ESC European Society of Cardiology
European Heart Journal - Case Reports (2025) **9**, ytaf256
https://doi.org/10.1093/ehjcr/ytaf256

ECG CHALLENGE
Electrophysiology

Cardiopulmonary exercise testing surprise: deciphering a shifting QRS axis in right isomerism—electrocardiogram challenge

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Received 6 January 2025; revised 11 March 2025; accepted 12 May 2025; online publish-ahead-of-print 24 May 2025

Clinical vignette

An 8-year-old boy presented for a treadmill cardiopulmonary exercise testing (CPET). He is followed in our paediatric cardiology unit for a univentricular heart resulting from an unbalanced atrioventricular septal defect (AVSD) with a hypoplastic right ventricle, transposition of the great arteries (TGAs), and total anomalous pulmonary venous return (TAPVR). This congenital heart defect occurred in the context of right isomerism (midline liver, asplenia, right-sided stomach). At 6 months of age, he underwent surgical correction of his TAPVR and a bidirectional superior cavopulmonary anastomosis. At 4.5 years, he completed a total cavopulmonary connection with fenestration, which was subsequently closed at the age of 6.

Nowadays, at 8 years old, he is clinically doing well. Echocardiography shows good single ventricle function, mild-to-moderate atrioventricular (AV) valve regurgitation, and a well-functioning cavopulmonary connection. The CPET was performed as part of his routine clinical follow-up. His resting electrocardiogram (ECG) is shown in *Figure 1*, panel *A*. The CPET was uneventful, and the patient demonstrated good exercise capacity given his cardiac condition (peak VO_2: 34 mL/kg/min; 9.7 metabolic equivalents of task (METs); maximum heart rate: 162 b.p.m., and 87% of the predicted value). However, the physician was surprised by an abrupt change in the QRS axis observed during exercise (see Supplementary material online, *Figure S2*), most prominent during the recovery phase (see *Figure 1*, panel *B*).

Questions

Question 1

The resting ECG shows sinus rhythm, first-degree AV block, a QRS axis of 83°, and repolarization abnormalities. Based on this patient's cardiac anatomy, which ECG feature would you expect to observe?

A. High-amplitude (>2.5 mm) P wave in Lead II
B. Left axis deviation
C. Complete AV block
D. Left bundle branch block
E. Giant T waves

Answer: B

Patients with AVSD are characterized by deficiencies in the atrial septum primum and the inlet portion of the ventricular septum. These anomalies result in a posterior displacement of the conduction system, which is located near the ostium of the coronary sinus (see Supplementary material online, Figure *S1A*). Consequently, the left bundle branch is displaced posteriorly and inferiorly, and the left anterior fascicle is often hypoplastic. This configuration typically leads to a characteristic left axis deviation.[1]

Question 2

What is the best hypothesis for the change in QRS axis observed during the treadmill CPET?

A. A block in the left anterior fascicle during exercise with conduction through the left posterior fascicle.
B. A complete AV block with a junctional rhythm originating from the posterior fascicle.
C. A re-entrant AV tachycardia with an anterograde limb involving a posterior atrio-fascicular tract.
D. The presence of two AV nodes, where the anterior AV node has a longer refractory period than the posterior one.
E. A sudden change in blood circulation due to the total cavopulmonary connection, causing the heart's apex to shift upwards during exercise, resulting in a superior axis.

Answer: D

In heterotaxy syndrome, patients with complete AVSD may have two AV nodes (with two His signals visible on electrophysiological studies): one situated in an anterosuperior position and the other located in a posteroinferior position[2] (see Supplementary material online, *Figure S1B*). Alternatively, a sling of conduction tissue may be present,

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Handling Editor: Rachel M.A. ter Bekke
Peer-reviewers: Ewout Boesaard; Antonius Peter Gorgels

