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Open Access Case Report

Quantitative Assessment of Right Ventricular Pacing-Associated Mechanical Dyssynchrony After Dual-Chamber Leadless Pacemaker Implantation: A Case Report

Review began 10/25/2026
Review ended 11/07/2026
Published 11/14/2026

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DOI: 10.7759/cureus.119677

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Abstract

Right ventricular (RV) myocardial pacing can produce non-physiological ventricular activation and mechanical dyssynchrony even when atrioventricular synchrony is preserved by a dual-chamber leadless pacing system. We report a 79-year-old man receiving maintenance hemodialysis who underwent implantation of an AVEIR DR Dual Chamber Leadless Pacemaker System for 2:1 atrioventricular block. During atrial-sensed RV pacing, the QRS duration increased from 142 ms at baseline to 202 ms. Transthoracic echocardiography during intrinsic ventricular conduction showed no visually apparent intraventricular mechanical dyssynchrony, whereas follow-up echocardiography 11 days after implantation demonstrated left ventricular wall motion suggestive of mechanical dyssynchrony during RV pacing. Gated myocardial perfusion single-photon emission computed tomography (SPECT) phase analysis performed during ventricular pacing demonstrated marked mechanical dyssynchrony, with a phase standard deviation of 33.7 degrees, a 95% histogram bandwidth of 113.0 degrees, and a phase entropy of 76.34 %. Several days later, device programming was modified to permit intrinsic ventricular conduction, and a second SPECT study was performed during intrinsic 2:1 atrioventricular conduction at 39-40 beats/min, with ventricular backup pacing set at 30 beats/min. The corresponding phase indices were substantially lower at 9.1 degrees, 35.0 degrees, and 44.55%, respectively. Because the patient's overall clinical status and hemodialysis-related conditions differed between the two examinations, the observed numerical differences cannot be attributed to pacing alone. Nevertheless, the concordant and marked changes across all phase indices provide objective evidence supporting RV pacing-associated mechanical dyssynchrony. This case highlights the potential value of gated SPECT phase analysis as a quantitative method for assessing mechanical synchrony after leadless pacemaker implantation.

Categories: Nuclear Medicine, Cardiology, Healthcare Technology
Keywords: electrical and mechanical dyssynchrony, gated spect imaging, leadless pacemaker implantation, phase analysis, right ventricular pacing

Introduction

Leadless pacemakers avoid complications associated with generator pockets and transvenous leads and are particularly attractive in patients receiving maintenance hemodialysis, in whom infection risk and preservation of central venous access are important considerations. The AVEIR DR Dual Chamber Leadless Pacemaker System (Abbott Medical, Sylmar, CA, USA) provides dual-chamber leadless pacing with atrioventricular synchrony through communication between atrial and ventricular devices [1,2]. However, the ventricular device still stimulates the right ventricular (RV) myocardium outside the native His-Purkinje conduction system. As with conventional RV myocardial pacing, this non-physiological activation sequence may prolong the QRS complex and produce ventricular mechanical dyssynchrony [3,4].

Electrocardiographically gated myocardial perfusion single-photon emission computed tomography (SPECT) phase analysis estimates the regional onset of mechanical contraction and provides quantitative indices, including phase standard deviation (Phase SD), 95% histogram bandwidth, and phase entropy [5-7]. These parameters reflect the dispersion of regional left ventricular contraction timing, with higher values generally indicating greater mechanical dyssynchrony. This technique enables objective quantification of mechanical dyssynchrony and may provide additional information beyond conventional echocardiographic assessment. We report a patient in whom RV pacing-associated mechanical dyssynchrony after AVEIR DR implantation was quantitatively evaluated by serial-gated myocardial perfusion SPECT phase analysis under ventricular-paced and intrinsic-conduction conditions.

Case Presentation

Initial presentation and leadless pacemaker implantation

A 79-year-old man undergoing maintenance hemodialysis for diabetic kidney disease was transferred to our hospital after bradycardia was noted at his dialysis clinic. His medical history included diabetes mellitus, hypertension, and previous endoscopic treatment of descending colon cancer. On admission, his blood pressure was 185/62 mmHg, heart rate was 49 beats/min, and oxygen saturation was 96% on room air. He had no dyspnea or chest pain.

Electrocardiography showed 2:1 atrioventricular block, complete right bundle branch block, right-axis deviation, and a native QRS duration of 142 ms (Figure *1*).

