly. The large, compliant right atrium and atrialized right ventricle, as well as right ventricular dysfunction, result in a low-velocity tricuspid regurgitation signal with rapid equalization of pressures.[23] Systolic reversal of flow in the hepatic veins is not common due to the compliant right atrium accommodating regurgitant flow.[15] In the setting of multiple jets of regurgitation, quantification with vena contracta and proximal isovelocity surface area is challenging. Optimal assessment, therefore, involves careful 2-dimensional (2-D) assessment of valve structure, color Doppler interrogation of visualized coaptation defects, and semiquantitative grading of all regurgitant jets.[15]

Attention also should be paid to the size and function of the right heart. An enlarged right atrium is expected, and in some cases can be severely enlarged.[22] The atrialized right ventricle is myopathic, appearing dilated, thin, and dysfunctional.[15] Traditional echocardiographic assessments of right ventricular function, including

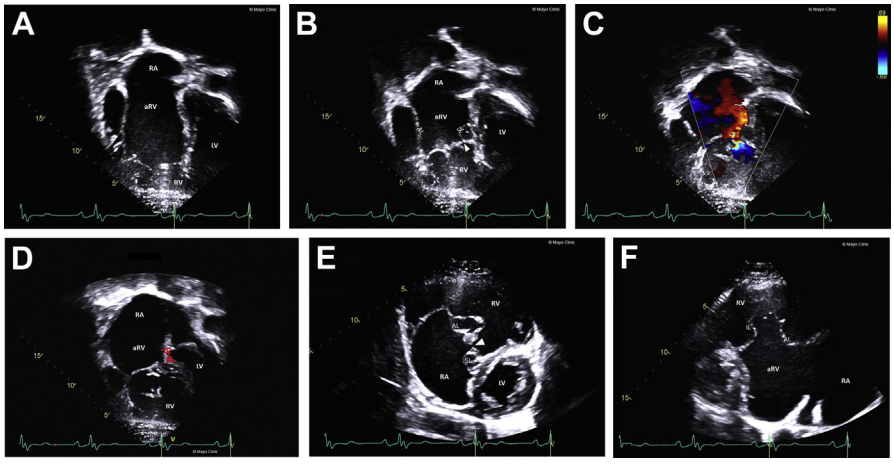


**Fig. 4.** Transthoracic echocardiographic images from a patient with Ebstein anomaly. Apical 4-chamber view (apex down format) in diastole (*A*), systole (*B*), and color Doppler (*C*), showing severe right heart enlargement, apical displacement of the septal leaflet, tethering of the anterior leaflet, coaptation defect (*B* [*arrowhead*]) and the origin of tricuspid regurgitation (*C*). (*D*) Measurement of apical displacement of the septal leaflet in a modified apical 4-chamber view. (*E*) Parasternal short axis view at the midventricle showing large, tethered anterior leaflet and rudimentary septal leaflet with coaptation defect (*arrowhead*). (*F*) Parasternal RV inflow view demonstrates anterior and inferior leaflets. AL, anterior tricuspid valve leaflet; aRV, atrialized right ventricle; IL, inferior tricuspid valve leaflet; LV, left ventricle; RA, right atrium; RV, right ventricle; SL, septal tricuspid valve leaflet.

lateral tissue Doppler and tricuspid annular plane systolic excursion, are of limited use in the assessment of the Ebstein ventricle, because the small functional right ventricle is primarily responsible for systolic function.[15] Qualitative visual assessment of the ventricular size (relative to the left ventricle) and function generally is used.

Echocardiography may demonstrate other associated anomalies. Careful inspection of the atrial septum should be performed, given the high incidence of atrial septal defect and patent foramen ovale. If imaging is suboptimal, agitated saline can be used to detect the presence of a right-to-left atrial-level shunt.[32] Close assessment of left ventricular function is important. Left ventricular dysfunction can occur in patients with Ebstein anomaly, either due to inherent myopathy or related to marked right ventricular dilation.[17]

Transesophageal echocardiogram generally is not required for diagnosis and evaluation of Ebstein anomaly. It can be helpful to better delineate tricuspid valve and atrial septal anatomy when transthoracic imaging is suboptimal due to limited acoustic windows.[15] It is used routinely during surgical intervention to assess anatomy prior to and after operation.