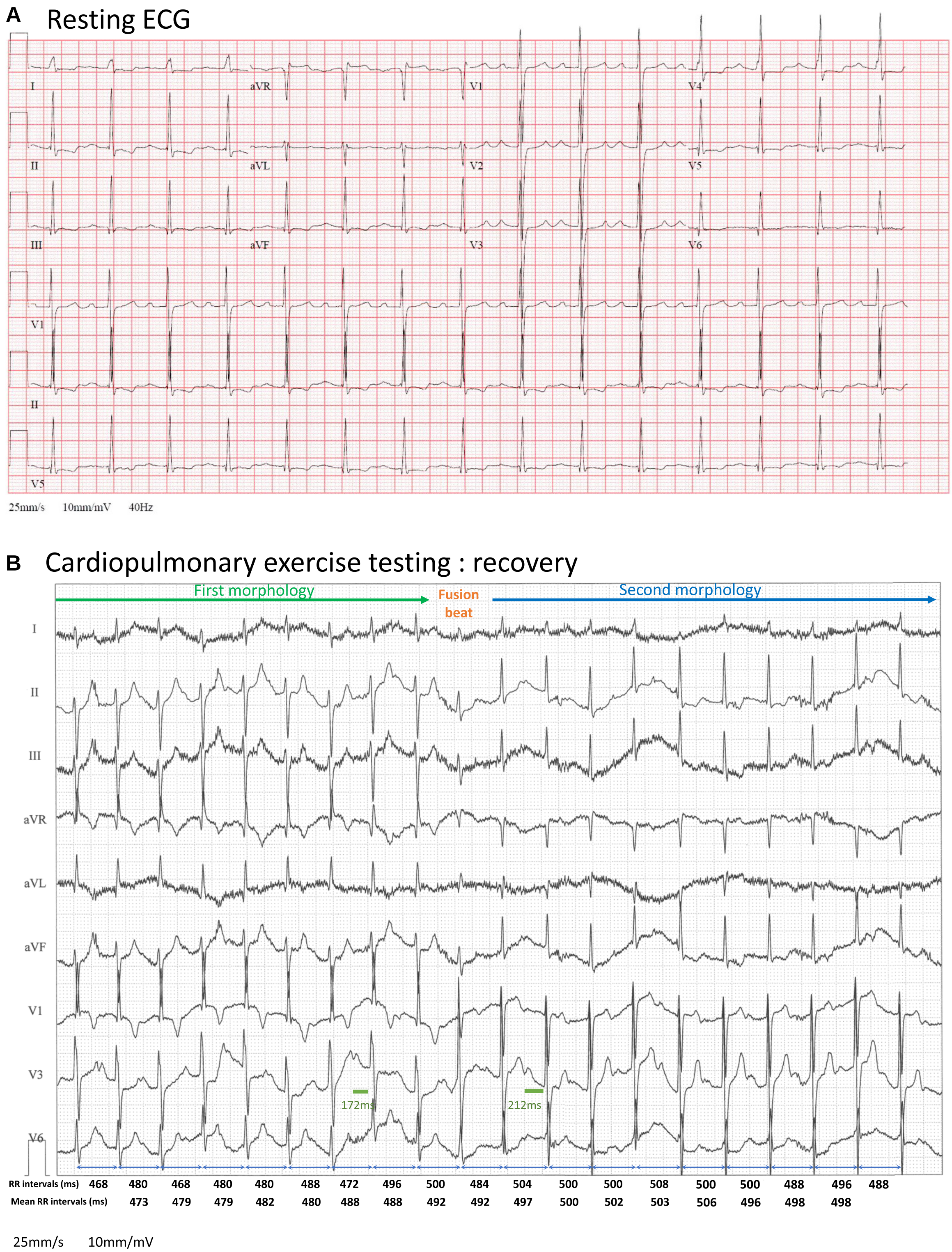

Figure 1 (*A*) Resting electrocardiogram showing atrial rhythm, first—degree atrioventricular block, a QRS axis of approximately +90°, and repolarization abnormalities. (*B*) Electrocardiogram recorded during recovery after cardiopulmonary exercise testing, illustrating an abrupt shift in QRS axis—from approximately −80° during exertion (green) to approximately +80° as the heart rate decreases (blue). A fusion beat is visible between the two QRS morphologies. RR intervals are indicated, along with the mean RR interval calculated over three consecutive beats.

referred to as the Mönckeberg sling[3] (see Supplementary material online, *Figure S1C*).