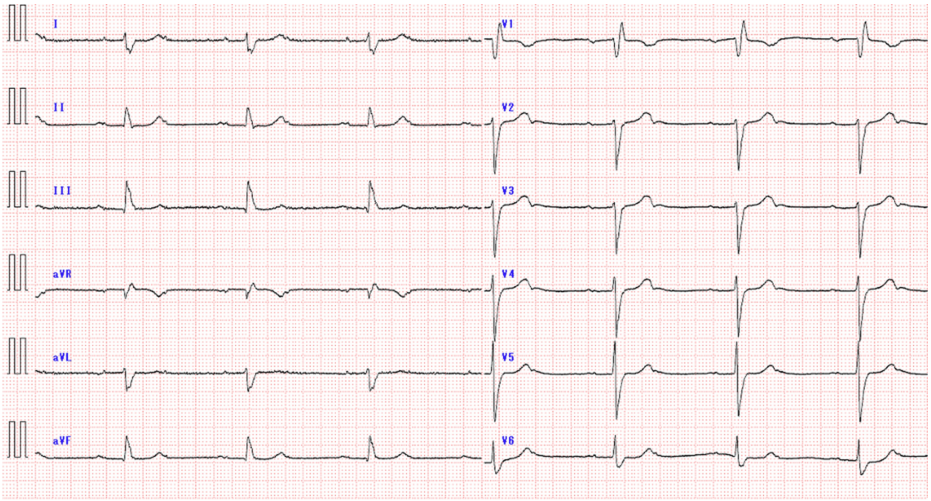


FIGURE 1: Twelve-lead electrocardiograms during intrinsic conduction

During intrinsic conduction, electrocardiography showed 2:1 atrioventricular block, complete right bundle branch block, a heart rate of 44 beats/min, and a QRS duration of 142 ms.

Transthoracic echocardiography showed no apparent regional wall-motion abnormality, and the left ventricular ejection fraction (LVEF) was >60%. The B-type natriuretic peptide concentration was 284.2 pg/mL.

Because no reversible cause of the atrioventricular block was identified, permanent pacing was considered indicated. An AVEIR DR dual-chamber leadless pacemaker system was selected to reduce infection risk and preserve venous access in this patient receiving long-term hemodialysis.

The ventricular device was fixed to the lower RV septum, and the atrial device was positioned near the base of the right atrial appendage (Figure *2*).

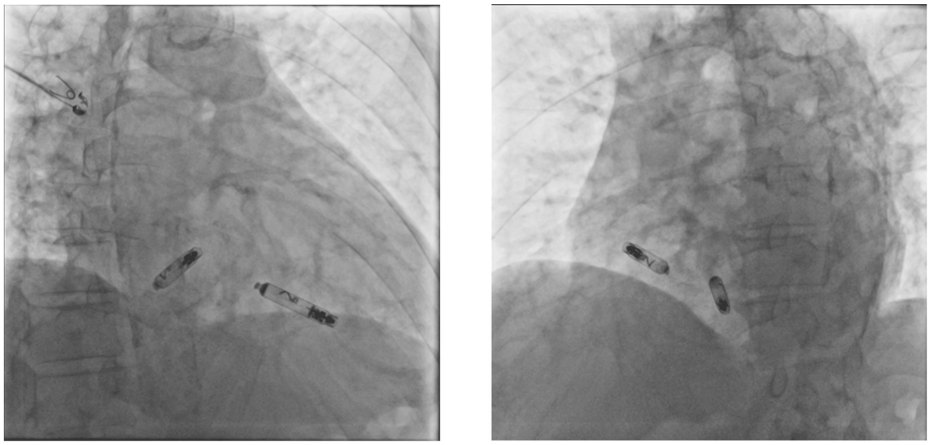


FIGURE 2: Fluoroscopic position of the dual-chamber leadless pacemaker system

Fluoroscopic images in the right anterior oblique 30-degree and left anterior oblique 50-degree views show the positions of the atrial and ventricular leadless pacemakers. The ventricular device was positioned in the lower right ventricular septum, and the atrial device was positioned near the base of the right atrial appendage.

Implantation was completed without procedure-related complications.

During atrial-sensed ventricular pacing after implantation, electrocardiography demonstrated a left bundle branch block-like paced morphology with marked QRS prolongation to 202 ms (Figure 3).

