Original Article

Association of Electrocardiographic Parameters with Left Ventricular Ejection Fraction in Patients with Left Bundle Branch Block and Permanent Cardiac Pacemakers

Annaev Muzaffar[1]*, Tashkenbaeva Eleonora[2], Abdieva Gulnora[1], Saidrasulova Gulizebo[3], Tillakobilov Ismoil[2], Aliakbarova Hamida[2]

[1] Kimyo International University in Tashkent, Samarkand Branch, Uzbekistan.
[2] Samarkand State Medical University, Samarkand, Uzbekistan.
[3] Tashkent State Medical University, Tashkent, Uzbekistan.

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Highlights

- ECG patterns of RV pacing resemble LBBB but relate differently to LVEF.
- In LBBB, longer QRS and lateral q waves were associated with reduced LVEF.
- In RV pacing, a lateral notched/slurred R wave was associated with reduced LVEF.
- First direct comparison of the ECG–LVEF association in LBBB versus RV pacing.

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*** Corresponding Author:**
Annaev Muzaffar
Dean of the Medical School, Kimyo International University, Tashkent Samarkand Branch, School of Medicine Department, Samarkand, Uzbekistan.
Tel: 9985 5702 4040
E-mail: m.annayev@kiut.uz

ABSTRACT

Background: Patients with right ventricular (RV) pacing from permanent cardiac pacemakers have electrocardiographic (ECG) patterns similar to those with left bundle branch block (LBBB). Although ECG criteria for LBBB in patients with reduced left ventricular ejection fraction (LVEF) are well established, these criteria have not been clarified for patients with RV pacing.

Methods: In this retrospective observational study, between January 2016 and August 2025, 193 patients were diagnosed with LBBB, of whom 118 were included. During the same period, 475 patients with permanent cardiac pacemakers were identified, of whom 178 were eligible for the study.

Results: In the LBBB group (male/female, 55/63; mean [SD] age, 67 [12] years), 57% of patients had LV systolic dysfunction (LVEF <50%), whereas in the pacemaker group (male/female, 93/85; mean [SD] age, 72 [11] years), only 26% had an LVEF less than 50%. Mean QRS duration was longer in patients with reduced LVEF than in those with normal LV systolic function (155 [13] vs 147 [12] milliseconds, respectively; P=.034).

Conclusion: Although the ECG pattern associated with RV pacing from a permanent cardiac pacemaker resembles that of LBBB, its association with LV dysfunction differs. In patients with LBBB, longer QRS duration and the presence of q waves in leads I, aVL, V5, and V6 were associated with reduced LVEF, whereas in patients with RV pacing, a broad, notched, or slurred R wave in leads I, aVL, V5, and V6 was associated with reduced LVEF.

Keywords: Left Bundle Branch Block (LBBB); Right Ventricular (RV) Pacing; Left Ventricular Ejection Fraction (LVEF); QRS Duration; Electrocardiography; Cardiac Pacemaker

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Introduction

The presence of left bundle branch block (LBBB) is widely associated with adverse cardiac consequences. Dyssynchronous ventricular contraction and left ventricular (LV) remodeling are consequences of underlying cardiac diseases-such as coronary artery disease, hypertension, and cardiomyopathy-and may, in turn, perpetuate progressive ventricular dysfunction. LV electrical, structural, and mechanical dysfunction is reflected by QRS prolongation, which results from dispersion of ventricular depolarization and conduction delay.[1] LBBB is also strongly associated with heart failure (HF), and it accounts for approximately one-quarter of all cases, and is regarded as a factor associated with worsening left ventricular ejection fraction (LVEF).[2] LVEF is an imaging-derived measure of global LV systolic performance. It is related to, albeit distinct from, LV remodeling and chamber dilation, which are structural abnormalities quantified by volumetric and dimensional indices. Several studies have reported that guideline-directed medical therapy achieves less LVEF recovery in patients with HF and LBBB than in those without conduction delay.[3-5] The contribution of LBBB to cardiovascular morbidity and mortality is, therefore, clear.

Implantable cardiac pacemakers are widely used to treat cardiac electrophysiologic disorders. The prevalence of pacing is high, with approximately 600 000 cases reported in 2000.[6] The right ventricular (RV) apex is the standard site for positioning the pacing lead and typically produces an LBBB-like morphology on ECG. Because the impulse is conducted from myocyte to myocyte rather than through the His-Purkinje system, RV pacing produces ECG patterns that resemble LBBB. The most common indications for permanent pacemaker implantation are bradycardia, usually caused by sick sinus syndrome; atrioventricular block; and bundle branch block.[7] In these settings, RV pacing has been shown to reduce symptoms and improve quality of life and survival.[8] Nonetheless, as suggested by several randomized clinical trials and other studies, RV pacing can also induce iatrogenic HF through LV systolic dysfunction, thereby increasing morbidity and the risk of hospitalization.

