Electrocardiographic QRS Duration Reflects Right Ventricular Remodeling in Patients Undergoing Corrective Surgery for Isolated Tricuspid Regurgitation: A Comparative Study with Cardiac Magnetic Resonance Imaging

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ABSTRACT

Background: The role of electrocardiogram (ECG) is unclear for the longitudinal follow-up of patients who undergo corrective surgery for isolated severe tricuspid regurgitation (TR).
Hypothesis: This study sought to investigate the usefulness of changes in QRS duration of ECG after TR surgery in predicting right ventricular (RV) reverse remodeling as determined by cardiac magnetic resonance imaging (CMR).
Methods: We enrolled 30 consecutive TR patients (27 women, aged 57.8 ± 9.6 years) who had undergone prior left-sided valve surgery. A computer-assisted analysis was performed for objective calculation of QRS duration before and after surgery.
Results: At a median CMR follow-up of 27.5 months postsurgery, QRS duration was cut by 14.6%, from 110.4 ± 14.6 msec to 96.9 ± 11.9 msec ($P < 0.001$), while CMR showed a decrease in RV end-diastolic volume index (RV-EDVI) from 179.5 ± 59.7 to 119.1 ± 30.4 mL/m² ($P < 0.001$). QRS duration correlated significantly with RV-EDVI and RV end-systolic volume index ($r = 0.65$, $P < 0.001$ and $r = 0.53$, $P < 0.001$, respectively), and a percent change in QRS duration was significantly correlated with a percent change in RV-EDVI ($r = 0.40$, $P = 0.03$). When significant RV reverse remodeling was defined as a reduction in RV-EDVI $\geq$20% following TR surgery, the sensitivity and specificity for significant RV reverse remodeling were 75% and 78%, respectively, with a 9% reduction in QRS duration ($P = 0.01$, area underneath the receiver operator curve [AUC] = 0.81).
Conclusions: The extent of changes in postoperative QRS duration can be used as a useful, inexpensive, and simple index reflecting the occurrence of significant RV reverse remodeling in patients undergoing corrective TR surgery.

Introduction

Tricuspid regurgitation (TR) is known to be an important complication in patients who have previously undergone left-sided valve surgery.[1–4] In contrast to the false belief in the past that TR is rare and clinically insignificant, recent studies have clearly demonstrated that TR is not a rare disease, and its prevalence is in fact rapidly increasing.[3–5] In addition, the development of late TR after left-sided valve surgery is closely linked to exercise intolerance and poor quality of life.[6,7] Nevertheless, the absence of consensus guideline leads many patients to miss the appropriate window to undergo corrective TR surgery, which may contribute to a poor prognosis for these patients,[5,8–10] even in the absence of left ventricular (LV) dysfunction or pulmonary hypertension.[11] Timely correction of severe TR should carry acceptable risks and improve functional capacity.[5,12]

Quantitative assessment of the change in right ventricular (RV) volumes before and after corrective TR surgery using echocardiography, the technique most frequently used to assess cardiac hemodynamics, is difficult, primarily due to the complex geometry of the RV, and requires high expertise. As such, cardiac magnetic resonance imaging (CMR) has emerged as the reference standard imaging modality for quantitative assessment of RV volumes.[13–15] More importantly, a potential role of CMR in patients undergoing corrective TR surgery has recently been

First two authors equally contributed to this work.

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illustrated.[12] However, the relatively high cost of CMR is a serious obstacle to its routine performance in patients before and after corrective TR surgery in clinical practice. Apart from its high cost, patients with claustrophobia or an implanted pacemaker cannot undergo CMR. Hence, the development of a simple, inexpensive, and widely applicable modality that is able to reflect changes in RV volume might be helpful for longitudinal follow-up of RV hemodynamics in patients undergoing corrective TR surgery.

The surface 12-lead electrocardiogram (ECG) is generally accepted as a widely used, inexpensive, and noninvasive screening test. A few earlier reports have shown QRS duration to be closely associated with RV dilatation in patients with repaired tetralogy of Fallot.[16–18] Accordingly, we hypothesized that QRS duration on ECG might provide reliable information on corrective TR surgery-induced RV remodeling in patients with severe TR. If so, this method may be considered a simple and inexpensive surrogate that could be employed as a screening tool prior to CMR performance before and after corrective TR surgery.

Therefore, the aim of our study was as follows: (1) to explore the relationship between QRS duration on ECG and CMR-determined RV volumes; and (2) to assess whether changes in QRS duration could reflect TR surgery-induced changes in CMR-determined RV volumes.