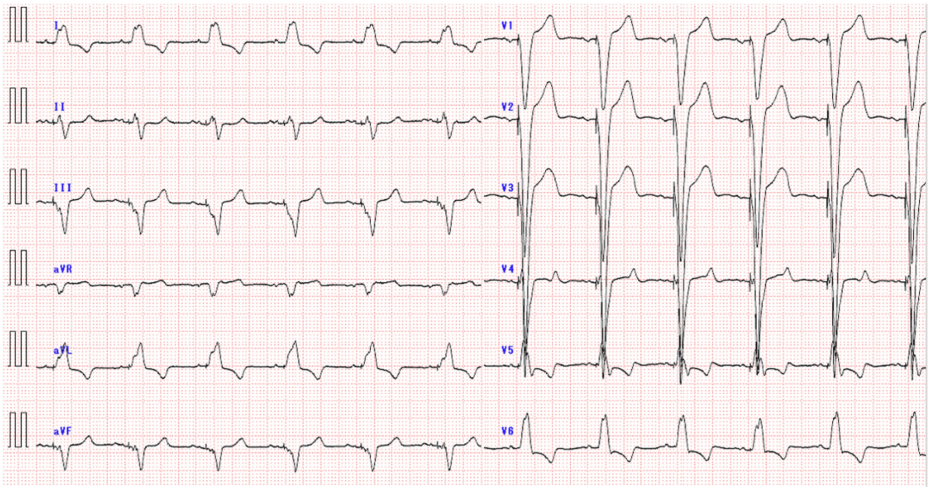


FIGURE 3: Twelve-lead electrocardiograms during right ventricular (RV) pacing

During atrial-sensed ventricular pacing after AVEIR DR implantation, the heart rate was 69 beats/min and the QRS duration increased to 202 ms with a left bundle branch block-like morphology.

Coronary angiography performed during the same hospitalization demonstrated severe stenosis of the left main coronary artery, with an instantaneous wave-free ratio of 0.77 toward the left anterior descending artery. Staged percutaneous coronary intervention was therefore planned.

Echocardiographic suspicion of mechanical dyssynchrony and first gated SPECT study

Transthoracic echocardiography during intrinsic ventricular conduction showed no visually apparent intraventricular mechanical dyssynchrony (Figure 4).

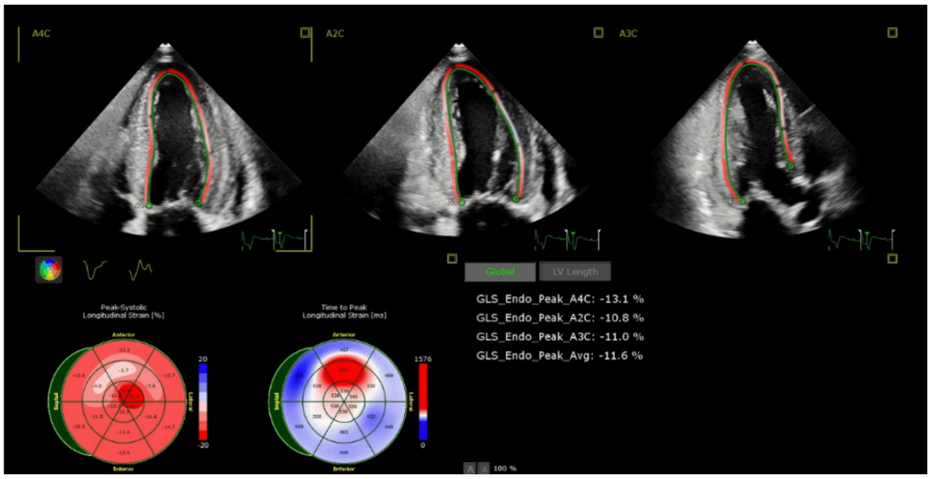


FIGURE 4: Transthoracic echocardiographic findings during intrinsic ventricular conduction

Transthoracic echocardiography during intrinsic ventricular conduction showed no visually apparent intraventricular mechanical dyssynchrony.

In contrast, follow-up transthoracic echocardiography 11 days after pacemaker implantation demonstrated left ventricular wall motion suggestive of intraventricular mechanical dyssynchrony during RV pacing (Figure *5*).

