



Original Article

Speckle Tracking Echocardiography for Predicting Early Left Ventricular Dysfunction After Right Ventricular Pacing

Al-Shimaa Mohamed Sabry^{*}, Khaled Emad Al-Rabbat, Mohamed Magdy Anwar, Shereen Ibrahim Farag

Department of Cardiology, Benha University Hospital, Faculty of Medicine, Benha University, Benha, Egypt

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*Corresponding Author:

Al-Shimaa Mohamed Sabry,
Email: shimaa.sabry@fmed.bu.edu.eg

Abstract

Introduction: Right ventricular (RV) pacing can negatively affect left ventricular (LV) function. Therefore, we aimed to assess the role of ventricular strain measured by speckle tracking echocardiography [STE] in the early prediction of LV dysfunction after pacemaker implantation.

Methods: Seventy-five patients with high-degree atrioventricular (AV) block scheduled for permanent pacemaker implantation with good LV systolic function were evaluated. STE was used to assess the left ventricular global longitudinal strain [GLS] 1 month after pacemaker implantation. Patients were followed after 1 year to detect patients with pacemaker-induced cardiomyopathy [PICM] and pacemaker-induced ventricular dysfunction [PIVD].

Results: patients with PICM and PIVD had significantly lower 1-month GLS with no significant statistical difference regarding LV ejection fraction. The percentage of pacing was substantially higher among PICM patients ($P = 0.0001$). Multivariate regression analysis revealed that age, one-month GLS, QRS duration after pacing, and percentage of pacing are independent predictors of one-year LV dysfunction. The ROC curve showed that one-month $GLS \geq -16$ (sensitivity = 95.65%, specificity = 98.08%, $AUC = 0.979$, $P = 0.001$), QRS duration after pacing ≥ 145 msec (sensitivity = 47.83%, specificity = 90.38%, $AUC = 0.824$, $P = 0.001$), and percentage of pacing $\geq 84\%$ (sensitivity = 65.22%, specificity = 90.38%, $AUC = 0.910$, $P = 0.001$) were the best diagnostic values for predicting LV dysfunction.

Conclusion: STE changes are earlier than LVEF in predicting LV dysfunction after RV pacing. It should be used to assess patients undergoing pacemaker implantation to predict those more likely to develop LV dysfunction.

Keywords: Global longitudinal strain, Pacemaker-Induced left ventricular dysfunction, Speckle tracking echocardiography

Introduction

Permanent cardiac pacing is a common, widely available technique for the management of bradycardia.¹ The growing elderly population with longer life expectancies has resulted in higher rates of permanent pacemaker (PPM) implantations with different challenges in managing bradycardia.² PPMs have significant advantages for bradycardia patients. However, improved follow-up of those patients revealed individuals who cannot tolerate right ventricular (RV) pacing.³

RV apical pacing leads to an abnormal sequence of ventricular activation, which skips the His-Purkinje system, causing electrical and, consequently, mechanical dyssynchrony.⁴

Moreover, long-term RV pacing may negatively impact left ventricular (LV) performance, which may lead to pacing-induced cardiomyopathy (PICM),⁵ heart failure (HF), atrial fibrillation (AF), and possibly increased risk of cardiac death.⁶ Efforts have been made to early identify individuals at a higher risk of PICM after pacemaker implantation.

Speckle tracking echocardiography (STE) is an advanced

imaging technique that assesses myocardial deformation and helps detect subclinical LV dysfunction before overt heart failure develops.⁷

The purpose of our study was to evaluate the role of STE in the early prediction of left ventricular impairment after pacemaker implantation.

Materials and Methods

Study Design

It was a single-center, prospective observational study that was conducted at the cardiology department of Benha University Hospital from August 2021 to July 2023. The study enrolled 75 patients aged 18 years or more with a high degree of AV block eligible for permanent pacemaker implantation with good LV systolic function (LV ejection fraction "LVEF" above 50 %). All participants provided informed consent. The research ethics committee of our institute approved the study. Patients with impaired LV systolic function (LVEF < 50%), significant valvular heart disease, ischemic heart disease, prior percutaneous coronary intervention (PCI), coronary artery bypass graft surgery (CABG), poor echogenic window, or patient



refusal were excluded.

