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Case Report

J Med Cases. 2025;16(8):277-281

Thinking Outside the Box: Case Report of a Rare Quadricuspid Aortic Valve as an Underrecognized Cause of Heart Failure and Atrial Fibrillation

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Abstract

Quadricuspid aortic valve (QAV) is a rare congenital anomaly with an estimated incidence of 0.008% to 0.043% based on autopsy and echocardiographic studies. Although often asymptomatic, it can lead to progressive aortic regurgitation (AR), left ventricular (LV) dysfunction, and arrhythmias such as atrial fibrillation (AF). Due to its rarity, QAV is often misdiagnosed or discovered incidentally, highlighting the need for advanced cardiac imaging in young patients presenting with unexplained heart failure symptoms and arrhythmias. We present the case of a 41-year-old female patient who was admitted with new-onset dyspnea classified as New York Heart Association (NYHA) class III and palpitations due to persistent AF with a European Heart Rhythm Association (EHRA) symptom class 2b. There was no family history of congenital or structural heart disease, with arterial hypertension being the only identified predisposing condition. Initial transthoracic echocardiography revealed moderate AR, but more detailed transesophageal echocardiography performed before pulmonary vein isolation incidentally revealed a QAV. Further cardiac magnetic resonance imaging confirmed normal aortic root dimensions with early LV remodeling. The patient was managed conservatively with rate control, anticoagulation, and regular follow-up to monitor disease progression. This case highlights the importance of advanced imaging techniques in the diagnosis of rare structural heart abnormalities in young patients presenting with unexplained heart failure symptoms and arrhythmias. Early identification of QAV allows for timely medical intervention, optimal patient monitoring, and prevention of long-term complications. Regular follow-up is essential to monitor disease progression and determine the need for surgical intervention.

Manuscript submitted June 14, 2025, accepted July 18, 2025
Published online August 7, 2025

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doi: https://doi.org/10.14740/jmc5153

Keywords: Quadricuspid aortic valve; Congenital heart disease; Aortic valve dysfunction; Aortic regurgitation; Atrial fibrillation

Introduction

Quadricuspid aortic valve (QAV) is a rare congenital malformation with an estimated prevalence between 0.008% and 0.043% [1]. Historically diagnosed post-mortem or during valve surgery, advances in echocardiography and cardiac imaging have significantly improved detection rates [2]. Despite its rarity, QAV is clinically significant due to its frequent association with aortic regurgitation (AR), left ventricular (LV) remodeling and in some cases, arrhythmias such as atrial fibrillation (AF). Over time, these structural abnormalities can result in hemodynamic disturbances, LV volume overload, and ultimately heart failure. In addition, QAV may be associated with other congenital anomalies, including coronary artery malformations, hypertrophic cardiomyopathy, subaortic stenosis, patent ductus arteriosus, ascending aorta coarctation, and ventricular septal defects [3-5]. The embryological origins of QAV remain uncertain, but proposed mechanisms include abnormal septation of the conotruncus, defective mesenchymal proliferation, or incomplete division of the valve cusps [6]. The Hurwitz and Roberts classification system describes seven morphological subtypes, of which type B (three larger and one smaller cusp) is the most common [7]. The classification ranges from type A (four equal cusps) to type G, with variations based on the relative size and symmetry of the cusps. Type C, as observed in our patient, consists of two larger and two smaller cusps. These morphological differences are clinically relevant, as asymmetric cusp configurations, especially in types B through G, can lead to unequal leaflet stress, impaired coaptation, and a higher likelihood of developing aortic regurgitation over time. Clinically, many patients with QAV remain asymptomatic for years, with symptoms often occurring in middle adulthood due to progressive valvular dysfunction [8]. The primary pathological consequence of QAV is AR, which can often require valve replacement in the fifth or sixth decade of life if it progresses [1]. While transthoracic echocar-