Methods

Study Population

From May 2004 to July 2008, 61 patients with severe TR who had undergone previous left-sided valve surgery underwent CMR prior to corrective TR surgery. Of these 61 patients, 54 underwent preoperative CMR and were considered initial candidates for the present study. The decision to perform preoperative CMR was totally at the discretion of the attending surgeon. Of these 54 patients, 7 had echocardiographic evidence of left-sided valve dysfunction (3 patients with a prosthetic aortic valve and 4 patients with a prosthetic mitral valve), 4 rejected follow-up performance of CMR, 6 passed away during the study period, 3 had suboptimal quality of preoperative CMR data for analysis, 3 could not undergo follow-up CMR due to an implanted pacemaker, and 1 was lost to follow-up. Consequently, the follow-up CMR was performed in the remaining 30 patients, who are the subject of this report.

All patients satisfied the following 3 criteria for severe TR on preoperative echocardiography: (1) TR jet area >30% of the right atrial area; (2) inadequate cusp coaptation of tricuspid leaflets; and (3) systolic flow reversal in the hepatic vein. Patients with documented organic disease in the tricuspid valve were excluded based on echocardiographic, surgical, and pathological findings. All patients were treated according to our routine clinical protocol. The study protocol was approved by the institutional review board of our hospital.

CMR Performance

CMR was performed with a 1.5-Tesla system (Sonata Magenetom; Siemens, Erlangen, Germany) before and after TR surgery. Postoperative CMR was repeated using the same protocol and the same machine in all patients. All images were acquired using a phased-array body surface coil during breath holds. Image procurement was triggered by ECG. After localizer imaging, cine true fast imaging with steady-state precession imaging (TrueFISP, repetition time/echo time 45 msec/1.3 msec, flip angle 80°, matrix 256 × 169, field of view 330 × 330 mm, slice thickness 8 mm) was performed in several long-axis planes (2-, 3-, and 4-chamber views) of the heart. Parallel short-axis sections from the valve plane to the apex were acquired for volumetric analysis. RV and LV end-diastolic (EDV) and end-systolic volumes (ESV), cardiac output, and ejection fractions (EF) were measured using dedicated software (QMASS MR; Medis, Leiden, the Netherlands). Ventricular volumes and cardiac output were corrected for body surface area.

Velocity-encoding cine CMR with free breathing and prospective ECG gating (repetition time/echo time 45 msec/3.2 msec, flip angle 30°, matrix 256 × 238, field of view 330 × 330 mm, slice thickness 5 mm) was performed in a plane orthogonal to the right and left pulmonary arteries to allow for calculation of the net forward volume of the RV. Flow profiles of the right and left pulmonary arteries were analyzed on velocity-encoding cine CMR images using specialized software (Argus; Siemens Medical Solutions). The contours of each pulmonary artery were automatically traced, with manual correction if necessary, on magnitude and velocity-map images of all 20 reconstructed phases. All measurements were performed by 1 independent observer.

The amount of TR was calculated by subtracting net pulmonary blood volume of the right and left pulmonary arteries from the RV stroke volume. TR fraction was calculated by dividing TR amount by the RV stroke volume and was expressed as a percentage. After RV ejection fraction (RV-EF) calculation, RV-EF was corrected for TR flow by dividing the net pulmonary forward flow (the sum of the flows in the right and left pulmonary arteries) by RV-EDV, ie, effective RV-EF (eRV-EF) = net pulmonary forward flow/RV-EDV.[13]

ECG Measurements

In our hospital, all 12-lead ECGs have been digitally stored since 2001. In order to select the ECGs closest in time to the CMR performance, we screened all available ECGs of the study patients. Such ECGs were recorded a median of 5 days (interquartile range [IQR] 3.8–7.3 days) prior to and a median of 642 days (IQR 296–1038 days) after corrective TR surgery. The preoperative ECGs closest in time to the preoperative CMR were recorded a median of 4 days (IQR 1–28.8 days) prior to CMR performance. The time difference between postoperative ECGs and the postoperative CMR were a median of 96 days (IQR 2.25–125 days).

All ECG analyses were conducted in a random order by 1 independent cardiologist who did not know the ECG date. For the analyses, standard resting 12-lead ECGs (speed, 25 mm/s and 1 mV/cm standardization) were used. To consistently detect points of interest on ECGs, a semiautomatic computer-assisted analysis program was adopted. First, a 12-lead ECG was imported and presented on the computer screen. Then, the onset and the end of the QRS complex were automatically identified. At this point, manual adjustment of the intervals could be made if necessary. The QRS duration was defined as the maximal

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QRS length in any lead from the first inflection to the final sharp vector crossing the isoelectric line, ascertained by using the zoom function of the analysis program to determine the most accurate point of the QRS complex. The dispersion of QRS duration was defined as the difference in QRS length between the longest and the shortest intervals in any of the 12 leads.