Methods

All patients underwent the following procedures Full detailed history including age, gender, and risk factors.

Electrocardiogram: Resting 12-lead ECG was done using a Nihon Kohden machine at a paper speed of 25 mm/s and a 10-mm/mV gain. It was evaluated to identify heart rate, rhythm, and QRS duration after pacemaker implantation.

Transthoracic echocardiography: It was performed by Philips EPIQ 7C, Release 1.7 (Philips Healthcare, Andover, MA, USA) machine with Q lab 10.4 using S5-1 probe with simultaneous electrocardiogram signal. Each measurement was averaged over three consecutive beats.

Global LV function was assessed by measuring LV end-diastolic (LVEDV) and end-systolic volumes (LVESV) from two-dimensional apical views, and LVEF was measured by means of the modified biplane Simpson's method.⁸

Speckle Tracking Echocardiography

Three consecutive end-expiratory cardiac cycles were acquired in the apical four-chamber, apical two-chamber (2-CH), and the long-axis views. The 2D-STE analysis was performed offline on grayscale images of the LV obtained in these views. A semi-automated method was utilized; 3 points in each view were identified (two basal points and one apical). After that, the software automatically tracked the myocardial region of interest. Once the areas of interest were optimized, the software automatically generated strain curves for different myocardial segments.⁹ Global longitudinal strain (GLS) has been calculated as the mean strain of all 17 segments (Figure 1). As LV-GLS represents myocardial shortening, it is expressed as a negative value. Lower values generally indicate impaired or reduced LV systolic function. GLS values better than -18% to -20% were considered normal. Values of -16% to -18% are considered borderline and values worse than -16% were considered as left ventricular dysfunction.¹⁰

Follow-Up

Patients underwent follow-up echocardiography 1 month and 1 year after implantation, along with follow-up programming of the pacemaker and documentation of pacing percentage.

Pacing-induced LV dysfunction (PIVD) was defined as a decrease in the LVEF of more than 10 percentage points, but it is still >50%.¹¹ PICM was defined as a decrease in LVEF by 10 percentage points from baseline, leading to EF <50% (in the absence of an alternative cause of cardiomyopathy).¹²

Statistical Analysis

Statistical analysis was conducted using the computerized statistical package STATA/SE version 11.2 for Windows (STATA Corporation, College Station, Texas). Quantitative variables were presented as means and standard deviations; they were compared between study groups using the Kruskal-Wallis test. Categorical variables were explained in terms of frequency and percentages, and compared using the Chi-square test. Sensitivity analysis was conducted to predict the incidence of left ventricular dysfunction among patients who underwent pacemaker insertion for cardiac arrhythmia to set the optimal cutoff point for this prediction. The receiver curve of the characteristic curve was constructed to visualize the area under the curve for predicted outcomes. Multivariate logistic regression of LV dysfunction one year after pacemaker implantation, conditioned on patients' sociodemographic characteristics and echocardiographic findings, was conducted, and the odds ratio (OR) and 95% Confidence Interval (95% CI) were presented. Any p-value <0.05 was considered significant.

Results

A total of 75 patients who were diagnosed with cardiac bradyarrhythmia underwent pacemaker insertion. They were assessed after one month and one year for cardiac functions using 2D conventional echocardiography and

