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Novel ECG criteria for right ventricular systolic dysfunction in patients with right bundle branch block

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ABSTRACT

Background: Altered hemodynamics of a failing right ventricle (RV) may place stress on the right bundle branch and Purkinje network, which may be evident as conduction delay on surface electrocardiogram (ECG). We hypothesized that prolonged R′ duration in lead V1 would be an indicator of RV dysfunction in patients with RBBB.

Methods: The Mayo Clinic Arizona echocardiography database was reviewed from 2007 to 2009 to identify patients with RV dysfunction and coexistent right bundle branch block (RBBB). Specific ECG features of RBBB were compared between the RV dysfunction cohort and a randomly selected control population. Features found to be predictive of RV dysfunction were then tested on 100 consecutive patients with RBBB on ECG between January and June 2010.

Results: In lead V1, the QRS duration was longer in the RV dysfunction cohort (164 ± 22 ms) compared to controls (148 ± 12 ms), predominantly due to R′ prolongation (117 ± 27 ms vs. 87 ± 13 ms, $p<.001$). Retrospective analysis suggested that V1 R′ duration ≥ 100 ms may be 82.3% specific for the presence of RV systolic dysfunction. When applied prospectively, V1 R′ duration ≥ 100 ms yielded sensitivity and specificity of 39.0% and 82.9% respectively for detection of abnormal RV systolic function with a positive predictive value of 76.7%.

Conclusion: Lead V1 R′ duration ≥ 100 ms is predictive of RV systolic dysfunction in patients with RBBB.

1. Introduction

Right bundle branch block (RBBB) is a common electrocardiographic (ECG) finding present in patients with or without underlying structural heart disease [1]. Common causes of RBBB include longstanding hypertension, coronary artery disease, congestive heart failure, degenerative conduction system disease, and cor pulmonale [2–4].

The right bundle branch is a structure that travels in the subendocardium of the right ventricular (RV) septum. It courses anteriorly and apically toward the distal RV septum where it arborizes into a network of intermyocardial fascicles, known as Purkinje fibers, that promote rapid conduction of electrical impulses to the myocardium [5,6]. In some cases, elevated RV pressure and/or volume can place stress on the right bundle branch and its associated Purkinje network, which may affect its electrical properties resulting in conduction delay or block. This conduction delay may manifest on 12-lead ECG as increased QRS duration. In RBBB, the duration of the initial portion of the QRS complex remains unchanged or is only minimally delayed, whereas the later portion of the QRS complex (i.e. R′ wave) widens as it reflects unopposed slow conduction across the RV myocardium [4]. With worsening RV dysfunction, conduction across the RV myocardium would be expected to become delayed and may be detectable as R′ prolongation on the surface ECG.

Recognition of RV dysfunction is clinically important, because impairment of RV systolic function is independently associated with adverse outcomes and may require careful adjustment of therapeutics [7–13]. The surface ECG may serve as a simple tool for detection of underlying RV dysfunction in patients with RBBB. We hypothesized that prolonged R′ duration in lead V1 would be an indicator of RV dysfunction in patients with RBBB.

2. Methods

The study was approved by the Mayo Clinic Institutional Review Board. The study included an initial retrospective analysis to define ECG criteria associated with RV dysfunction in patients with RBBB. Validation was subsequently performed by

Abbreviations: ECG, electrocardiogram; LR−, negative likelihood ratio; LR+, positive likelihood ratio; mm, millimeters; ms, milliseconds; mV, millivolts; NPV, negative predictive value; PPV, positive predictive value; RBBB, right bundle branch block; ROC, receiver operating characteristic; RV, right ventricle; SD, standard deviation; TAM, tricuspid annular motion; yrs, years.

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applying the newly developed criteria to 100 consecutive patients presenting with RBBB on ECG.

The initial component of the study was a case–control design that compared ECG features of RBBB in a cohort of patients with RV systolic dysfunction to a randomly selected control population with RBBB and normal RV systolic function. The RV dysfunction cohort was identified by searching the Mayo Clinic echocardiography database from January 2007 through June 2009 for patients imaged at Mayo Clinic Arizona with an echocardiographic impression of RV systolic dysfunction. ECGs of all RV dysfunction patients were then reviewed, and all individuals with coexistent RV dysfunction and complete RBBB were included. Using a computerized random number generator, a control group was randomly selected from all patients found to have complete RBBB on ECG at our institution over the same time period. Echocardiograms of the controls were reviewed for confirmation of preserved RV systolic function. Exclusion criteria for the control group included bifascicular block, RV systolic dysfunction, or congenital heart disease. Subjects with a paced rhythm or prior tricuspid valve surgery were excluded from both groups.

In the second part of the study, ECG measurements associated with RV dysfunction in the retrospective analysis were tested in a prospective review of 100 consecutive patients with RBBB who also underwent echocardiography at our institution from January to June 2010. Patients with a paced rhythm or prior tricuspid valve surgery were excluded. ECGs and echocardiograms were reviewed independent of one another by two different investigators in a blinded fashion.

Demographic and comorbidity data were obtained from the medical record. ECGs recorded closest to the time of the 2D echocardiogram were carefully reviewed for all patients. Complete RBBB was defined by standard criteria [14]. All ECG measurements were performed using MUSE Editor software version 7.1.1 (General Electric Company, Fairfield, CT). The software provides an electronic caliper tool that is accurate to 4 ms. Specific measurements included QRS duration, R′ wave duration and amplitude, and R′:QRS duration ratio in lead V1. Amplitude measurements were defined as maximum deviation from the isoelectric line. A sample of the ECG measurements performed is illustrated in Fig. 1.