The electrocardiogram (ECG) is a noninvasive, widely available tool for evaluating cardiac electrophysiologic disorders, especially arrhythmias and conduction abnormalities such as bundle branch block. Under normal circumstances, systolic contraction involves simultaneous activation of the LV and RV. Within the specialized conduction system, the impulse propagates at 3-4 m/s, enabling synchronous ventricular contraction. In LBBB and RV pacing, however, conduction occurs predominantly through the ventricular myocardium rather than the specialized conduction system. The impulse then propagates at only 0.15 to 1.0 meters per second, approximately one-quarter of the normal velocity,[9] which can result in dyssynchronous and heterogeneous ventricular activation. Electrical dyssynchrony is usually assessed by QRS duration on the ECG. A prolonged QRS duration may result from discoordination of activation between the 2 ventricles (interventricular dyssynchrony), discoordination of activation within the LV (intraventricular dyssynchrony), or both.[10]

Although the association between LVEF and ECG variables has been well studied, there is a paucity of evidence regarding the association between ECG abnormalities and LV systolic dysfunction in patients with RV pacing. Accordingly, the present study aimed to describe and compare the associations between ECG abnormalities and LVEF in patients with intrinsic LBBB and those with permanent RV pacemakers.

Methods

Study Design

This was a retrospective, single-center observational study. Participants were identified retrospectively from institutional records, and ECG and echocardiographic data obtained within the same clinical episode were compared. No longitudinal follow-up was undertaken, and no time-to-event analysis was performed. Two groups were studied: participants with intrinsic LBBB (group 1) and participants with RV pacing from permanent cardiac pacemakers (group 2). Within each group, participants were divided into 2 subgroups according to LV systolic function: LVEF

of 50% or greater (preserved) and LVEF less than 50% (reduced). The 2 subgroups were then compared with respect to the ECG characteristics used to define LBBB.[11] Additional ECG and echocardiographic variables-PR, QT, and QTc interval duration; QRS axis; LAVI; and the presence of significant intraventricular mechanical delay-were also collected to characterize the differences between the subgroups. Demographic data, clinical presentation, and underlying diseases were obtained from the electronic medical records of the Samarkand Branch of the Republican Specialized Scientific-Practical Medical Center of Cardiology.

LBBB Group

From January 2016 through August 2025, 193 participants were diagnosed with LBBB at the Samarkand Branch of the Republican Specialized Scientific-Practical Medical Center of Cardiology. Of these, 48 were excluded because ECG or echocardiographic data were unavailable or because of misdiagnosis of LBBB. An additional 27 participants were excluded because of the presence of an implantable cardioverter-defibrillator or cardiac pacemaker, atrial fibrillation or flutter, or severe valvular heart disease (Figure 1). Severe valvular heart disease was excluded from the LBBB cohort to isolate the effect of electrical dyssynchrony on LV function and to avoid confounding by valvular pressure or volume overload.

Permanent Pacemaker Group

During the same period, 475 participants with cardiac pacemakers were initially recruited. Because 177 participants had insufficient ECG or echocardiographic records for review, they were excluded. Similarly, to the previous group, 120 individuals were excluded because of an implantable cardioverter-defibrillator, cardiac resynchronization therapy (CRT), or an atrial or LV pacing device, or atrial fibrillation, flutter, or atrioventricular block (Figure 1). Atrioventricular block was excluded from the pacing cohort to restrict the analysis to participants whose LBBB-like paced morphology was purely iatrogenic (eg, participants paced for sick sinus syndrome), thereby minimizing confounding from preexisting extensive conduction system disease.

Data Collection

The condition for entry into the database was availability of sufficient ECG and echocardiographic data recorded around the time of diagnosis of LBBB or implantation of an RV pacing cardiac pacemaker. Participants who did not meet the inclusion criteria were excluded. Collected variables included demographic characteristics, underlying diseases, and ECG and echocardiographic variables.

ECG Examination

ECG strips recorded at rest were accepted as ECG data. Twelve-lead ECGs were recorded at a paper speed of 25 mm/s and a calibration of 10 mm/mV. Throughout this report, the lateral leads are defined as leads I, aVL, V5, and V6. LBBB was defined according to the following recommendations of the American Heart Association/American College of Cardiology Foundation/Heart Rhythm Society: QRS duration greater than or equal to 120 milliseconds; broad notched or slurred R wave in leads I, aVL, V5, and V6 (displaced transition of the QRS complex may account for an occasional RS pattern in lateral leads); absence of q waves in the lateral leads; and a QRS complex usually discordant with the direction of the ST segment and T wave.11 Diagnosis was based on QRS duration and QRS morphology; the R peak time criterion (>60 ms in leads V5 and V6) described in the same statement was not applied. Left-axis deviation was defined as a QRS axis more negative than −30°.