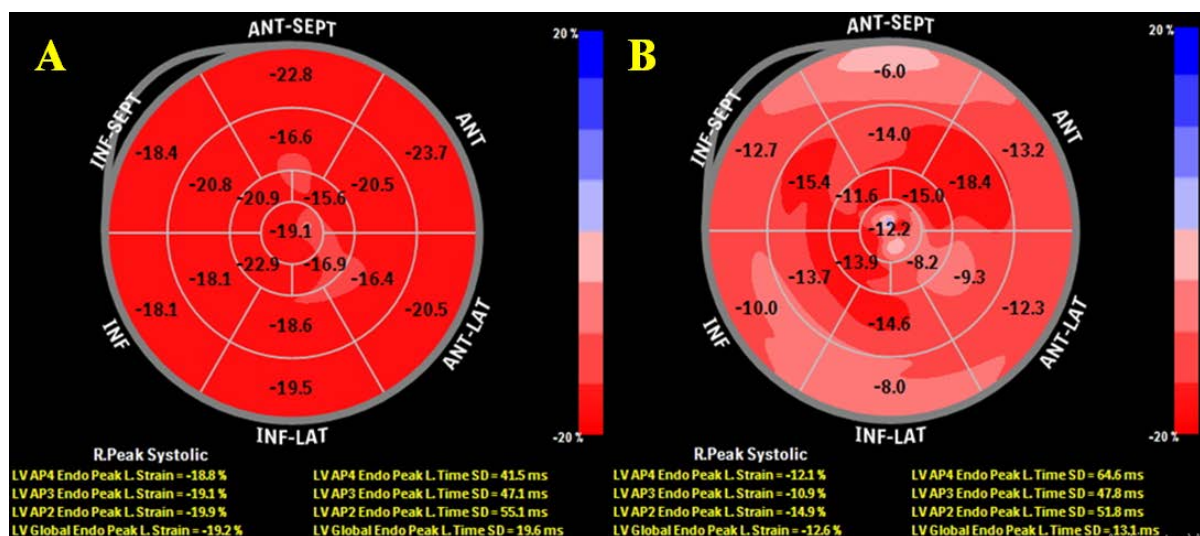


Figure 1. Bull's eye of LV longitudinal strain after 1 month of 2 cases [A] patient of the normal group (LVGLS=-19.2%) and [B] patient of the PICM group (LVGLS=-12.6%). LV: left ventricular, LVGLS: left ventricular global longitudinal strain, PICM: pacemaker induced cardiomyopathy

speckled tracking echocardiography.

The mean age was 65.33 ± 11.15 years, 41 patients (54.67%) were females, 18 patients (24%) were diabetics, 25 patients (33.33%) were hypertensive, 18 patients (24%) had dyslipidemia, and 23 patients (30.67%) were smokers.

Complete heart block (CHB), 65.33% was the most common indication for pacing, followed by Mobitz II (32%) and tachy-brady syndrome (2.67%). The mean QRS duration after pacing was 139.65 ± 7.38 msec. The mean percentage of pacing was 62.76 ± 23.76 %.

After one year of follow-up, 16 (21.3%) patients developed pacemaker-induced ventricular dysfunction, 7 (9.33%) patients developed PICM, and 52 (69.33%) had normal cardiac function.

Baseline Clinical Characteristics

PICM patients were significantly older compared to the other two groups ($P=0.0001$). There was no significant statistical difference between the study groups regarding their gender, risk factors such as diabetes, hypertension, dyslipidemia, or smoking (Table 1).

ECG and Echocardiographic Parameters

A significantly longer QRS duration was reported among patients with PICM and PIVD ($P=0.0001$); otherwise, there was no significant difference between study groups in terms of baseline EF and GLS. However, one-month follow-up showed that PICM and PIVD had significantly lower GLS ($P=0.0001$). However, there was no statistically significant difference between all study groups as regards their one-month ejection fraction, EDV, or ESV. Additionally, a one-year follow-up showed that PICM had significantly lower EF and GLS among other groups ($P=0.0001$). The percentage of pacing was significantly higher among PICM compared to the other groups ($P=0.0001$) (Table 2).

Predictors of LV Dysfunction

Multivariate regression analysis revealed that age, one-month GLS, QRS duration after pacing, and percentage of pacing are independent predictors of one-year LV

dysfunction (Table 3). The ROC curve was utilized to assess the best diagnostic values in predicting LV dysfunction, it revealed that age ≥ 75 (sensitivity = 52.17%, specificity = 96.15%, AUC = 0.773, $P=0.001$), one-months GLS ≥ -16 (sensitivity = 95.65%, specificity = 98.08%, AUC = 0.979, $P=0.001$), QRS duration after pacing ≥ 145 msec (sensitivity = 47.83%, specificity = 90.38%, AUC = 0.824, $P=0.001$), and percentage of pacing ≥ 84 % (sensitivity = 65.22%, specificity = 90.38%, AUC = 0.910, $P=0.001$) were the best diagnostic values for predicting LV dysfunction (Figure 2).

Reproducibility

A total of 10 patients were randomly selected and assessed by the same operator for intra-observer variability. The same patients were assessed by two operators who were blinded to the previously obtained results for inter-observer variability. They were calculated using the interclass correlation coefficient (ICC). The ICCs were 0.854 for inter-observer variability and 0.795 for intra-observer variability.