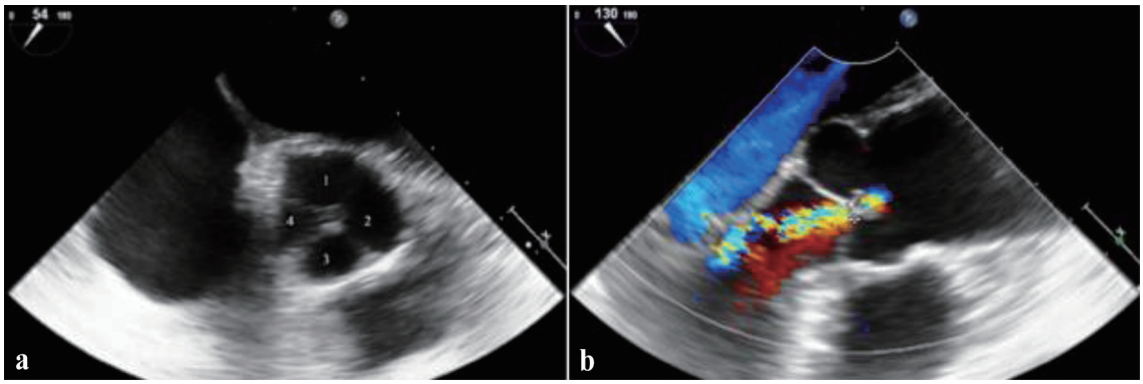

Figure 1. Transesophageal echocardiography views of the aortic valve. (a) Mid-esophageal short-axis view at 54°, demonstrating a quadricuspid aortic valve (Hurwitz and Roberts type C) with four distinct cusps. The individual cusps are labeled to aid visualization. (b) Mid-esophageal long-axis view at 130° with color Doppler, showing central aortic regurgitation jet consistent with moderate aortic insufficiency.

diography (TTE) is the initial diagnostic tool, transesophageal echocardiography (TEE) provides superior visualization, and cardiac magnetic resonance (CMR) imaging or computed tomography angiography (CTA) may further aid in assessment. Management of QAV varies from observation in asymptomatic cases to surgical intervention in those with severe regurgitation or LV dysfunction. Early detection and regular follow-ups are crucial for optimizing patient outcomes, especially given its potential for progressive deterioration.

Case Report

A 41-year-old female patient presented to the emergency department with new-onset dyspnea in New York Heart Association (NYHA) class III and palpitations attributed to AF with a European Heart Rhythm Association (EHRA) score of 2b. She denied chest pain, syncope, alcohol consumption, or tobacco use and reported no symptoms suggestive of obstructive sleep apnea. Her medical history was notable only for arterial hypertension and her body mass index was 24.3 kg/m^2. There was no known family history of congenital or structural heart disease.

Physical examination revealed an arrhythmic heart rate of 110 beats per minute. Auscultation identified a grade II/VI high-pitched, early diastolic decrescendo murmur at the left third-fourth intercostal space along the sternal border. A resting electrocardiogram showed AF with a rapid ventricular response. Laboratory tests showed an N-terminal pro-B-type natriuretic peptide (NT-proBNP) level of 780 pg/mL and normal levels of troponin and thyroid hormones. TTE demonstrated moderate AR with a pressure half-time of 390 ms and a preserved LV ejection fraction (LVEF) of 55%, without evidence of LV dilation. Given the patient's young age, the presence of AF, and unexplained symptoms in the absence of severe AR, further cardiovascular imaging was performed. TEE confirmed the presence of a QAV with Hurwitz and Roberts type C morphology and moderate AR based on an integrative semi-quantitative assessment, including a vena contracta of 0.31 cm and a pressure half-time of 390 ms (Fig. 1). Due to AF and suboptimal conditions for volumetric assessment, a comprehensive quantitative evaluation could not be reliably performed. CMR imaging showed normal aortic root dimensions, no evidence of significant aortopathy, and preserved LV function with early remodeling changes (Fig. 2). The severity of AR was classified as moderate in the CMR report; however, no quantitative parameters such as regurgitant volume or regurgitant fraction were documented. The presence of symptoms such as exertional dyspnea and persistent AF, together with elevated NT-proBNP values and an H_2FPEF score of 6 indicated a high probability of heart failure with preserved ejection fraction (HFpEF) being the underlying disease. The patient was initiated on guideline-directed medical therapy for HFpEF and anticoagulated with apixaban (CHA_2DS_2-VASc score of 3) to reduce the risk of thromboembolic events. Despite medical management, she continued to experience episodes of AF. Given her young age, recent-onset AF, and the presence of moderate AR, rhythm control was preferred over rate control to preserve atrial contraction and optimize diastolic filling [9]. Therefore, pulmonary vein isolation via catheter ablation was performed successfully.