Echocardiographic Data

Individuals were eligible only if the interval between the echocardiographic examination and the ECG did not exceed 3 months. This interval was selected because both tests could not be performed simultaneously in a participant owing to the lack of integration of the regional health insurance system at that time. Thus, we included only participants who remained clinically stable throughout this interval, without an intervening acute cardiac event or decompensation, so that the ECG and echocardiographic findings reflected the same clinical episode. LVEF was obtained from the modified Simpson biplane measurement recorded in the archived echocardiographic report,

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according to the recommendations of the American Society of Echocardiography. Records with missing, erroneous, or internally inconsistent measurements were excluded during eligibility screening in order that all included participants had complete and reliable echocardiographic data. LAVI was calculated as LAV indexed to body surface area and was analyzed as a continuous variable. For descriptive stratification only, a threshold greater than 34 mL/m² was employed to represent LA enlargement, consistent with the current American Society of Echocardiography/European Association of Cardiovascular Imaging reference limit.[23] LAVI was not used as a categorical variable in any inferential analysis. LVEF was utilized as the defining measure of LV systolic function and was categorized in accordance with the American College of Cardiology/American Heart Association/Heart Failure Society of America classification: reduced (LVEF ≤40%), mildly reduced (LVEF =41%-49%), and preserved (LVEF ≥50%). For the primary analysis, participants were dichotomized at an LVEF of 50% into reduced LV systolic function (LVEF <50%, comprising the reduced and mildly reduced categories) and preserved LV systolic function (LVEF ≥50%). This dichotomization was chosen because an LVEF of 50% represents the guideline threshold separating preserved from nonpreserved systolic function and provided adequate subgroup sizes for the planned analyses.

Statistical Analysis

Continuous variables are shown as mean (SD), and categorical variables are expressed as frequencies and percentages. Associations between categorical variables were assessed using the χ^2 test, and correlations between continuous variables were assessed employing the Pearson correlation. Univariable binary logistic regression was performed between ECG variables and decreased LVEF (<50%), which was predefined as the only outcome of interest. Receiver operating characteristic (ROC) curve analysis was drawn upon to calculate cutoff values for sensitivity and specificity. Odds ratios (ORs) and 95% confidence intervals (CIs) are given, corresponding to the 1-unit change in the relevant variable. No formal sample size or power calculations were performed a priori; the sample consisted of all consecutive participants fulfilling the inclusion criteria. Multivariable logistic regression was not undertaken because the number of outcome events in the smaller subgroups was insufficient to support a stable multivariable model. Applying the widely accepted minimum of approximately 10 events per candidate covariate, the reduced-LVEF pacing subgroup (n= 46) would permit no more than 4 covariates, and fitting a larger model would risk overfitting and yield unstable, nonreproducible estimates. A univariable approach was, therefore, adopted to limit spurious associations arising from multiple comparisons. A 2-sided *P* value less than .05 was considered statistically significant. Analyses were performed with SPSS, version 25 (IBM Corp, Armonk, NY).

To determine whether the fixed census sample was adequate for this study, a sensitivity power analysis was performed for the primary test rather than a post hoc power analysis for the observed effect. With respect to the primary continuous variable (QRS duration in the LBBB group: n = 67 for LVEF reduced and n = 51 for LVEF preserved; α = .05, 2-sided), the study had sufficient power to detect a between-group difference of approximately 6.6 milliseconds (Cohen *d* ≈ 0.52) with 80% power and approximately 7.6 milliseconds with 90% power. The observed difference of 8 milliseconds was, thus, higher than the smallest difference detectable by the study (power achieved ≈ 92%). The power for categorical ECG differences was correspondingly lower (≈65%), so nonsignificant results for those variables should be interpreted with caution.

Ethics Approval and Informed Consent

The present study was conducted in accordance with the ethical principles of the Declaration of Helsinki (revised 2013). The retrospective analysis of deidentified electronic medical records was approved by the Institutional Review Board of the Samarkand Branch of the Republican Specialized Scientific-Practical Medical Center of Cardiology. Because of the retrospective nature of the study and the use of anonymized medical records, the requirement for individual participant informed consent was waived by the Ethics Committee. All participant data were handled confidentially throughout the study.

Results

Baseline Characteristics of the Study Population

(Table 1) illustrates the baseline characteristics of participants with LBBB. A total of 118 individuals with LBBB fulfilled the eligibility requirements and were included in the study (Figure 1). The mean age was 67 years; 55 participants (47%) were male, 96 (81%) had a notched or slurred R wave, and 87 (74%) had no q waves in the lateral leads. The mean QRS duration was 151 (13) milliseconds and was considerably longer in participants with LV dysfunction than in those with preserved LV function (155 [13] ms vs 147 [12] ms). According to LVEF, 67 participants (57%) had reduced LVEF (group a) and 51 (43%) had preserved LVEF (group b). The proportion of women was higher among participants with preserved LVEF (59%) than among those with reduced LVEF (49%). Age did not differ between the groups.

The mean LVEF in group b was almost twice that in group a (59% [5%] vs 33% [10%]). Notched R waves in the lateral ECG leads were more frequent in participants with LV dysfunction than in those with preserved LVEF (85% vs 77%). In contrast, absent q waves were more prevalent in participants with preserved LVEF than in those with LV dysfunction (84% vs 66%). The mean value of all selected ECG variables except the QT interval was greater among participants with LVEF less than 50%. Left-axis deviation was similarly frequent in both groups (approximately 29%). LAVI was inversely related to LVEF, with a mean of 41 (18) for participants with LVEF less than 50% and 27 (8) for those with preserved LVEF.