Discussion

Permanent pacemaker implantation is a definitive treatment strategy for symptomatic bradyarrhythmia.

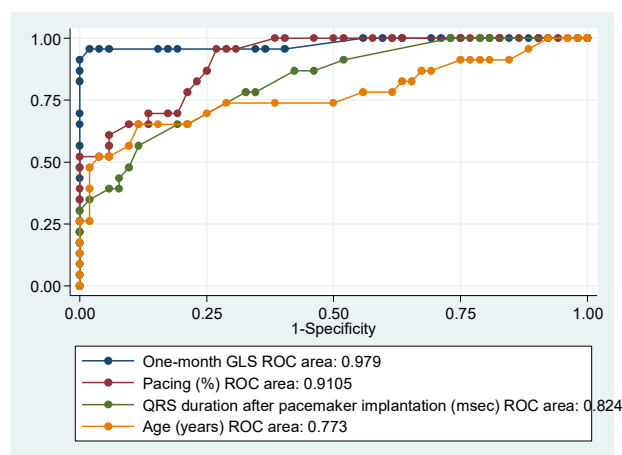


Figure 2. ROC curve for predictors of LV dysfunction

Table 1. Comparisons of baseline clinical characteristics between study groups.

General characteristics	Normal (n=52), No (%)	PIVD (n=16), No (%)	PICM (n=7), No (%)	P
Age in years (Mean $\pm$ SD)	62.19 $\pm$ 9.60	69.5 $\pm$ 12.08	79.14 $\pm$ 5.52	0.0001*
Gender				
Female	32 (61.54)	8 (50)	1 (14.29)	0.06
Male	20 (38.46)	8 (50)	6 (85.71)	
Diabetes	12 (23.08)	4 (25)	2 (28.57)	0.91
Hypertension	17 (32.69)	6 (37.50)	2 (28.57)	0.93
Dyslipidemia	12 (23.08)	4 (25)	2 (28.57)	0.91
Smoking	14 (26.92)	5 (31.25)	4 (57.14)	0.29
Baseline ECG				
CHB	32 (61.54)	11 (68.75)	6 (85.71)	0.8
Mobitz II	18 (34.62)	5 (31.25)	1 (14.29)	
Tachy-brady syndrome	2 (3.85)	0 (0)	0 (0)	

* Significant. PIVD: Pacing-induced LV dysfunction, PICM: Pacemaker-induced cardiomyopathy, ECG: Electrocardiography, CHB: Complete heart block.

Table 2. Comparisons of baseline and follow-up echocardiographic data

Variables	LV dysfunction			P
	Normal (n. = 52)	PIVD (n. = 16)	PICM (n. = 7)	
	Mean ± SD	Mean ± SD	Mean ± SD	
LVEF (%)				
Baseline	65.01 ± 3.53	63.84 ± 2.06	62.51 ± 1.98	0.07
One month	60.44 ± 3.36	59.22 ± 2.62	58.34 ± 3.61	0.21
One year	61.56 ± 3.43	51.87 ± 1.57	45.66 ± 1.34	0.0001 ^{a,b}
LVEDV (ml)				
Baseline	86.25 ± 15.20	85.46 ± 13.87	85.43 ± 23.61	0.96
One-month	88.83 ± 15.01	90.66 ± 15.84	92.27 ± 23.49	0.83
One-year	92.72 ± 14.65	103.05 ± 15.91	111.14 ± 23.46	0.01
LVESV (ml)				
Baseline	30.31 ± 6.01	31.06 ± 6.20	31.78 ± 8.26	0.79
One-month	34.45 ± 6.68	37.16 ± 8.02	37.4 ± 9.69	0.28
One-year	35.69 ± 6.34	49.62 ± 8.06	60.64 ± 13.32	0.0001 ^{a,b}
GLS (%)				
Baseline	-19.23 ± 2.25	-18.79 ± 1.09	-18.78 ± 1.33	0.85
One-month	-20.23 ± 2.20	-15.01 ± 1.49	-12.98 ± 1.08	0.0001 ^{a,b}
One-year	-19.30 ± 2.01	-13.60 ± 1.72	-10.6 ± 0.99	0.0001 ^{a,b}
QRS duration after pacemaker implantation (msec)	136.98 ± 5.16	142.56 ± 5.55	152.86 ± 8.99	0.0001 ^{a,b}
Pacing (%)	52.77 ± 19.99	80.56 ± 14.39	96.28 ± 5.19	0.0001 ^{a,b}