As the patient remained asymptomatic from a valvular standpoint, a conservative approach was adopted with close cardiological follow-up and serial echocardiographic monitoring. Given the diagnosis of QAV and its potential for progressive AR, we established a structured follow-up strategy with echocardiographic evaluations every 6 months and provided patient counseling on infective endocarditis precautions. Future surgical intervention may be considered in the event of progressive AR or LV dysfunction.

Discussion

This case underscores the importance of a thorough cardiovascular workup in young patients presenting with unexplained heart failure symptoms and arrhythmias. Although bicuspid aortic valve remains the most common congenital anomaly of

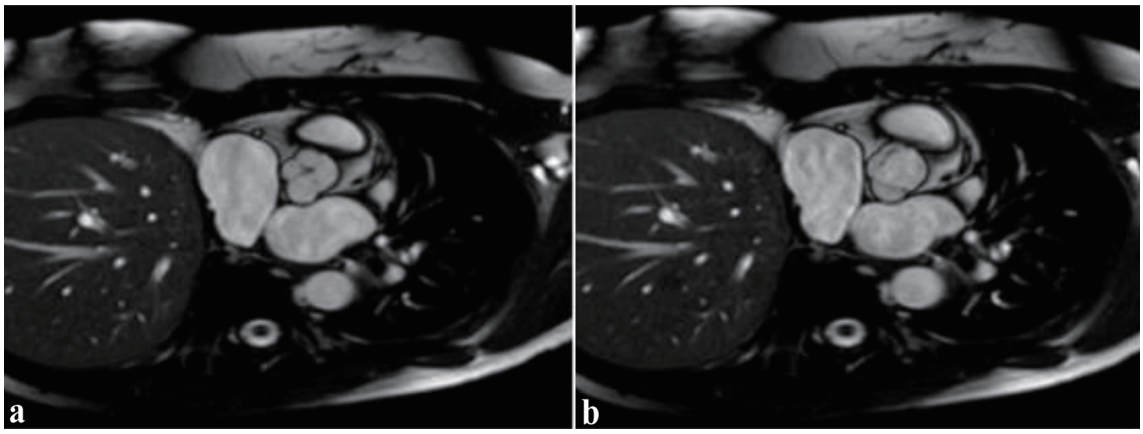

Figure 2. Cardiac magnetic resonance imaging in short-axis view demonstrating quadricuspid aortic valve morphology. (a) Diastolic phase: incomplete cusp coaptation with central aortic regurgitation orifice, consistent with moderate aortic regurgitation. (b) Systolic phase: the aortic valve leaflets are fully open, visualizing four distinct cusps.

the aortic valve, rarer entities such as QAV should also be considered, particularly in cases of unexplained AR [10]. In such scenarios, reliance on TTE alone may lead to underdiagnosis. Therefore, advanced imaging modalities like TEE or CMR should be employed to enhance diagnostic accuracy and detect subtle congenital abnormalities.

