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Slow Conducting Electroanatomic Isthmuses: An Important Link Between QRS Duration and VT in Tetralogy of Fallot

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ABSTRACT

OBJECTIVES This study sought to evaluate the influence of slow conducting anatomic isthmuses (SCAI) as dominant ventricular tachycardia (VT) substrate on QRS duration.

BACKGROUND QRS prolongation has been associated with VT in repaired tetralogy of Fallot.

METHODS Seventy-eight repaired tetralogy of Fallot patients (age 37 ± 15 years, 52 male, QRS duration 153 ± 29 ms, 67 right bundle branch blocks [RBBB]) underwent programmed stimulation and electroanatomic activation mapping during sinus rhythm. Right ventricular (RV) surface, RV activation pattern, RV activation time, conduction velocity at AI, and remote RV sites were determined.

RESULTS Twenty-four patients were inducible for VT (VT+); SCAI was present in 22 of 24 VT+ but only in 2 of 54 patients without inducible VT (VT−). Conduction velocity through AI was slower in VT+ patients (median of 0.3 (0.3-0.4) vs. 0.7 (0.6-0.9) m/s; $p < 0.01$) but conduction velocity in the remote RV did not differ between groups. In non-RBBB, QRS duration was similar in VT+ patients ($n = 6$) and VT− patients ($n = 5$), but RV activation within SCAI exceeded QRS offset in VT+ patients (37 ± 20 ms vs. -5 ± 9 ms, $p < 0.01$). In RBBB, both QRS duration and RV activation time were longer in VT+ patients ($n = 18$, 17 of 18 QRS > 150 ms) compared with VT− patients ($n = 49$, 27 of 49 QRS > 150 ms) (173 ± 22 ms vs. 156 ± 20 ms; $p < 0.01$; 141 ± 22 ms vs. 129 ± 21 ms; $p = 0.04$). In VT+ patients, QRS prolongation >150 ms ($n = 17$) was due to SCAI or blocked isthmus in 15 patients (88%) and 1 (6%). In contrast, in VT− patients, QRS prolongation >150 ms ($n = 27$) was due to enlarged RV or blocked isthmus in 10 patients (37%) and 8 (30%), but due to SCAI in only 1 (4%). After exclusion of a severely enlarged RV, a QRS duration >150 ms was highly predictive for SCAI/blocked AI (OR: 17; 95% CI: 3.3 to 84; $p < 0.01$).

CONCLUSIONS A narrow QRS interval does not exclude VT-related SCAI. In the presence of RBBB, SCAI further prolongs QRS duration. QRS duration >150 ms is highly suspicious for SCAI or isthmus block distinguishable by electroanatomic mapping. (J Am Coll Cardiol EP 2018;■:■-■) © 2018 by the American College of Cardiology Foundation.