Statistical Analysis

Data are expressed as means ± SDs or median with IQR for continuous variables and as numbers (%) for categorical variables, as appropriate. Two-sided paired *t* test or the Wilcoxon signed rank test was employed for comparison of preoperative versus postoperative data, depending on the results of normality testing using Shapiro-Wilk test. Pearson's correlation coefficient was calculated to quantify correlations between the continuous variables. To identify the optimal cutoff value for changes in QRS duration for predicting significant RV reverse remodeling (defined as a reduction in RV end-diastolic volume index [RV-EDVI] ≥20%), a receiver-operating characteristic curve analysis was employed. The cutoff value was defined as one with maximal sum of the sensitivity and specificity. SPSS version 17.0 was used for statistical analyses. A probability value of $P < 0.05$ was considered statistically significant.

Results

Patient Characteristics

Baseline characteristics of the 30 patients (mean age, 57.8 ± 9.6 years) are summarized in Table 1. Twelve patients (40%) were in New York Heart Association (NYHA) functional class II, 17 (56.7%) were in class III, and 1 (3.3%) was in class IV. Twenty-four patients were on atrial fibrillation and 27 patients were female. Median follow-up time for CMR after TR surgery was 27.5 (range, 18–36) months. At the time of the previous left-sided valve surgery, tricuspid valvuloplasty was performed in 2 patients and tricuspid annuloplasty was done in 4 patients, due to significant TR and/or tricuspid annular dilation. The median time interval between the previous left-sided valve surgery and the current TR surgery was 216 months (range, 96–348 months). Eleven of 30 patients (36.7%) had a right bundle branch block on ECGs before TR surgery. No patient had a left bundle branch block pattern on ECGs. There was no patient who developed a new right or left bundle branch block after surgery.

Table 1. Clinical Characteristics of Patients Enrolled

Variables	(n = 30)
Age (years)	57.8 ± 9.6
Male/female	3/27
Weight (kg)	53.7 ± 9.3
Height (cm)	154.6 ± 7.1
Preoperative functional class	
I	0
II	12
III	17
IV	1
Type of previous valve surgery	
MVR (mechanical vs bioprosthetic)	29 (28 vs 1)
MVP	1
TVP	2
TAP	4
AVR (mechanical vs bioprosthetic)	13 (13 vs 0)
Type of TR surgery	
TVR	26
TAP only	1
TVP and TAP	3
Cardiac rhythm	
Sinus	6
Atrial fibrillation	24
Medications	
Digoxin	19
ACEi or ARB	6
Beta-blockers	4
Loop diuretics	19
Spironolactone	23
Thiazide	4

Abbreviations: ACEi, angiotensin-converting enzyme inhibitors; ARB, angiotensin-receptor blockers; AVR, aortic valve replacement; MVP, mitral valvuloplasty; MVR, mitral valve replacement; TAP, tricuspid annuloplasty; TVP, tricuspid valvuloplasty.

Changes in Clinical and CMR Variables after Corrective TR Surgery

Corrective TR surgery significantly improved NYHA functional class from 2.6 ± 0.6 to 1.9 ± 0.7 ($P < 0.001$), without a significant change in heart rate ($P = 0.35$). As expected, a significant reduction in TR fraction was noted, from 48.4% ± 16.2% presurgery to 1.4% ± 3.8% postsurgery ($P < 0.001$), with only 1 patient having more than mild TR following corrective surgery for severe TR (Table 2).

There was a significant decrement in RV-EF after TR surgery, whereas eRV-EF increased by approximately 36.5% (28.4% ± 11.3% preoperatively vs 49.5% ± 14.7% during follow-up, $P < 0.001$). Corrective TR surgery resulted in a significant reduction in RV volumes, including RV-EDVI (from 179.5 ± 59.7 to 119.1 ± 30.4 mL/m^2, $P < 0.001$) and RV end-systolic volume index (RV-ESVI) (from 86.6 ± 29.6 to 69.5 ± 31.3 mL/m^2, $P = 0.005$). The RV-EDVI returned to the normal range (defined as <108 mL/m^2) in 11 patients (36.7%), whereas RV-ESVI (defined as <47 mL/m^2) normalized in 7 patients (23.3%). In terms of LV volumes,

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Table 2. Changes in Clinical, CMR, and ECG Variables Induced by Surgical Correction of TR in 30 Patients