(Table 2) presents the baseline characteristics of participants with RV pacing from permanent cardiac pacemakers. One hundred seventy-eight participants with permanent cardiac pacemakers were considered eligible for inclusion and were divided into 2 subgroups: LVEF less than 50% (group c, n=46) and LVEF of 50% or greater (group d, n= 32). As in the first study group, age did not differ between the 2 subgroups (72 [11] years), and men constituted the majority of participants with LV dysfunction (61%).

Participants with reduced LVEF showed a higher frequency of QRS morphological abnormalities. Notched R waves and absent q waves in leads I, aVL, V_5, and V_6 were approximately 26% and 10% more frequent, respectively, in group c than in group d. QRS duration was also 20 milliseconds longer in participants with reduced LVEF than in those with preserved LVEF (163 [27] ms vs 143 [34] ms). Left-axis deviation was present in 43% of participants in group c, approximately 11% more than in those with preserved LV systolic function (32%).

Association Between ECG Variables and LVEF

The χ^2 analysis of the association between categorical ECG variables and LV systolic dysfunction exhibited a statistically significant association with lateral-lead q waves in participants with LBBB. Absent q waves were more frequent among participants with preserved LVEF than among those with reduced LVEF (84.3% vs 65.7%; P=.023), with a weak effect size based on φ and Cramer V. By contrast, in participants with RV pacing, a broad, notched, or slurred R wave in leads I, aVL, V_5, and V_6 was significantly associated with reduced LVEF (67.4% vs 40.9%; P=.002).

Univariable binary logistic regression identified QRS duration as the only continuous ECG variable significantly associated with LV systolic dysfunction in participants with LBBB. The odds ratio for QRS duration was 1.049 (95% CI, 1.004 to 1.096; P=.034) (Figure 3). The Pearson correlation test showed a significant inverse correlation between QRS duration and LVEF (r=−0.448; P<.001) (Figure 5). ROC curve analysis yielded an area under the curve (AUC) of 0.658 (P=.003) (Figure 2). A QRS duration of 143 milliseconds was associated with reduced LVEF, with 81% sensitivity and 63% specificity (Figure 4). An AUC of 0.658 indicates only modest discrimination; consequently, this threshold should be regarded as hypothesis-generating rather than as having established clinical utility.

Logistic regression analyses did not identify a statistically significant model associated with reduced LVEF in participants with RV pacing from permanent cardiac pacemakers.

Table 1. Baseline characteristics of LV systolic dysfunction among participants with LBBB

Variable	All Participants, mean (SD) or No. (%)	LV Systolic Dysfunction, LVEF ≥50% (n = 51, 43%)	LV Systolic Dysfunction, LVEF <50% (n = 67, 57%)	P
Demographic Characteristic				
Age, y	67 (12)	66 (12)	67 (13)	.650
Male sex, No. (%)	55 (46.6)	21 (41.2)	34 (50.7)	.302
Electrocardiographic Parameter				
Broad, notched, or slurred R wave in leads I, aVL, V_5, and V_6, No. (%)	96 (81.4)	39 (76.5)	57 (85.1)	.235
Absent q waves in leads I, aVL, V_5, and V_6, No. (%)	87 (73.7)	43 (84.3)	44 (65.7)	.023
Heart rate, bpm	73 (13)	68 (10)	77 (14)	.380
QRS axis, °	−5 (36)	−6 (35)	−4 (37)	.653
Duration, ms				
PR interval	175 (31)	173 (34)	177 (28)	.304
QRS complex	151 (13)	147 (12)	155 (13)	.034
QT interval	450 (32)	451 (24)	448 (37)	.255
QTc interval	492 (31)	476 (25)	504 (30)	.103
Left-axis deviation, No. (%)	33 (28.0)	15 (29.4)	18 (26.9)	.722
Echocardiographic Parameter				
LAVI, mL/m^2	35 (16)	27 (8)	41 (18)	.004
LVEF, %	44 (15)	59 (5)	33 (10)	—

LAVI: left atrial volume index; LBBB: left bundle branch block; LVEF: left ventricular ejection fraction

Table 2. Baseline characteristics of LV systolic dysfunction among participants with permanent cardiac pacemakers