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ABBREVIATIONS AND ACRONYMS

AI = anatomic isthmus

CI = confidence interval

CMR = cardiac magnetic resonance

CV = conduction velocity

EAM = electroanatomic map

ECG = electrocardiogram

IQR = interquartile range

LV = left ventricle

MVT = monomorphic ventricular tachycardia

OR = odds ratio

PV = pulmonary valve

PES = programmed electrical stimulation

RBBB = right bundle branch block

rTOF = repaired tetralogy of Fallot

RV = right ventricle

RVAT = total right ventricular activation time

RVOT = right ventricular outflow tract

SAECG = signal-averaged electrocardiography

SCAI = slow conducting anatomic isthmus

SCD = sudden cardiac death

SR = sinus rhythm

TA = tricuspid annulus

VA = ventricular arrhythmia

VSD = ventricular septal defect

VT = ventricular tachycardia

As a result of earlier repair and evolving surgical techniques, the majority of patients with repaired tetralogy of Fallot (rTOF) survive to adulthood (1-3), but they may remain at risk of sudden cardiac death (SCD) due to ventricular arrhythmias (VA) (4,5). Monomorphic ventricular tachycardia (VT) is the most common arrhythmia subtype affecting >14% of patients and accounting for >80% of appropriate implantable cardioverter-defibrillator therapies (6,7). Over the last decades, efforts have been made to noninvasively identify rTOF patients at risk for VT. Although no single risk factor has shown sufficient independent predictive value for the presence of an arrhythmic substrate in an individual patient, a prolonged QRS duration >180 ms has consistently been associated with VT and SCD (8-10). In contemporary cohorts, a lower QRS cutoff value to identify a patient at risk has been suggested and attributed to advances in surgical approaches (11,12). The modern transatrial-transpulmonary surgical approach with smaller transannular patches may not only prevent severe pulmonary valve regurgitation and right ventricular (RV) dilatation, but also right bundle branch damage. Accordingly, contemporary rTOF patients may have less RV dilatation, different RV activation patterns, and even a narrow post-operative QRS interval (13). QRS prolongation was initially thought to be the combined effect of a surgically created right bundle branch block (RBBB) and progressive, RV dilatation with global conduction delay, the latter creating a substrate for VT (9). However, invasive electroanatomic mapping studies have demonstrated that the dominant substrate for VT are slow conducting anatomic isthmuses (SCAI) confined to the right ventricular outflow tract (RVOT) (14). We hypothesize that the interplay between a post-operative RBBB and conduction delay in SCAI determines the RV activation pattern and QRS prolongation. The objective of this study is to evaluate, with the use of invasive electroanatomic mapping, whether QRS prolongation is due to localized conduction delay across SCAI, rather than due to global conduction delay.

METHODS

PATIENT SELECTION. The cohort consisted of 83 consecutive rTOF patients with either documented sustained VT, or considered at risk for VT and/or with indication for reoperation who underwent electrophysiological evaluation and RV electroanatomic mapping (EAM) between 2005 and 2013 at Leiden University Medical Center (n = 53) and Bordeaux University Hospital (n = 30). Patients were considered at risk for VT if ≥1 of the following risk factors was present: syncope, nonsustained VT on Holter monitor, QRS duration ≥180 ms, late repair (≥5 years), at least moderately depressed RV or left ventricular (LV) function or presence of a transannular patch (9,10,15-19). The Dutch Central Committee on Human-Related Research permits use of anonymous data without prior approval of an institutional review board, if the data are obtained for patient care and if the data do not contain identifiers that could be traced back to the individual patient. All patients were treated according to our standard clinical protocol and provided informed consent (14).

BASELINE EVALUATION. Patient records were reviewed for date and type of repair, device implantation, and documented VA. Nonpaced 12-lead electrocardiograms (ECG) recorded at 25 mm/s were assessed for QRS duration and intraventricular conduction disturbances. In 53 of 83 patients, QRS duration was also measured using LEADS (Leiden ECG Analysis and Decomposition Software) (Leiden University Medical Center, Leiden, the Netherlands) (see the Online Methods) (20). Holter recordings were reviewed for nonsustained VT. RV and LV cardiac function was assessed by cardiac magnetic resonance (CMR) and/or echocardiography. A mildly reduced or good RV function (RV ejection fraction >40%) with a tricuspid plane systolic excursion ≥14 mm and LV ejection fraction ≥40% were classified as preserved RV and LV function, respectively (21). Cardiac volumes were determined by CMR and indexed for body surface area. RV end-diastolic volume index ≥180 ml/m^2 was considered severely enlarged (22).

EAM AND ELECTROPHYSIOLOGICAL EVALUATION. Programmed electrical stimulation (PES) was performed (see the Online Methods). Sustained VT was defined as lasting ≥30 s or causing hemodynamic compromise requiring termination. A detailed 3-dimensional EAM of the RV was constructed during sinus rhythm (SR) using a nonfluoroscopic mapping system (Carto3 and CartoXP, Biosense Webster, Irvine, California). The endocardial RV surface was measured using dedicated tools of the Carto system. EAM RV surface was compared with CMR-derived volume. All mapping points were reviewed offline for correct annotation of the local activation time, defined as the sharp bipolar electrogram coinciding