### *Cardiac Magnetic Resonance Imaging*

Data obtained from cardiac magnetic resonance imaging (MRI) in patients with Ebstein anomaly are complementary to echocardiographic assessment, and both modalities often are appropriate to evaluate these patients. Cardiac MRI can quantify right heart size and function more easily,[33] which may be of use when deciding on a management strategy for a particular patient. When comparing the assessment of right ventricular function by echocardiography and MRI, only 2-D global longitudinal right ventricular strain correlates with cardiac MRI–derived right ventricular ejection fraction.[34] Cardiac MRI also can better demonstrate the inferior tricuspid leaflet anatomy in some patients.[33] Echocardiography remains the test of choice to evaluate the degree of tricuspid regurgitation and to identify other associated cardiac anomalies.[15] For patients who cannot undergo MRI, cardiac computed tomography also can be utilized to assess ventricular volumes and ejection fraction.[15] It also is useful for the preoperative assessment of the coronary arteries.

## TESTING AFTER DIAGNOSIS

### *Exercise Test*

Exercise testing in patients with Ebstein anomaly can provide an objective measure of functional capacity[35] and is helpful especially in adult patients with no reported symptoms. Exercise performance has been demonstrated to decline in patients with Ebstein anomaly and at least grade 2 tricuspid regurgitation who are managed medically.[36] Monitoring oxygen saturation at rest and during exercise also provides important information. Resting oxygen saturation is a major predictor of maximal oxygen uptake with exercise as well as peak exercise oxygen saturation.[37] Exercise-induced cyanosis may be demonstrated in the presence of right-to-left shunt and can be a major cause of exertional symptoms.

### *Cardiac Catheterization*

Cardiac catheterization is not required for the diagnosis of Ebstein anomaly, and hemodynamic assessment usually is not necessary when making management decisions.[22] In select cases of bidirectional cavopulmonary shunt considered, hemodynamic catheterization may be indicated to assess left ventricular end-diastolic pulmonary artery pressures.[12] Coronary angiography should be performed prior to surgical repair for patients with an intermediate or high pretest probability of coronary disease.[35]

### *Electrophysiology Evaluation*

The need for specialized electrophysiology evaluation is dependent on historical features and noninvasive testing. Due to the high rate of atrial arrhythmias in Ebstein anomaly, both a resting ECG and an ambulatory ECG monitor should be performed as part of the baseline assessment.[35] Patients with a history of unexplained syncope, documented supraventricular tachycardia (excluding atrial fibrillation), sustained ventricular tachycardia, or ventricular preexcitation should be seen by a congenital electrophysiologist and may benefit from an electrophysiologic study.[38] In addition, an electrophysiology study often is performed as part of preoperative planning prior to tricuspid valve repair or replacement.[35] Sudden death increasingly has been recognized as a threat to this patient population, with risk factors including prior ventricular tachycardia, heart failure, syncope, and pulmonic stenosis.[29] Some patients should be considered for primary prevention implantable cardioverter-defibrillator (ICD).

## MANAGEMENT

All adults with Ebstein anomaly should be followed at a center with expertise in caring for adults with congenital heart disease. Patient management involves monitoring over time as well as consideration of surgical intervention and arrhythmia

treatment, depending on an individual patient's course.