Variables	Before Surgery	After Surgery	Difference (%)	P
Clinical variables				
HR (bpm)	70 ± 12	74 ± 20	0.7 ± 27.7	0.35
Median (IQR)	68 (63–75)	72 (62, 84)	–	
NYHA Fc	2.6 ± 0.6	1.9 ± 0.7	–	<0.001
BSA (g/m²)	1.5 ± 0.1	1.5 ± 0.1	2.3 ± 7.9	0.10
CMR variables				
RV-EDVI (mL/m²)	179.5 ± 59.7	119.1 ± 30.4	−52.1 ± 64.2	<0.001
RV-ESVI (mL/m²)	86.6 ± 29.6	69.5 ± 31.3	−37.5 ± 53.1	0.005
RV-EF (%)	51.7 ± 6.3	43.2 ± 14.0	−38.4 ± 67.6	0.005
Median (IQR)	52.9 (46.7–56.8)	42.0 (35.2–56.2)	—	
eRV-EF (%)	28.4 ± 11.3	49.5 ± 14.7	36.5 ± 34.1	<0.001
LV-EDVI (mL/m²)	99.7 ± 26.4	125.0 ± 32.6	16.7 ± 28.1	<0.001
LV-ESVI (mL/m²)	48.1 ± 20.2	68.2 ± 29.4	19.7 ± 42.4	0.001
Median (IQR)	45.0 (33.6–60.4)	65.5 (44.3–87.5)	—	
LV-EF (%)	53.1 ± 10.9	48.4 ± 12.0	−17.1 ± 41.1	0.12
CI (L/min/m²)	3.5 ± 0.8	4.1 ± 0.9	11.1 ± 25.6	0.001
TR fraction (%)	48.4 ± 16.2	1.4 ± 3.8	−95.7 ± 12.0	<0.001
Median (IQR)	49.7 (35.7–61.0)	0 (0–0)	—	
TR grade > mild (%)[a]	30 (100)	0 (0)	—	<0.001
ECG variables				
QRS duration (msec)	110.4 ± 14.6	96.9 ± 11.9	−14.6 ± 14.4	<0.001
QRS dispersion (msec)	13.3 ± 4.3	12.7 ± 4.2	−15.4 ± 51.4	0.55

Abbreviations: bpm, beats per minute; BSA, body surface area; CI, cardiac index; CMR, cardiac magnetic resonance image; ECG, electrocardiographic; EF, ejection fraction; HR, heart rate; IQR, interquartile range; LV, left ventricle; NYHA Fc, New York Heart Association functional class; RV-ED(S)VI, right ventricular end-diastolic (systolic) volume index; (e)RV-EF, (effective) right ventricular ejection fraction; TR, tricuspid regurgitation. [a]TR grade was determined based on follow-up echocardiographic findings.

significant increases in LV-EDV index (LV-EDVI) and LV end-systolic volume index (LV-ESVI) were demonstrated (for LV-EDVI, 99.7 ± 26. vs 125.0 ± 32.6 mL/m^2, $P < 0.001$; for LV-ESVI, 48.1 ± 20.2 vs 68.2 ± 29.4 mL/m^2, $P = 0.001$), without a significant change in LV-EF before versus after TR surgery, despite a trend toward a slight decrease after TR surgery (53.1 ± 10.9% vs 48.4 ± 12.0%, $P = 0.12$). The cardiac index (CI) showed a significant rise postoperatively (3.5 ± 0.8 vs 4.1 ± 0.9 L/min/m^2, $P = 0.001$).

Changes in ECG Variables in Relation to Changes in CMR Variables

Successful surgical correction of TR led to a 14.6% decrease in QRS duration ($P < 0.001$) (figure 1), whereas no significant changes were noted in terms of QRS dispersion ($P = 0.55$) (Table 2). When pre- and postoperative values were combined, QRS duration was significantly correlated with RV-EDVI ($r = 0.65$, $P < 0.001$), RV-ESVI ($r = 0.53$, $P < 0.001$), and eRV-EF ($r = -0.52$, $P < 0.001$) (figure 2A–C, respectively). The relationship between the change in QRS duration and the change in RV-EDVI is presented in Figure 3.