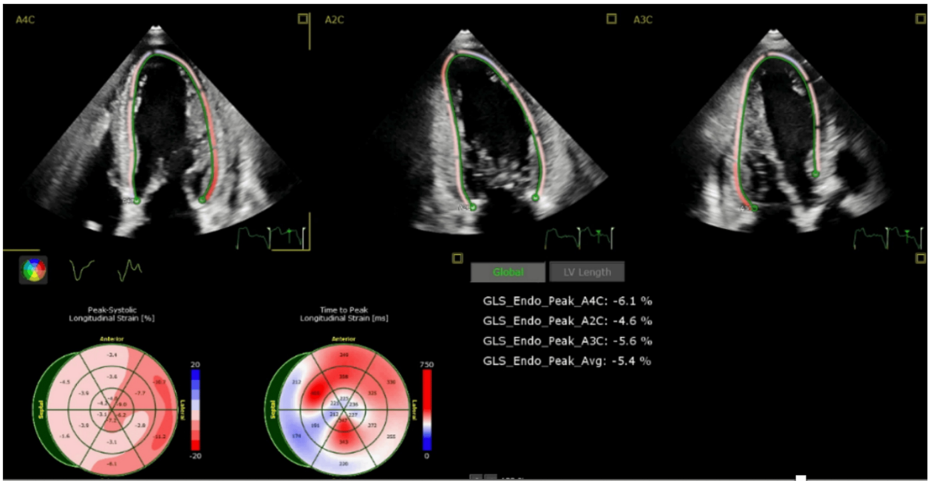


FIGURE 5: Transthoracic echocardiographic findings during right ventricular (RV) pacing

Follow-up transthoracic echocardiography 11 days after AVEIR DR implantation demonstrated left ventricular wall motion suggestive of intraventricular mechanical dyssynchrony during RV pacing.

To objectively and quantitatively assess the difference in left ventricular mechanical synchrony between the two ventricular activation conditions, gated myocardial perfusion SPECT phase analysis was performed.

At the first examination, the patient was asymptomatic on room air. His heart rate was approximately 70 beats/min during essentially continuous ventricular pacing, blood pressure was 138/59 mmHg, and body weight was 53.7 kg, with a dry weight of 53.8 kg. Hemodialysis had been performed on the previous day, with 3.4 kg of ultrafiltration. Device interrogation documented a ventricular pacing burden of approximately 100% around the time of the examination.

The study was performed using technetium-99m tetrofosmin and an NM/CT 870 DR system (GE HealthCare, Chicago, IL, USA), with 12 frames per cardiac cycle. Images were reconstructed using filtered back projection and processed using a Xeleris V workstation (GE HealthCare, Chicago, IL, USA).

Early gated imaging showed a left ventricular end-diastolic volume of 167.0 mL, an end-systolic volume of 91.8 mL, and LVEF of 45.0%. Delayed imaging showed corresponding values of 172.7 mL, 99.1 mL, and 42.6%, respectively.

Phase analysis during RV pacing demonstrated marked dispersion and heterogeneity of the onset of mechanical contraction. The phase standard deviation was 33.7 degrees, the 95% histogram bandwidth was 113.0 degrees, and the phase entropy was 76.34% (Figure 6).

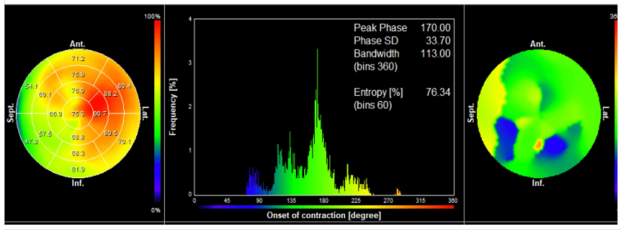


FIGURE 6: Gated myocardial perfusion single-photon emission computed tomography (SPECT) phase analysis according to ventricular conduction condition during RV pacing

During right ventricular (RV) pacing, phase polar maps and histograms demonstrated broad dispersion of contraction onset. Phase standard deviation was 33.7 degrees, 95% histogram bandwidth was 113.0 degrees, and phase entropy was 76.34%.

Second gated SPECT study during intrinsic ventricular conduction

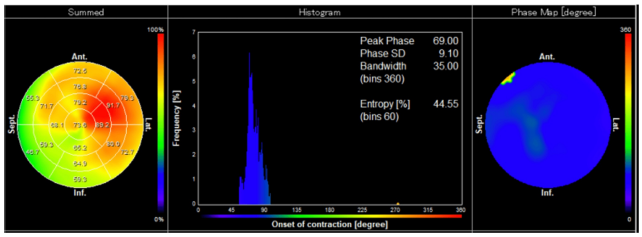
Several days later, a second gated myocardial perfusion SPECT study was performed to evaluate left ventricular mechanical synchrony during intrinsic ventricular conduction. Device programming was modified to permit intrinsic ventricular conduction, with ventricular backup pacing set at 30 beats/min.