### Monitoring

Most patients with Ebstein anomaly should be seen annually in an adult congenital heart disease clinic, with assessment of heart failure, cyanosis, and arrhythmia. Testing at the annual visit should include pulse oximetry, ECG, and echocardiogram. Patients with moderate or greater functional limitation should have annual Holter monitoring and an exercise test; it may be appropriate for patients with no or mild cardiac symptoms to be tested every 2 years to 3 years. Cardiac MRI, assessing right heart size and function as well as tricuspid valve anatomy and regurgitation, should be performed every 1 year to 2 years in patients with significant functional impairment and every 3 years to 5 years in patients with no or mild symptoms.[35]

Medical therapy does not have a prominent role in the management of patients with Ebstein anomaly; those patients with symptoms should be referred for surgical intervention. Despite the high prevalence of right ventricular dysfunction and not infrequent associated left ventricular dysfunction, there are no studies to date supporting the use of traditional heart failure medications in Ebstein anomaly.[39] Diuretics can be used to manage heart failure prior to surgery or if a patient is not a surgical candidate. Pharmacologic management of rhythm disturbances can be considered where otherwise indicated. Endocarditis prophylaxis is indicated if the patient has cyanosis, a prosthetic heart valve, or a history of endocarditis.[35]

### Indication for Surgery

Surgery is recommended for adults with Ebstein anomaly who have significant tricuspid regurgitation as well as one of the following: heart failure symptoms, worsening exercise capacity, and progressive right ventricular dysfunction. Surgery also can be considered in the setting of progressive right ventricular enlargement, cyanosis from right-to-left shunt, paradoxic embolism, and atrial arrhythmia.[35]

### Surgical Management

Tricuspid valve repair is the goal of operative intervention where possible.[14] Repair techniques have undergone significant evolution since first performed in the 1970s. Early repairs by Danielson and colleagues[40] and Carpentier and colleagues[41] involved using the anterior leaflet to create a monocuspid valve. The current repair technique is the cone reconstruction, introduced by da Silva and colleagues in 2007[42] and subsequently modified by Dearani.[43] This technique involves mobilizing the septal and posterior leaflet tissue as well as the anterior leaflet, creating a 360° cone that is reattached at the true annulus.[14,42] Relative contraindications to tricuspid valve repair include technical factors (absent septal leaflet, poor delamination of the anterior leaflet, and severe dilation of the tricuspid annulus) as well as clinical factors (age >55–60 years, moderate pulmonary hypertension, and left ventricular ejection fraction <30%).[12] When tricuspid valve repair is not feasible, tricuspid valve replacement should be performed. Bioprosthetic valve is favored over mechanical prosthesis. Tricuspid valve bioprosthesis in Ebstein anomaly have demonstrated good durability.[44] Compared with Ebstein patients with mechanical prostheses, those with a bioprosthesis have similar operation-free survival and better overall 20-year survival.[45] Because tricuspid valve replacement can be performed quickly without cross-clamp, it is an attractive option for patients with poor biventricular function.[12] The tricuspid prosthesis often is placed above the anatomic annulus in the right atrium in an effort to avoid injury to the conduction tissue and the right coronary artery, leaving the coronary sinus to drain into the right ventricle.[12] This is an important consideration should biventricular pacing be pursued in the future.

In the setting of severe right ventricular dilation and dysfunction, a 1.5-ventricle repair with creation of a bidirectional cavopulmonary shunt can be pursued to off-load the right ventricle. Although uncommon in Ebstein anomaly, pulmonary hypertension should be excluded prior to shunt creation, especially in patients where left ventricular diastolic dysfunction is suspected.[14] Shunt creation also can be considered for patients with tricuspid valve stenosis after repair. Data from a high-volume center demonstrate that patients undergoing bidirectional cavopulmonary shunt creation have very good long-term survival and a low rate of reoperation.[46] Caution should be exercised when combining bioprosthetic tricuspid valve replacement and bidirectional cavopulmonary shunt due to concern for bioprosthetic valve thrombosis, which occurs with increased frequency in patients with a large prosthesis and low-flow state.[46]

If present, atrial septal defect or patent foramen ovale should be closed at the time of operative intervention. This primarily is to address the risk of paradoxic embolism. In patients with severe right ventricular dysfunction, leaving an atrial septal fenestration is sometimes employed to

provide a pop-off for the dysfunctional right ventricle. Although useful in infants and young children, this generally should be avoided in the adult patient.[12]