A significant correlation was found between percent changes in QRS duration after corrective TR surgery and its respective preoperative value ($r = -0.58$, $P < 0.001$) (figure 4). Of interest, we could not identify an upper limit, above which QRS duration did not decrease after corrective TR surgery. A percentage change in QRS duration displayed a significant correlation with a percentage change in RV-EDVI ($r = 0.40$, $P = 0.03$) and a percentage change in LV-EDVI ($r = 0.21$, $P = 0.02$), but not with a percentage change in RV-ESVI ($r = 0.28$, $P = 0.14$), a percentage change in LV-ESVI ($r = 0.19$, $P = 0.11$) or a percentage change in LV-EF ($r = -0.03$, $P = 0.86$). When significant RV reverse remodeling was defined as a reduction in RV-EDVI ≥20% after corrective TR surgery, the sensitivity and specificity for predicting significant reverse remodeling of the RV postsurgery were 75% and 78%, respectively, with a

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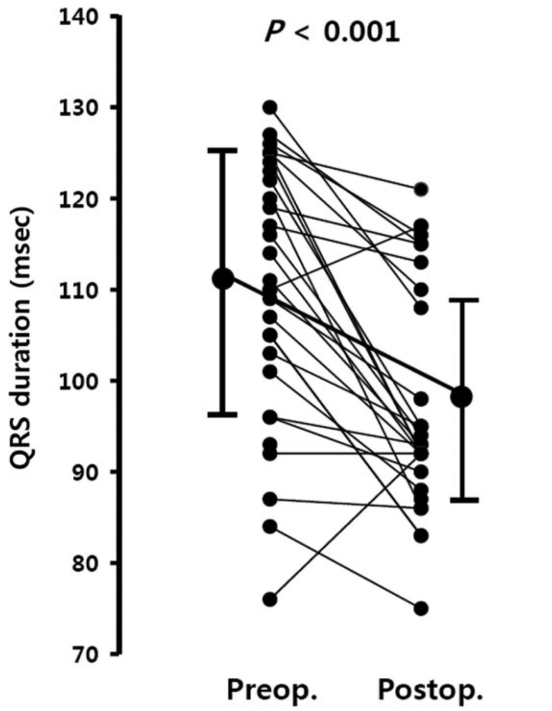

Figure 1. The changes in QRS duration following corrective TR surgery are shown on an individual basis. Abbreviation: TR, tricuspid regurgitation.

cutoff reduction in QRS duration value of 9% ($P = 0.01$, area under the curve = 0.81) (Figure 5).

When normal RV-EF was defined as ≥48% for males and ≥50% for females,[19] postoperative RV-EF values were within normal ranges in 13 patients (43.3%). We could not find any differences between patients with and without normal RV-EF after successful TR surgery in terms of pre- and postsurgical QRS duration ($P = 0.51$ and 0.08 for pre- and postsurgery QRS duration, respectively), QRS dispersion ($P = 0.22$ and 0.99 for pre- and postsurgery QRS dispersion, respectively), and changes in QRS duration ($P = 0.42$) or QRS dispersion ($P = 0.40$) after corrective TR surgery.

Measurement Variability

Inter- and intraobserver variabilities for measurement of QRS duration and QRS dispersion were determined by 2 independent blinded cardiologists who analyzed 10 randomly selected patients. These 2 observers showed correlations of $r = 0.99$ (standard error of estimate = 1.5) for QRS duration and $r = 0.93$ (standard error of estimate = 3.53) for QRS dispersion. In terms of intraobserver variability, the correlations were found to be 0.99 (standard error of estimate = 1.5) for QRS duration and 0.92 (standard error of estimate = 1.19) for QRS dispersion. Measurement reproducibility of CMR volumes was previously reported.[12]

Discussion

The principal findings of the present study can be summarized as follows: (1) QRS duration on the ECG obtained closest in time to CMR was positively correlated with RV-EDVI ($r = 0.62$) and RV-ESVI ($r = 0.53$); (2) corrective TR surgery led to significant RV reverse remodeling, as demonstrated by a 52.1% reduction in RV-EDVI, which was partially reflected by a concomitant change in QRS duration on the postsurgical ECG; and (3) a 9% reduction in QRS duration emerged as a potential cutoff value for significant RV reverse remodeling (defined as a reduction in RV-EDVI ≥20% postsurgery relative to preoperative RV-EDVI) following corrective TR surgery.