Our case highlights the diagnostic overlap between valvular heart disease and HFpEF. QAV is often associated with AR due to impaired cusp coaptation leading to progressive LV volume overload and remodeling. Prolonged volume stress may also result in left atrial dilation, predisposing to arrhythmias such as AF, even in the absence of overt ventricular dysfunction. While AF is a common arrhythmia in valvular heart disease, its presence in a young patient with no known structural heart disease warrants further imaging to rule out congenital anomalies such as QAV. A major challenge with QAV is its frequent under-diagnosis on routine echocardiography. TTE, although widely used, has limited sensitivity for detecting QAV. To date, no large-scale studies have reported specific sensitivity values for TTE or TEE in diagnosing QAV, likely due to the rarity of the condition. Most available data stem from case reports or small series, which describe TTE as having limited sensitivity, especially when short-axis imaging is suboptimal [11]. TEE is consistently regarded as superior to TTE for visualizing cusp morphology and remains the preferred modality for definitive diagnosis [2]. Although CMR offers high spatial resolution and is non-invasive, it may not consistently provide the same level of detail regarding cusp structure. Therefore, the two modalities should be considered complementary. In addition, CMR and CTA play a crucial role in the assessment of LV function, aortic root dimensions, and associated cardiovascular abnormalities, particularly when surgical planning is required. Management of QAV depends on the severity of AR and associated symptoms. Asymptomatic patients with mild to moderate AR can be managed conservatively with regular echocardiographic follow-up to monitor progression. In cases of progressive LV dilatation or worsening LV function, surgical intervention should be considered. Although specific long-term data in QAV are limited, most patients with QAV-related AR progress to require intervention (66.7% in small series), usually between the fifth and sixth decades [12, 13]. Five- and 10-year survival rates after surgery are excellent (about 90% and 85%, respectively) [14]. Current guidelines recommend valve surgery for symptomatic patients with severe AR, or for asymptomatic patients with LVEF $\leq$ 50%, LV end-systolic diameter (LVESD) > 50 mm, or indexed LVESD > 25 mm/m^2 [15]. Valve replacement remains the most common treatment; however, valve-sparing procedures and transcatheter aortic valve implantation have been explored in selected cases [16-19]. While QAV does not inherently increase the risk of infective endocarditis, abnormal cusp coaptation can create turbulent flow that could theoretically favor bacterial colonization [20]. However, guidelines do not recommend routine antibiotic prophylaxis in these patients [21].

Beyond structural and hemodynamic considerations, accumulating evidence points to the role of immune cell activation and inflammation in the progression of cardiovascular disease. In both congenital and acquired valvular disorders, immune mechanisms, such as monocyte infiltration, T-cell subpopulation dynamics, and the interplay between innate and adaptive immunity, may contribute to valvular degeneration and myocardial remodeling [22-24]. While such processes have not been specifically studied in QAV, they may represent an underrecognized aspect of disease progression and offer a valuable direction for future research.

Conclusion

Early identification of rare congenital anomalies such as QAV is crucial in young patients presenting with unexplained heart failure symptoms and arrhythmias. Multimodal cardiac imaging, combined with structured diagnostic tools such as the H_2FPEF score, can uncover overlapping etiologies such as moderate AR and HFpEF. Conservative management may be appropriate in stable patients, but close follow-up is essential to monitor for disease progression. Delayed or missed diagnosis may lead to progressive valvular dysfunction and irrevers-

ible LV remodeling, ultimately necessitating earlier surgical intervention. Further research is warranted to better define the long-term outcomes of valve-sparing and minimally invasive interventions in patients with QAV.

Acknowledgments

None to declare.

Financial Disclosure

This research received no specific grant from any funding agency.

Conflict of Interest

The authors declare that they have no conflict of interest.

Informed Consent

Written informed consent was obtained from the patient for the publication of this case report.

Author Contributions

Conceptualization: Klevis Mihali and Marcus Bauer; writing manuscript: Klevis Mihali and Julian Kreutz; writing review and editing: Birgit Markus, Bernhard Schieffer, and Marcus Bauer; visualization: Klevis Mihali and Marcus Bauer; supervision: Julian Kreutz, Birgit Markus, and Bernhard Schieffer. All authors have read and agreed to the published version of the manuscript.

Data Availability

The authors declare that all data generated or analyzed during this case are included in this article.

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