The two AV nodes often have distinct electrical properties, including different refractory periods, which can be precisely evaluated during electrophysiological studies. This dual-node configuration can lead to varying ventricular activation patterns depending on which AV node is conducting.

In this case, at an atrial rate of ∼120 b.p.m. (RR interval 500 ms), the Wenckebach period of the anterior AV node was reached, while the posterior AV node continued to conduct, resulting in a change in QRS morphology (see Supplementary material online, *Figure S1D*). During recovery, as the heart rate decreased and fell below the Wenckebach point of the anterior AV node, conduction resumed through it, restoring the resting QRS morphology (see Supplementary material online, *Figure S1F*). A fusion beat can also be observed, likely resulting from simultaneous conduction through both AV nodes (see Supplementary material online, *Figure S1E*).

The presence of two AV nodes can also result in a rare but often unrecognized arrhythmia known as twin AV node re-entrant tachycardia, where one AV node serves as the anterograde limb of the tachycardia and the other as the retrograde limb.

Question 3

All cardiac and non-cardiac anomalies listed below are typically associated with right isomerism, except one. Which one is the exception?

A. A transverse liver
B. Asplenia
C. Two trilobed lungs
D. Duplicated sinus node
E. Interruption of the inferior vena cava

Answer: E

In the context of isomerism, interruption of the inferior vena cava (IVC) with azygos continuation is a hallmark feature of **left isomerism** rather than right isomerism. Right isomerism, characterized by bilateral right-sided structures, is more commonly associated with systemic venous anomalies such as abnormal positioning of the IVC or total anomalous pulmonary venous connection, but not with IVC interruption. Other typical cardiac anomalies in right isomerism include duplicated sinus nodes, AV canal defect, and TGAs. Extracardiac manifestations include asplenia, which increases susceptibility to infections, bilateral trilobed lungs, a midline or transverse liver, and malrotation of the intestines. However, it is not uncommon for patients to present with incomplete or atypical manifestations of the syndrome, making diagnosis and management more challenging.[4,5]

Supplementary material

Supplementary material is available at *European Heart Journal – Case Reports* online.

Consent: The patient's parent provided informed consent for the use of the patient's medical information for publication purposes, with all identifying details removed to ensure anonymity, in compliance with COPE guidelines for ethical publishing.

Conflict of interest. None declared.

Funding: None declared.

Data availability

The data underlying this article are available in the article and in its online supplementary material.

References

1. Kertesz NJ. The conduction system and arrhythmias in common atrioventricular canal. *Prog Pediatr Cardiol* 1999;**10**:153–159.
2. Walsh EP, Cecchin F. Arrhythmias in adult patients with congenital heart disease. *Circulation* 2007;**115**:534–545.
3. Mönckeberg JG. Zur entwicklungsgeschichte des atrioventrikularsystems. *Verhand Deutsch Path Gesell* 1913;**16**:228–249.
4. Yim D, Nagata H, Lam CZ, Grosse-Wortmann L, Seed M, Jaeggi E, et al. Disharmonious patterns of heterotaxy and isomerism: how often are the classic patterns breached? *Circ Cardiovasc Imaging* 2018;**11**:e006917.
5. Jacobs JP, Franklin RCG, Béland MJ, Spicer DE, Colan SD, Walters HL III, et al. Nomenclature for pediatric and congenital cardiac care: unification of clinical and administrative nomenclature—the 2021 International Paediatric and Congenital Cardiac Code (IPCCC) and the Eleventh Revision of the International Classification of Diseases (ICD-11). *World J Pediatr Congenit Heart Surg* 2021;**12**:E1–E18.