Outcomes of tricuspid valve repair vary based on patient characteristics, the operative repair strategy, and where the surgery is performed. A European multicenter study of 150 patients undergoing a variety of surgical approaches at different centers cited an overall operative mortality of 13.3%, although all mortalities were in children under the age of 10, many of whom underwent palliative surgical procedures.[47] Patients in that series had a 76% complication rate, most commonly postoperative arrhythmia, delayed sternal closure, and low cardiac output. In contrast, a review of 539 patients undergoing operative management at Mayo Clinic, with mean age 24 years, revealed an overall 30-day mortality of 5.9%, improving to 2.7% for those undergoing surgery after 2001.[16] A later series reviewing 235 Mayo Clinic patients who underwent cone repair demonstrates very low early mortality (0.4%) and 98% freedom from reoperation at 6 years.[43] The findings of both series demonstrate that at an experienced center valve repair or replacement is safe, and most patients do well long term. Risk factors for poor surgical outcome include right or left ventricular systolic dysfunction, right ventricular outflow tract obstruction, and elevated hemoglobin and hematocrit.[16] For patients undergoing operative intervention, survival free of reoperation is 74% at 10 years and 46% at 20 years, with most patients reporting good functional status.[48]

### *Atrial Septal Defect Device Closure*

In most cases, an atrial septal defect or patent foramen ovale should be addressed surgically at the time of tricuspid valve intervention. Uncommonly, a patient with Ebstein anomaly has tricuspid regurgitation but prominent right-to-left shunting across the atrial septum at rest or with exercise. In this case, percutaneous device closure of the atrial septal defect or patent foramen ovale can be considered. Studies have demonstrated that this is feasible and safe and that most patients have improvement in exertional capacity.[49,50] In the setting of significant right ventricular dysfunction, careful hemodynamic assessment with balloon test occlusion is required to ensure that shunt closure is tolerated.[49]

### *Indication for Reoperation*

In a patient with prior tricuspid valve repair, reoperation should be considered for severe tricuspid regurgitation with declining exercise capacity, progressive right ventricular dilation or dysfunction, or the onset or progression of atrial or ventricular arrhythmia.[22] Patients with a tricuspid bioprosthesis should be considered for re-replacement in the setting of significant regurgitation with associated symptoms, severe stenosis (mean gradient >12–15 mm Hg), or progressive, nonsevere stenosis in the presence of symptoms.[22]

As an alternative to operative intervention, patients with a tricuspid valve prosthesis can consider percutaneous valve-in-valve implantation. An international multicenter registry of 81 Ebstein patients undergoing valve-in-valve replacement demonstrated successful deployment in all patients with no procedural mortality.[51] There was a 5% rate of acute valve thrombosis and of endocarditis, with 8 patients requiring reintervention (percutaneous or surgical) to address valve dysfunction. The long-term outcomes in this cohort of patients are not yet known.

### *Arrhythmia Management*

As reviewed previously, all patients with Ebstein anomaly should have baseline ECG and ambulatory ECG monitor due to the high incidence of cardiac arrhythmias in this population. Those patients with symptomatic rhythm disturbances, unexplained syncope, or documented ventricular preexcitation should be referred for electrophysiologic study.[35,38] A series of patients undergoing cone repair revealed that, in those having preoperative electrophysiologic studies, 69% had a significant electrophysiologic finding, even in the absence of symptoms or ventricular preexcitation.[52] Because of the high prevalence of (sometimes multiple) accessory pathways in this patient population, it is recommended that electrophysiology study be considered prior to surgical intervention for symptomatic patients. Pathway ablation, if required, is performed more easily prior to tricuspid valve surgery. Additionally, the identification of atrial fibrillation or flutter allows for operative planning of surgical atrial ablation.