The patient had stable intrinsic 2:1 atrioventricular conduction at 39-40 beats/min and remained asymptomatic during the examination. The study could therefore be completed without continuous ventricular pacing. Device interrogation documented a ventricular pacing burden of approximately 1% around the time of the examination.

At the second examination, blood pressure was 117/40 mmHg, oxygen supplementation was not required, and body weight was 55.2 kg, with a dry weight of 53.7 kg. The examination was performed before hemodialysis, two days after the previous dialysis session, during which 3.7 kg of ultrafiltration had been performed.

Gated imaging demonstrated a left ventricular end-diastolic volume of 169.8 mL, an end-systolic volume of 97.1 mL, and an LVEF of 42.8%.

In contrast to the RV-paced examination, the phase distribution was substantially narrower during intrinsic ventricular conduction. The phase standard deviation was 9.1 degrees, the 95% histogram bandwidth was 35.0 degrees, and the phase entropy was 44.55% (Figure 7).



Intrinsic Conduction

Phase SD 9.1 °
Bandwidth 35.0 °
Entropy 44.55 %

FIGURE 7: Gated myocardial perfusion single-photon emission computed tomography (SPECT) phase analysis according to ventricular conduction condition during intrinsic ventricular conduction

During intrinsic ventricular conduction several days later, the phase distribution was substantially narrower. Phase standard deviation was 9.1 degrees, 95% histogram bandwidth was 35.0 degrees, and phase entropy was 44.55%.

The clinical and imaging conditions of the two gated SPECT examinations are summarized in Table *1*.

Parameter	First SPECT: RV-paced condition	Second SPECT: intrinsic-conduction condition
Rhythm/pacing	Atrial-sensed RV pacing	Intrinsic 2:1 AV conduction
Ventricular backup pacing rate (bpm)	Not applicable	30
Ventricular pacing burden (%)	Approximately 100	Approximately 1
Heart rate (bpm)	Approximately 70	39-40
Systolic blood pressure (mmHg)	138	117
Diastolic blood pressure (mmHg)	59	40
Oxygen supplementation	None	None
Symptoms	Asymptomatic	Asymptomatic
Body weight (kg)	53.7	55.2
Dry weight (kg)	53.8	53.7
Timing relative to hemodialysis	Day after hemodialysis	Before hemodialysis
Previous ultrafiltration volume (kg)	3.4	3.7
Days since ultrafiltration	1	2
LV EDV (mL)	167.0	169.8
LV ESV (mL)	91.8	97.1
LVEF (%)	45.0	42.8
Phase SD (degrees)	33.7	9.1
95% histogram bandwidth (degrees)	113.0	35.0
Phase entropy (%)	76.34	44.55

TABLE 1: Clinical and imaging conditions during the two gated SPECT examinations

Comparison of clinical status, pacing conditions, hemodialysis-related variables, left ventricular functional parameters, and phase-analysis indices between the first gated SPECT examination performed during right ventricular pacing and the second examination performed during intrinsic ventricular conduction.

AV, atrioventricular; EDV, end-diastolic volume; ESV, end-systolic volume; LV, left ventricular; LVEF, left ventricular ejection fraction; RV, right ventricular; SD, standard deviation; SPECT, single-photon emission computed tomography.

Discussion

The principal finding of this case is the quantitative demonstration of mechanical dyssynchrony associated with RV pacing after implantation of an AVEIR DR dual-chamber leadless pacemaker.

Although atrioventricular synchrony was maintained by the dual-chamber leadless pacing system, the QRS duration increased markedly from 142 ms during intrinsic conduction to 202 ms during RV pacing. Transthoracic echocardiography during intrinsic ventricular conduction showed no visually apparent intraventricular mechanical dyssynchrony, whereas follow-up echocardiography during RV pacing demonstrated left ventricular wall motion suggestive of mechanical dyssynchrony. These observations prompted further quantitative assessment using gated myocardial perfusion single-photon emission computed tomography (SPECT) phase analysis.

RV myocardial pacing activates the ventricles outside the native His-Purkinje conduction system. Electrical propagation therefore proceeds through the working myocardium in a non-physiological sequence and may result in delayed and heterogeneous ventricular activation [3,4]. Although leadless pacing eliminates complications associated with generator pockets and transvenous leads, it does not eliminate the potential mechanical consequences of non-physiological RV myocardial activation [1-4].