LVEF: Left ventricular ejection fraction, LVEDV: Left ventricular end-diastolic volume, LVESV: Left ventricular end-systolic volume, GLS: Global longitudinal strain.

a: significant differences between normal and PIVD

b: significant differences between normal and PICM

Table 3. Multivariate logistic regression of LV dysfunction

Variable	Multivariate logistic regression	
	OR (95%CI)	P
Age in years	1.12(1.05-1.20)	0.001
Gender		
Female	2.49(0.91-6.81)	0.08
Male		
Diabetes	1.18(0.38-3.65)	0.78
Hypertension	1.1 (0.39-3.09)	0.86
Dyslipidemia	1.18(0.38-3.65)	0.78
Smoking	1.74(0.62-4.92)	0.29
Baseline ECG		
CHB	1.00	
MOBTIZ II	0.63(0.21-1.88)	0.40
Tachy-brady syndrome	Empty	-
Baseline LVEF	0.85(0.72-1.00)	0.06
Baseline LVEDV	1.00(0.96-1.03)	0.83
Baseline LVESV	1.02(0.95-1.11)	0.53
Baseline GLS	1.12(0.87-1.46)	0.38
one-month LVEF	0.86(0.73-1.01)	0.07
One-month LVEDV	1.01(0.98-1.04)	0.56
One-month LVESV	1.05(0.98-1.13)	0.13
One-month GLS	4.99(2.20-11.30)	<0.001
QRS duration after pacemaker implantation (msec)	1.23(1.11-1.38)	<0.001
Pacing (%)	1.10(1.06-1.15)	<0.001

LVEF: Left ventricular ejection fraction, LVEDV: Left ventricular end-diastolic volume, LVESV: Left ventricular end-systolic volume, GLS: Global longitudinal strain.

While most patients can tolerate RV pacing, some patients develop pacing-induced cardiomyopathy following pacemaker implantation as a result of abnormal ventricular activation and ventricular dyssynchrony.¹³

Accurate assessment of LV function is essential for risk assessment and management of these patients. The most widely used method for evaluation of LV systolic function is measurement of LVEF.⁸ PICM has been defined using various LVEF thresholds. Most studies have used an LVEF of either $\leq 40\%$ or 50% , with an absolute decline of at least 5- 10%.¹⁴ However, EF might not be enough to identify LV dysfunction early.

Two-dimensional STE measured GLS appears to be a reliable and accessible tool for the early assessment of LV function.¹⁵ RV pacing leads to impaired LV function and strain. Therefore, GLS can detect subclinical LV dysfunction before changes in LVEF.¹⁶

In this study, we investigated the role of STE in the early prediction of LV dysfunction after pacemaker implantation. We tend to assess both LVEF and GLS pre-implantation, 1-month, and 1-year after RV pacing. After 12 months of RV pacing, we found a significant reduction in LVEF. This was consistent with progressive LV remodeling following RV pacing.¹⁷

According to LVEF, patients were classified into three groups: 16 (21.3%) patients developed PIVD, 7 (9.3%) patients developed PICM, and 52 (69.33%) had normal cardiac function. This finding was similar to that of Ahmed et al.,¹⁸ who also found that PIVD was 20% at 1-year follow-up, and PICM was 7.2% at 1-year follow-

up. Similarly, Abdin et al.¹⁹ found that 16% of patients developed PICM 1 year after pacemaker implantation. In addition, Cho et al.²⁰ also found that PICM occurred in 14.1% of patients.

In our study, patients who developed PICM were significantly older compared to the other two groups. This was discordant with the findings of Cho et al.²⁰ who did not find a statistical significance between patients who developed PICM and those who didn't, regarding age ($P=0.06$). This could be explained by a larger sample size (618) of patients and a longer duration of follow-up (up to 8 years).