Although most atrial arrhythmias in Ebstein patients are amenable to catheter ablation, these ablations can be challenging due to presence of multiple pathways and related to technical issues around the dysplastic tricuspid valve and annulus. In a multicenter series of 32 Ebstein patients undergoing catheter ablation, procedural success rates were 80% to 100%, but 56% of the cohort ultimately required repeat ablation of the same or a different rhythm disturbance.[53] If catheter ablation is unsuccessful or not technically feasible, surgical ablation can be pursued at the time of tricuspid

valve operation, in some series with high success rates and few operative complications.[19,54]

A single-center series of 968 patients with Ebstein anomaly demonstrated the 70-year cumulative incidence of sudden death to be 14.6%.[29] Predictors of sudden death in this population were history of ventricular tachycardia, heart failure, tricuspid valve surgery, syncope, pulmonic stenosis, and hemoglobin greater than 15 g/dL. To date, there are no guidelines regarding primary prevention ICD in this patient population[38]; however, risk stratification and individualized decision making are appropriate.

### *Pregnancy*

The normal hemodynamic changes of pregnancy involve an increase in cardiac output and blood volume up to 50% above baseline by 32 weeks of pregnancy. The inability to augment cardiac output in the setting of right ventricular systolic dysfunction and tricuspid regurgitation predisposes patients with Ebstein anomaly to heart failure, especially in the third trimester of pregnancy.[55] Arrhythmias can occur, driven by both an underlying predisposition and hemodynamic and hormonal changes.[56] In patients with atrial-level shunt, cyanosis can occur or worsen and contribute to symptomatic limitation as well as fetal growth restriction.[55] Paradoxic embolism is a concern given enhanced hypercoagulability during pregnancy and potential immobility during pregnancy or after delivery.

Despite the potential morbidity, most patients with Ebstein anomaly tolerate pregnancy without significant complications. A single-center series of 111 pregnancies in 44 women (including 20 with atrial-level shunt and 16 with cyanosis) found no maternal mortality or significant adverse cardiac events.[57] A multicenter series reviewing only the hospitalization for delivery demonstrated that, compared with patients without Ebstein anomaly, Ebstein patients had more frequent major adverse cardiac events, most commonly heart failure and atrial arrhythmias, with an incidence of approximately 10%.[58]

Obstetric and fetal outcomes also are a consideration. Most series suggest that preterm delivery is more common in patients with Ebstein anomaly compared to the general population, with preterm delivery rates reported as 20% to 27%.[57,58] Maternal cyanosis is known to contribute to low fetal birth weight and mortality.[57,59] There is increased risk of congenital heart disease in the fetus when the mother has Ebstein anomaly, observed to be 4% to 6%, depending on the series.[48,59] The impact of paternal Ebstein anomaly is less certain but may contribute to slightly increased risk of fetal congenital heart disease.[57] Pregnancies complicated by parental Ebstein anomaly should be managed with fetal echocardiogram at approximately 20 weeks of pregnancy.[35]

## SUMMARY

Ebstein anomaly is a rare congenital malformation that involves primarily abnormalities of the tricuspid valve and a right ventricular myopathy. Echocardiography is the diagnostic procedure of choice, demonstrating the myocardium, tricuspid valve anatomy, and regurgitation. Common associated lesions include atrial septal defect and patent foramen ovale. Other right and left heart congenital anomalies are associated with Ebstein anomaly, including ventricular septal defect, pulmonary stenosis, left ventricular noncompaction, and left heart valve abnormalities. Tricuspid valve cone repair is the optimal surgical approach when valve anatomy is suitable, and intermediate follow-up data suggest that this approach can provide a durable repair in most patients. Bidirectional cavopulmonary shunt can off-load the right ventricle and allow for repair in patients with severe right ventricular dysfunction. Arrhythmias are common in Ebstein anomaly, including accessory-pathway and atrial arrhythmias, and patients have a lifelong risk of sudden cardiac death. Electrophysiology study should be performed in the setting of symptoms, preferably prior to operative intervention. Pregnancy generally is well tolerated, and the risk of congenital heart disease in the fetus is approximately 4%. Patients with Ebstein anomaly require lifelong follow-up at a specialized adult congenital heart disease center.

## DISCLOSURE

The authors have nothing to disclose.

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