In this patient, gated SPECT phase analysis provided quantitative findings supporting the echocardiographic suspicion of mechanical dyssynchrony. During RV pacing, the phase standard deviation (Phase SD) was 33.7 degrees, the 95% histogram bandwidth was 113.0 degrees, and the phase entropy was 76.34%. In contrast, during intrinsic ventricular conduction, these values were substantially lower at 9.1 degrees, 35.0 degrees, and 44.55%, respectively.

Phase SD reflects the dispersion of regional myocardial contraction onset, whereas histogram bandwidth represents the phase interval containing 95% of myocardial samples. Phase entropy reflects the overall heterogeneity of the phase distribution. Higher values generally indicate greater left ventricular mechanical dyssynchrony [5-7]. The marked differences in these indices between the two examinations suggest substantial differences in mechanical synchrony under the respective ventricular activation conditions.

An important strength of the present case is the within-patient comparison using the same imaging modality and analysis platform under two different ventricular activation conditions. Rather than relying solely on universal cutoff values for mechanical dyssynchrony, the concordant differences in three quantitative phase-analysis indices provide objective evidence of a difference in mechanical synchrony between the RV-paced and intrinsic-conduction states.

However, several limitations should be acknowledged. First, the two SPECT examinations were not performed under identical physiological conditions. Differences in heart rate, blood pressure, and the timing of hemodialysis may have influenced ventricular loading conditions and the phase-analysis measurements. In particular, changes in intravascular volume associated with hemodialysis could have affected ventricular contraction patterns. Therefore, the observed differences in phase indices cannot be attributed exclusively to RV pacing. Although left ventricular volumes and LVEF were broadly similar between the examinations, the potential influence of these confounding factors cannot be excluded.

Second, the patient had concomitant coronary artery disease requiring percutaneous coronary intervention (PCI), which was performed several days after the SPECT examinations. No apparent improvement in cardiac function or heart failure symptoms was observed following PCI. Nevertheless, the potential contribution of myocardial ischemia to the observed mechanical abnormalities cannot be completely excluded. Accordingly, the present findings support an association between RV pacing and mechanical dyssynchrony but do not establish a definitive causal relationship.

Previous studies have demonstrated the utility of gated myocardial perfusion SPECT phase analysis for characterizing left ventricular mechanical synchrony [5-7]. RV pacing may also affect regional wall motion and apparent myocardial perfusion on SPECT imaging, emphasizing the importance of considering pacing status during image interpretation [8].

The present findings should not be interpreted as evidence of established pacing-induced cardiomyopathy. Pacing-induced cardiomyopathy generally refers to persistent deterioration in left ventricular systolic function associated with substantial RV pacing exposure [3,4,9,10]. Instead, this report focuses on the more limited observation that RV pacing was associated with greater mechanical dyssynchrony than intrinsic ventricular conduction under the conditions examined.

For patients with a high RV pacing burden and a markedly prolonged paced QRS complex, gated SPECT phase analysis may provide complementary quantitative information when mechanical dyssynchrony is suspected. However, larger studies with standardized imaging conditions are needed to clarify the relationship between RV pacing and mechanical dyssynchrony and to determine whether SPECT phase-analysis findings are associated with subsequent ventricular remodeling or clinical outcomes after leadless

pacemaker implantation.

Conclusions

In this patient with an AVEIR DR dual-chamber leadless pacemaker, gated myocardial perfusion SPECT phase analysis demonstrated marked mechanical dyssynchrony during RV pacing and substantially less phase dispersion during intrinsic ventricular conduction. Although differences in physiological conditions, including heart rate, blood pressure, and hemodialysis-related factors, may have influenced the measurements, the concordant differences in phase standard deviation, 95% histogram bandwidth, and phase entropy support an association between RV pacing and mechanical dyssynchrony without establishing a definitive causal relationship. Gated myocardial perfusion SPECT phase analysis may serve as a complementary quantitative method for evaluating ventricular mechanical synchrony after leadless pacemaker implantation. Further studies involving larger patient populations are needed to establish its clinical significance and potential prognostic value.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Wakaba Kobayashi

Acquisition, analysis, or interpretation of data: Wakaba Kobayashi, Kohei Sawasaki, Natsuko Hosoya, Masahiro Mutoh, Yuichiro Maekawa

Drafting of the manuscript: Wakaba Kobayashi

Critical review of the manuscript for important intellectual content: Kohei Sawasaki, Natsuko Hosoya, Masahiro Mutoh, Yuichiro Maekawa

Supervision: Kohei Sawasaki

Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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