Variable	All Participants, mean (SD) or No. (%)	LV Systolic Dysfunction, LVEF ≥50% (n=132, 74%)	LV Systolic Dysfunction, LVEF <50% (n=46, 26%)	P
Demographic Characteristic				
Age, y	72 (11)	72 (11)	72 (11)	.260
Male sex, No. (%)	93 (52)	65 (49)	28 (61)	.174
Electrocardiographic Parameter				
Broad, notched, or slurred R wave in leads I, aVL, V_5, and V_6, No. (%)	85 (47.8)	54 (40.9)	31 (67.4)	.002
Absent q waves in leads I, aVL, V_5, and V_6, No. (%)	57 (32.8)	39 (29.5)	18 (39.1)	.230
Heart rate, bpm	69 (11)	67 (11)	72 (11)	.709
QRS axis, °	14 (70)	17 (69)	3 (73)	.660
Duration, ms				
PR interval	187 (50)	191 (50)	173 (47)	.123
QRS complex	149 (33)	143 (34)	163 (27)	.186
QT interval	466 (40)	461 (39)	481 (40)	.951
QTc interval	493 (45)	484 (42)	520 (41)	.131
Left-axis deviation, No. (%)	62 (34.8)	42 (31.8)	20 (43.5)	.091
Echocardiographic Parameter				
LAVI, mL/m^2	36 (16)	34 (16)	41 (14)	.020
LVEF, %	54 (11)	60 (4)	38 (9)	—

LAVI: left atrial volume index; LVEF: left ventricular ejection fraction

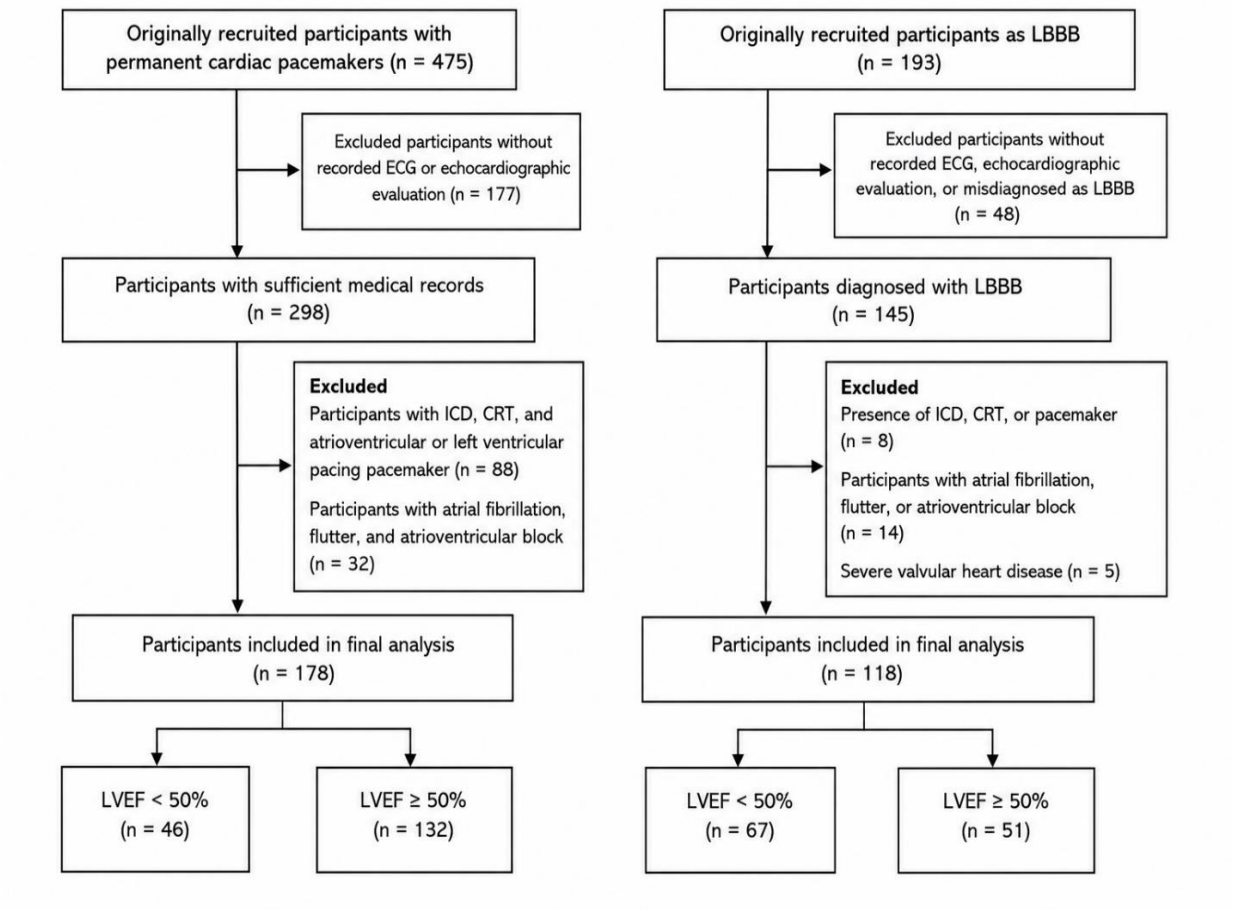


Figure 1. The flow chart of the present study
AV: atrioventricular; CRT: cardiac resynchronization therapy; ECG: electrocardiogram; ICD: implantable cardioverter-defibrillator; LBBB: left bundle branch block; LVEF: left ventricular ejection fraction