PICM patients had longer QRS duration (152.26 msec) and a higher percentage of pacing, indicating worse electrical dyssynchrony, which was consistent with Cho et al.²⁰ and Balli et al.²¹ who found that a longer QRS duration after pacemaker implantation can contribute to the development of PICM. They also had a higher pacing burden (96.28%), supporting the role of frequent RV pacing in cardiomyopathy. On the other side, that was discordant with Abdin et al.¹⁹ who didn't find any statistical significance between the two groups regarding cumulative percentage of RV pacing ($P=0.6$).

We found a significant reduction in the 1-month GLS value in patients who developed PIVD and PICM, while there was no significant reduction in EF. This was confirmed by logistic regression analysis, which stated the significance of 1-month GLS as a predictor of LV dysfunction after RV pacing. Thus, GLS may be used to predict patients more likely to suffer LV dysfunction after RV pacing and who would benefit from closer echocardiographic surveillance following pacemaker implantation. This was concordant with Ahmed et al.¹⁸ and Xu et al.²² who found significantly lower values of 1-month GLS in patients who developed PIVD and PICM. In addition, Inoue et al.²³ and Dawood et al.²⁴ found lower values of 1-month GLS in patients who developed PICM.

In the current study, baseline GLS didn't show a significant statistical difference between the different studied groups. However, Chin et al.²⁵ found that baseline GLS was significantly impaired in the PICM group, even though the baseline LVEF wasn't considerably different.

According to the sensitivity analysis in our study, one-month GLS can significantly predict LV dysfunction using a cutoff point 16%, with a sensitivity=95.65 and a specificity=98.08. Prior studies supported our results²³; however, they have evaluated the short-term and long-term effects of RVA pacing separately. Moreover, these studies focused on either GLS or LVEF instead of measuring the two parameters together.

Yu et al.²⁶ evaluated LV function by measuring LVEF in patients with RVA and biventricular pacing. Patients with RVA pacing who developed PIVD after 1 year showed more significant LVEF decrease on extended follow-up for 2 years (LVEF decreased by 7% vs. 9.9% at 1 and 2 years, respectively). Therefore, relatively mild impairment in LV function at 1 year in our study may show further significant LVEF impairment with long-term follow-up.

GLS is an essential tool that can early identify patients who will suffer from LV systolic dysfunction after RV pacing. Moreover, our study revealed a significant decline in 1-month GLS in patients who developed PICM at 12 months.

Serial evaluation of LVEF is a commonly used research method for determining the detrimental effects of RV pacing on LV systolic function. Before a notable decline in LVEF happens, as shown in our study, abnormal GLS may be observed at an earlier stage.

Early identification of patients who will develop PICM and PIVD is essential for close monitoring, as among RV pacemaker-dependent patients who developed LV dysfunction, echocardiographic parameters and duration of LV dysfunction are valid predictors of CRT's ability to normalize LV systolic function. A higher rate of CRT hyper response is linked to smaller LV dimensions and a shorter duration of cardiomyopathy, which results in lower HF morbidity and better long-term survival.²⁷

This study has some limitations. It was a single-center study with a small sample size. Also, we did not take into consideration patients' symptoms. The study had only two follow-up visits. Moreover, GLS measurements are vendor specific and dependent on the equipment used. Therefore, larger multicenter and multivendor studies with a more extended follow-up period are recommended for the validity of the results.

Conclusion

Changes in GLS occur earlier than LVEF, therefore; it can be used to early predict LV dysfunction after RV pacing even before visible changes in LVEF.

Authors' Contribution

Conceptualization: Al-Shimaa Mohamed Sabry, Shereen Ibrahim Farag, Khaled Emad Al-Rabbat

Data curation: Mohamed Magdy Anwar, Shereen Ibrahim Farag

Methodology: Al-Shimaa Mohamed Sabry, Shereen Ibrahim Farag, Mohamed Magdy Anwar, Khaled Emad Al-Rabbat

Supervision: Khaled Emad Al-Rabbat

Visualization: Al-Shimaa Mohamed Sabry, Shereen Ibrahim Farag, Mohamed Magdy Anwar

Writing-original draft: Shereen Ibrahim Farag, Al-Shimaa Mohamed Sabry

Writing-review & editing: Al-Shimaa Mohamed Sabry, Shereen Ibrahim Farag

Competing Interests

The authors declare that there are no conflicts of interest.

Ethical Approval

The Ethics Committee of Benha University approved the current study (MD 3-8-2020).

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