The development of late TR after left-sided valve surgery is not infrequently encountered and is well known to be closely linked to exercise intolerance and grave prognosis.[5–7,10–12] Moreover, the prevalence of functional TR development long after left-sided valve surgery is not rare and, in fact, it is more frequently recognized.[4] In addition, operative morbidity and mortality associated with corrective TR surgery are not negligible, as evidenced by our own previous reports and those of others.[4,5,10,12] This frequently causes cardiologists to hesitate in strongly recommending TR surgery to their patients. Given the unique ability of CMR to reliably assess RV hemodynamics, we previously reported that successful corrective TR surgery can accomplish a remarkable reduction in RV volumes in association with significant increases in LV preload and CI. This, in turn, contributed to significant amelioration in functional capacity of the patients.[12] Although there is no doubt on the usefulness of CMR in tracking RV hemodynamic changes after corrective TR surgery, high cost and time intensiveness of CMR are serious impediments to its routine performance in real world clinical practice for all patients before and after corrective TR surgery. Furthermore, CMR is difficult to perform in some patients with claustrophobia or who have a permanent pacemaker implanted. In this respect, an inexpensive, simple, and widely available screening modality is required for this population, which should significantly improve the quality of patient care, especially throughout longitudinal follow-up. In that situation, CMR could be reserved for highly selected patients in whom screening results are inconclusive or incompatible with clinical status.

The results of ECG represent an amplified signal of the electrical activity of the heart captured transthoracically over time. It is generally accepted as the most widely used, simple, inexpensive, time-saving, and noninvasive screening modality that is performed in almost all cardiac patients. Of the various ECG components, the QRS complex is known to reflect rapid depolarization of the ventricles and recently has received much attention in association with RV enlargement and the corresponding propensity for the development of arrhythmia.[16,17,19] A close relationship between QRS prolongation and RV-EDVI has been repeatedly reported in patients with repaired tetralogy of Fallot and significant pulmonary regurgitation.[16,17,19,20] A similar relationship between QRS duration and RV-EDVI has also been suggested in other congenital heart diseases.[19] However, the effort has not previously been made to use QRS duration or its dispersion throughout the 12 leads as a representative marker in predicting RV reverse remodeling in patients undergoing corrective surgery for severe TR.

Ventricular remodeling is one of the major mechanisms of heart failure progression, and its alleviation is known to be the primary mechanism for improvement in symptoms and clinical outcome in cardiac patients.[21–25] Thus,

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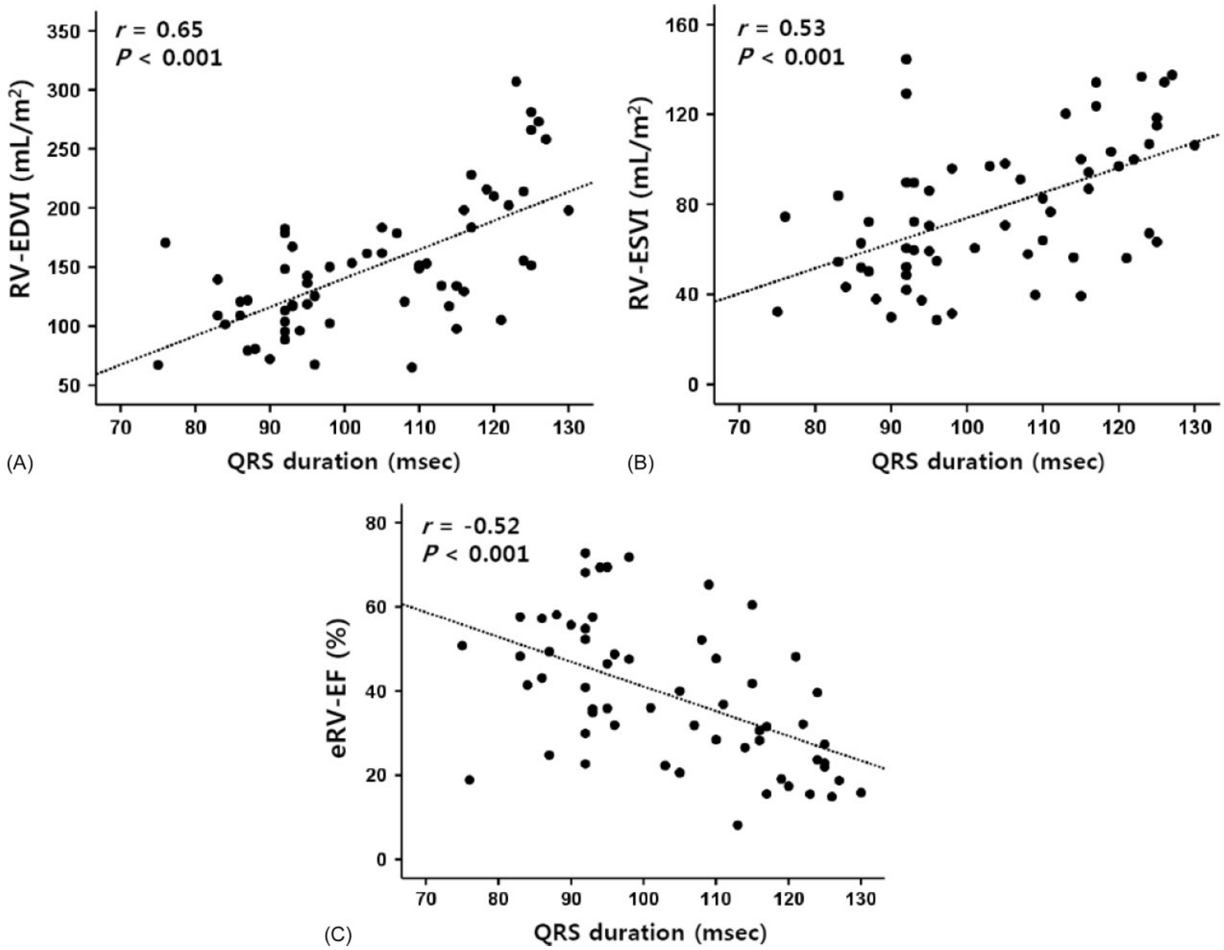