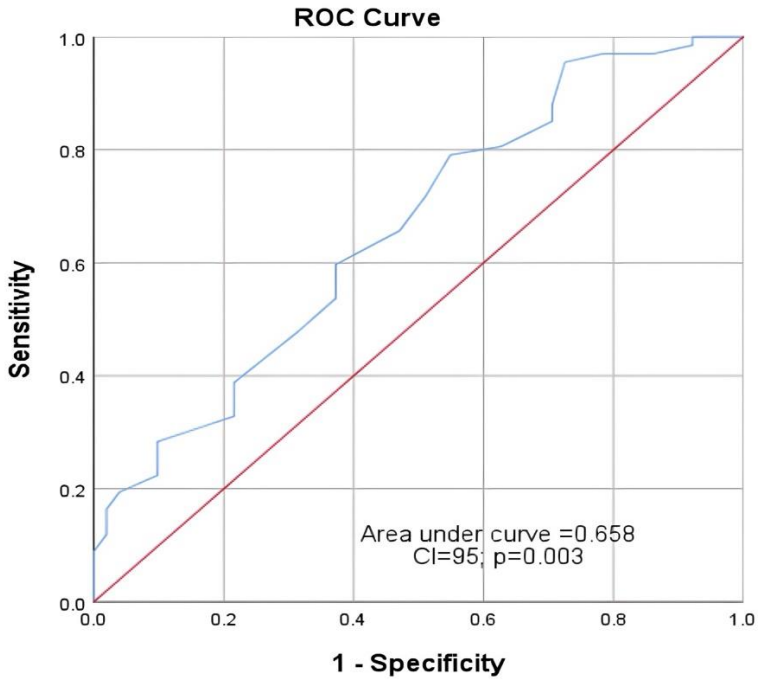


Figure 2. Receiver-operating characteristic curve analysis: area under the curve of QRS duration is associated with left ventricular systolic dysfunction.

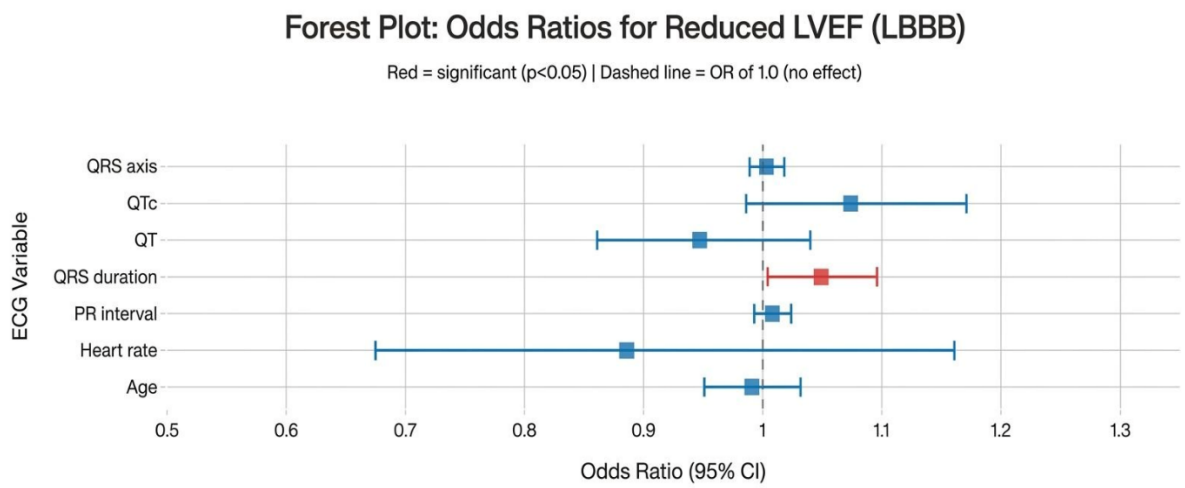


Figure 3. Forest plot of odds ratios for reduced LVEF
LBBB: left bundle branch block; LVEF: left ventricular ejection fraction

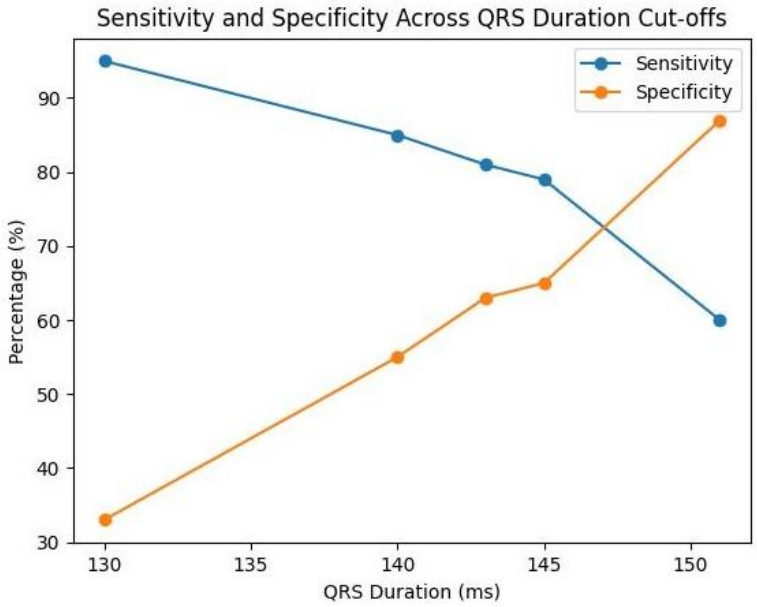


Figure 4. Sensitivity and specificity of different QRS duration cutoff values for stratification of patients with LBBB according to left ventricular systolic dysfunction.
LBBB: left bundle branch block