Two-dimensional echocardiograms were reviewed for all patients included in the study. RV systolic function was assessed by measuring displacement of the tricuspid annulus during systole from the apical 4-chamber view using ProSolv software version 3.0 (ProSolv CardioVascular, Indianapolis, IN). RV systolic dysfunction was defined as tricuspid annular motion (TAM) <16 mm, as indicated by echocardiography guidelines [15]. TAM measurement is demonstrated in Fig. 2.

Statistical analysis was completed using SAS analytical software version 9.1.3 (SAS Institute Inc., Cary, NC). All continuous variables were tested for normality of distribution. Student's t-tests were conducted to evaluate continuous variables and a 2-tailed Fisher's exact test was used to assess nominal data. Receiver operating characteristic (ROC) curves were used to determine appropriate limits of ECG measurements that were predictive of RV systolic dysfunction. Statistical significance was set at $p<0.05$.

3. Results

The Mayo Clinic echocardiography database included 19,688 patients who underwent echocardiography at Mayo Clinic Arizona from January 2007 through June 2009. From this population, 34 cases were identified as having RV dysfunction and concomitant RBBB. Clinical diagnoses of patients with RV dysfunction are listed in Table 1. Cases were compared with a control population that was randomly selected from 4617 patients found to have RBBB on ECG over the same time period. Thirty-four controls with RBBB and normal RV function on 2D echocardiography were identified.

The clinical characteristics of the study participants are summarized in Table 2. Compared to controls, the RV dysfunction cohort had a greater prevalence of coronary artery disease, lower left ventricular ejection fractions, and higher RV systolic pressures. A difference in overall tobacco use was observed with more active smokers identified in the RV dysfunction group and more patients with a remote smoking history in the control group. Nonsmokers were similar between the two groups. Medical therapy was similar between the two groups with the exception of a trend toward more frequent amiodarone use in the RV dysfunction cohort.

Mean TAM was 22.1 ± 3.5 mm for controls and 7.4 ± 3.1 mm for patients with RV dysfunction ($p<.001$). All patients in the control group were in sinus rhythm. Rhythms for the RV dysfunction cohort included five patients with atrial fibrillation and two patients with atrial flutter. All others were in sinus rhythm at the time of the study.

A comparison of ECG measurements is listed in Table 3. Mean V1 QRS duration was 16 ms longer in the RV dysfunction cohort relative to the control group ($p<.001$). Similarly, mean V1 R′ duration was 30 ms longer in RV dysfunction patients relative to controls, and R′ duration consumed a mean 71% of the total QRS duration in the RV dysfunction cohort compared to 58% in the control group ($p<.001$). ROC curves were developed to define ECG criteria that would be predictive of RV systolic dysfunction in patients with RBBB (Fig. 3).

The ECG criteria developed in the retrospective analysis were then applied to 100 consecutive cases of RBBB that presented from January to June 2010. The population was 69% male with mean age 62 ± 18 years. Seven were in atrial fibrillation with all others in sinus rhythm. Five patients were taking antiarrhythmic drugs. The mean time from ECG to echocardiogram was 16 ± 32 days. Overall, the mean ejection fraction was $56\pm15\%$. A total of 59 patients were found to have TAM <16 mm, which for the purposes of this study classified them having abnormal RV systolic function. Patients with impaired RV systolic function were younger (58 ± 21 years vs 69 ± 10 years, $p<.001$) and had lower left ventricular ejection fraction ($51\pm17\%$ vs $63\pm8\%$, $p<.001$) compared to those with preserved RV systolic function. Demographics were otherwise similar between the two groups.

V1 R′ duration ≥100 ms continued to be associated with the presence of RV systolic dysfunction, occurring in 23/59 (39%) of patients with TAM <16 mm versus 7/41 (17%) of patients with TAM >16 mm ($p=.03$). Lead V1 QRS duration ≥150 ms was observed in 27/59 (45.8%) patients with impaired RV function compared to 11/41 (26.8%) of those with normal RV function ($p=0.06$). V1 R′ duration ≥100 ms was 39.0% sensitive and 82.9% specific for abnormal RV systolic function. The ratio of R′:QRS duration was not associated with RV dysfunction ($p=.29$) and the addition of this parameter did not significantly augment the sensitivity or specificity of R′ duration alone. The validation results are organized in Table 4.

4. Discussion

The presence of RV dysfunction is of high clinical significance as it has both prognostic and therapeutic implications in patients with cardiopulmonary disease. Poor RV function is a predictor of mortality in patients with pulmonary hypertension, and the presence of RV dysfunction has been associated with development of heart failure and reduced survival in patients suffering myocardial infarction

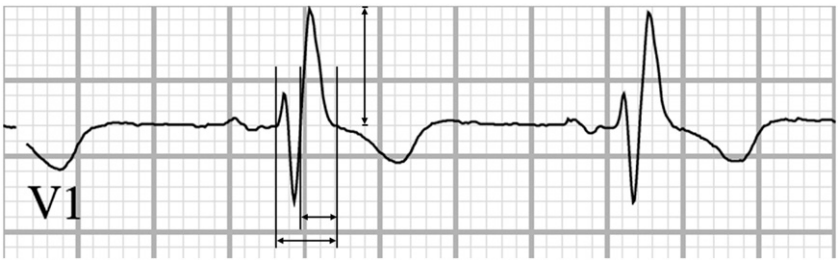

Fig. 1. Sample of ECG measurements performed. A representation of ECG measurements from a patient with RV dysfunction. All amplitude measurements were defined as deviation from the isoelectric line. QRS duration, R′ duration, and R′ amplitude were measured in lead V1. Abbreviations: ECG, electrocardiogram; RV, right ventricular.