Figure 2. Associations between QRS duration on ECG and RV-EDVI (A), RV-ESVI (B), or eRV-EF (C) are illustrated. Data are presented as pooled preoperative and postoperative values. Abbreviations: ECG, electrocardiogram; eRV-EF, right ventricular ejection fraction corrected for tricuspid regurgitation flow, or effective RV-EF; RV-EDVI, right ventricular end-diastolic volume index; RV-ESVI, right ventricular end-systolic volume index.

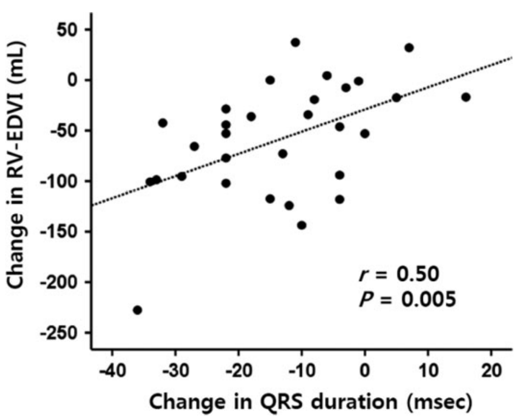

Figure 3. Scattergram showing the relationship between the change in QRS duration and the change in RV-EDVI. Abbreviation: RV-EDVI, right ventricular end-diastolic volume index.

many earlier investigations have used the presence of ventricular reverse remodeling as a surrogate marker for the presence of beneficial effects of any administered treatment modality.[21–28] For these reasons, assessment of ventricular reverse remodeling in heart failure patients is of crucial value. Based on the present study, a 9% reduction in QRS duration on the postoperative ECG is associated with significant RV reverse remodeling (defined as a reduction in RV-EDVI ≥20%). This measure has a sensitivity of 75% and a specificity of 78%, values that are acceptable for allowing an ECG to serve as a useful, longitudinal follow-up modality in screening for the presence of RV reverse remodeling in patients undergoing corrective TR surgery. Of note, the extent of changes in QRS duration was found to be in close association with preoperative QRS duration; ie, a longer QRS duration on preoperative ECG predicted a larger reduction in QRS duration postsurgery. These findings are similar to those observed in patients with corrected tetralogy of Fallot undergoing pulmonary valve replacement.[29] Furthermore, no ceiling effect was evident. In this respect, QRS duration on preoperative ECG cannot be used as the sole index for determining whether to proceed with corrective TR surgery. This notion is further supported by the fact that achievement of a normal postoperative RV-EF could not be predicted based on the preoperative QRS duration. Thus, it is conceivable that QRS duration and its changes play a beneficial role in predicting RV reverse remodeling in

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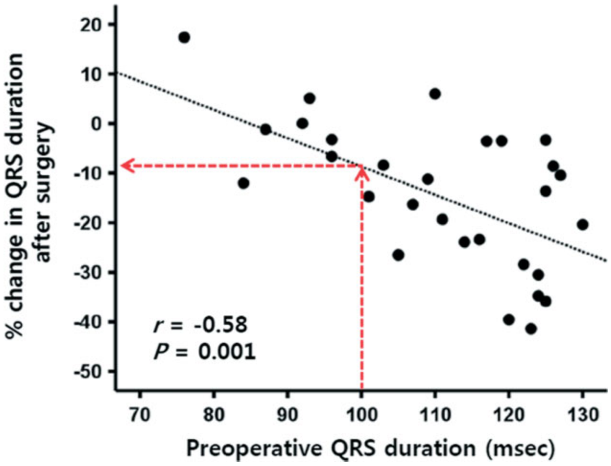