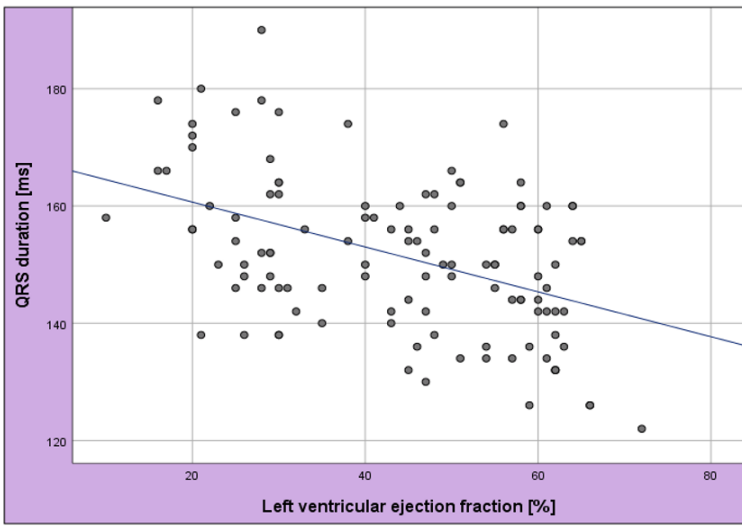


Figure 5. Scatter plot showing the negative correlation between QRS duration and left ventricular ejection fraction

Discussion

Throughout this discussion, LVEF denotes the quantitative echocardiographic measurement, whereas LV systolic dysfunction represents the functional condition, defined here by an LVEF below 50%. The 2 terms are used accordingly and are not treated as synonymous. In the LBBB group, participants with reduced LVEF were more prevalent than in the pacemaker group at baseline. Among participants with reduced LVEF, mean LVEF was lower in the LBBB group than in the pacemaker group (mean [SD], 33% [10%] vs 38% [9%]), and mean LAVI was correspondingly higher in the LBBB group. Participants with LBBB showed a higher rate of altered ECG morphology at baseline. In the pacing group, a broad, notched, or slurred R wave in leads I, aVL, V_5, and V_6 was significantly more frequent among participants with reduced LVEF (67.4% vs 40.9%; P=.002), whereas in the LBBB group. this feature was not significantly associated with LVEF (85.1% vs 76.5%; P=.235). No other statistically significant associations between ECG variables and LVEF were found.

In the LBBB group, absent lateral q waves were more frequent among participants with preserved LVEF than among those with reduced LVEF (84.3% vs 65.7%; P=.023). The presence of lateral q waves was, therefore, associated with reduced LVEF. A QRS duration threshold of 143 milliseconds was associated with reduced LVEF with modest discriminatory accuracy. Among the continuous ECG variables, only QRS duration was significantly associated with LVEF. Although the discriminatory accuracy of this threshold was modest and its direct clinical application as a stand-alone test is, thus, limited, this does not diminish the scientific value of the findings. To our knowledge, this is among the first studies to directly compare the association between ECG parameters and LVEF in individuals with intrinsic LBBB vs RV pacing. Moreover, the observation that this association differs between the 2 groups is a novel, hypothesis-generating contribution that warrants confirmation in larger, prospective cohorts.

This direction of association is physiologically coherent. Absence of q waves in leads I, aVL, V_5, and V_6 is itself a defining feature of uncomplicated LBBB, reflecting reversal of septal activation. Accordingly, the presence of lateral q waves in a participant with LBBB is an anomalous finding, commonly attributed to underlying myocardial scar. Its association with reduced LVEF in our data is consistent with that interpretation.

LAVI was higher among participants with reduced LVEF in both groups. This association should be interpreted with caution and not as evidence of an independent mechanistic relationship. LA enlargement is an expected downstream consequence of chronically elevated LV filling pressure and diastolic dysfunction, both of which accompany impaired LV systolic function. The higher LAVI observed in participants with reduced LVEF is, therefore, best regarded as a marker of the hemodynamic burden associated with systolic dysfunction rather than as a contributor to it.

Baseline analysis showed that participants were of similar age across the 2 groups. The modest male predominance in both dysfunction subgroups does not support male sex as a marker of low LVEF. In participants with LBBB, QRS duration was the only continuous variable significantly associated with LVEF. Conversely, in the pacing group, no continuous ECG variable was significantly associated with LVEF. Thus, although the QRS morphology of participants with RV pacing resembles that of LBBB, the statistical relationship between ECG variables and LVEF differed between the 2 groups.

Shenkman et al[13] reported that approximately 1 in 3 participants with HF had LBBB. LBBB has been shown to be an adverse prognostic marker of LV dysfunction and an independent risk factor for cardiovascular death in the general population.[14] Abnormal electrical conduction in LBBB alters the normal depolarization pattern of the LV and the QRS axis. Park et al[15] reported that left-axis deviation in participants with LBBB might be a prognostic indicator of major adverse cardiovascular events, such as ventricular tachycardia or fibrillation, CRT implantation, HF, and cardiovascular mortality. The underlying electrophysiological abnormalities caused by abnormal LV activation in LBBB impair normal LV hemodynamics and systolic and diastolic function; consequently, LBBB is typically accompanied by LV dilatation and reduced LVEF.[16-18] In a prospective observational study, Bouqata et al[1]

also reported that participants with LBBB had substantially lower LVEF than those without LBBB. The evaluation of LVEF in participants with LBBB is, therefore, essential.

Several studies have reported an inverse correlation between QRS duration and LVEF.[19–22] Nevertheless, this relationship has not been thoroughly examined by comparative analysis in participants with LBBB and RV pacing. The present study found that, although the ECG morphology of participants with RV pacing is comparable to the LBBB pattern, the relationship between ECG variables and EF differs between the 2 groups.

Our analysis was deliberately confined to univariable testing. Although LBBB and RV pacing are both relatively frequent phenomena, the stringent inclusion and exclusion criteria used in the current investigation-including exclusion of atrial fibrillation and flutter, severe valvular disease, and any devices that incorporate ICD/CRT and atrial/LV pacing-resulted in a relatively infrequent participant group at a single-center level. Thus, the recruited cohorts (n=118 for LBBB and n=178 for pacing) were carefully selected to ensure that the association between ECG and LVEF was retained without dilution from broader samples. As a result of having only 46 events in the pacing cohort with reduced LVEF, use of a multivariable model would likely lead to overfitting and provide biased estimates. Thus, the emphasis on the univariable approach is highlighted as a limitation of our study.

Limitations

The present study has several limitations. First, it was a single-center, retrospective observational analysis without longitudinal follow-up or time-to-event data; therefore, the findings describe associations rather than predictive or causal relationships. Second, although the strict eligibility criteria contributed to the internal validity of the relationship between ECG and LVEF, the modest sample sizes and limited number of outcome events prevented reliable multivariable modeling, and residual confounding factors cannot be excluded. Third, potentially important covariates were not analyzed: chronic kidney disease and the distinction between complete and incomplete LBBB were not recorded consistently for all participants and were excluded to avoid degrading statistical accuracy through missing data, and medication data were not available for analysis. Fourth, for the pacing cohort, reliable information was not available regarding pacing burden (percentage of ventricular pacing), ventricular lead position (apical vs septal), pacing mode, or time since implantation, all of which are recognized determinants of pacing-induced LV dysfunction; this limits the interpretation of the pacing analysis. Fifth, the duration of ventricular dyssynchrony before assessment was unavailable; neither the time since pacemaker implantation nor the onset of native LBBB could be established, and disease duration is a determinant of ventricular remodeling. Sixth, severe valvular disease was formally listed as an exclusion criterion only in the LBBB cohort. Although significant valvular disease was uncommon in the pacing cohort, this inconsistency is acknowledged, as is the fact that excluding atrioventricular block (a leading indication for permanent pacing) narrows the pacing population and may limit generalizability. Seventh, because enrollment spanned approximately 10 years, echocardiographic protocols underwent only minor refinements while ECG standards remained essentially unchanged. Despite the fact that these variations are unlikely to have materially affected the results, residual temporal measurement variability cannot be entirely excluded. Finally, the results derive from a single center and require external validation in larger, multicenter cohorts.

Conclusion

Although the ECG pattern of participants with RV pacing from permanent cardiac pacemakers resembled that of LBBB, its relationship with LV dysfunction differed. In participants with LBBB, longer QRS duration and the presence of q waves in leads I, aVL, V_5, and V_6 were associated with reduced LVEF, whereas in participants with RV pacing, a broad, notched, or slurred R wave in leads I, aVL, V_5, and V_6 was associated with reduced LVEF. To our knowledge, this is among the first studies to directly compare the association between ECG parameters and LVEF in intrinsic LBBB by comparison with RV pacing. Even though the discriminatory accuracy of individual parameters was modest, the finding that this association differs between the 2 groups is a novel

contribution that warrants confirmation in larger, prospective studies.

Declarations:

Ethical Approval

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki (revised 2013). The retrospective analysis of de-identified electronic medical records was approved by the nstitutional Review Board of the Samarkand Branch of the Republican Specialized Scientific-Practical Medical Center of Cardiology. Due to the retrospective nature of the study and the use of anonymized medical records, the requirement for individual patient informed consent was waived by the ethics committee. All patient data were handled confidentially throughout the study.

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Conflict of Interest

The authors report no conflict of interest.

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