Figure 4. Scattergrams showing the close relationships between preoperative QRS duration on ECG and the absolute (A) and percent changes in QRS duration (B) after corrective TR surgery. There is no threshold above which no reduction in QRS duration takes place. Note that only 1 patient out of 7 who have a preoperative QRS duration of <100 msec experiences significant right ventricular reverse remodeling postsurgery, implicating that electrocardiographic screening may be not so helpful in predicting right ventricular reverse remodeling in patients who had a QRS duration of <100 msec presurgery. Abbreviations: ECG, electrocardiogram; TR, tricuspid regurgitation.

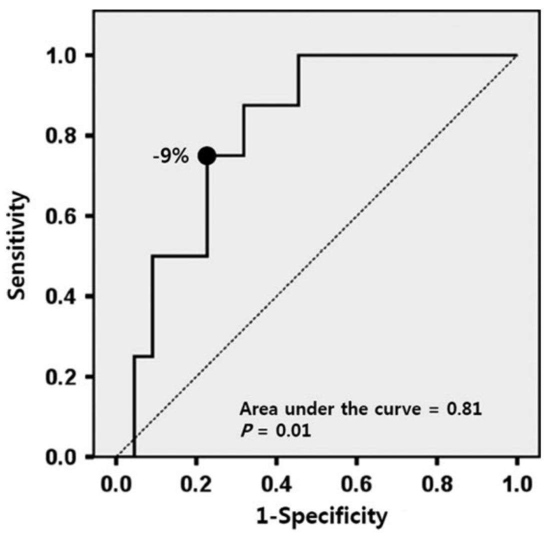

Figure 5. A receiver-operating characteristic curve is depicted for significant right ventricular reverse remodeling (defined as a reduction in RV-EDVI $\geq$20%) in association with the percent change in QRS duration on ECG. With a cutoff value of 9%, the sensitivity and specificity for predicting postoperative significant RV reverse remodeling were 75% and 78%, respectively (area under the curve = 0.81 and $P = 0.01$). Abbreviations: RV-EDVI, right ventricular end-diastolic volume index.

TR patients undergoing corrective surgery. It is worth mentioning that if a patient had a QRS duration of less than 100 msec presurgery, that patient was highly unlikely to experience significant RV reverse remodeling postsurgery, as shown in the red lines of Figure 4, where among 7 patients with a QRS duration ¡100 msec, only 1 reached the threshold of 9% decrease in QRS duration. Based on this finding, electrocardiographic screening may be not so helpful in predicting RV reverse remodeling in patients who had a QRS duration of <100 msec presurgery. Taking an earlier report into consideration,[12] it is reasonable that preoperative CMR is used as an indicator for postoperative normalization of RV-EF and a change in QRS duration on 12-lead ECG, as a simple index for a significant RV reverse remodeling. Despite the inclusion of wide ranges of QRS duration and RV-EF in the present study, this finding requires further confirmation in large scale studies.

This study has several limitations. First, definitive conclusions cannot be drawn based only on the present study, because the number of patients enrolled was relatively small. However, in an attempt to minimize bias caused by including a heterogeneous group of patients with severe TR, we recruited only patients with isolated severe TR and without left-sided valve dysfunction. We believe that this strengthens our conclusions. Second, there was a time lag between CMR and ECG performance, which could influence results of the current study. Third, a change in LV-EDVI or LV-EF could exert an effect on a change in QRS duration. However, a percentage change in QRS duration displayed a weak correlation with a percentage change in LV-EDVI ($r = 0.21$, $P = 0.02$) and no correlation with a percentage change in LV-EF ($r = -0.03$, $P = 0.86$). Thus, it is unlikely that the influence of a change in LV hemodynamics could significantly alter the results of the current study. Fourth, a large proportion of patients were in atrial fibrillation, which could affect CMR image quality. However, as shown in our earlier report,[12] we had no significant difficulty in analyzing CMR data in these patients. Finally, we did not provide echocardiographic information on RV volumes. Presumably, the combination of both ECG and echocardiographic information could have improved the sensitivity and specificity reported. However, the main purpose of the present study was to provide the clinical utility of routine ECG in the follow-up of patients undergoing corrective TR surgery, and thus combined approaches with both ECG and echo are beyond the scope of our study.

Conclusion

In conclusion, the degree of change in postoperative QRS duration can serve as a useful, inexpensive, and simple index that can be reflective of the occurrence of significant RV reverse remodeling in patients undergoing corrective TR surgery.

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