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Rapid ventricular tachycardia in patients with tetralogy of Fallot and implantable cardioverterdefibrillator: Insights from the DAI-T4F nationwide registry

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KEYWORDS

Adult congenital heart disease; Sudden cardiac death; Ventricular arrhythmia; Rapid ventricular tachycardia; Tetralogy of Fallot; Implantable cardioverter-defibrillator

BACKGROUND

In repaired tetralogy of Fallot (TOF), little is known about characteristics of patients with rapid ventricular tachycardia (VT). Also, whether patients with a first episode of nonrapid VT may subsequently develop rapid VT or ventricular fibrillation (VF) has not been addressed.

OBJECTIVES

The objectives of this study were to compare patients with rapid VT/VF with those with nonrapid VT and to assess the evolution of VT cycle lengths (VTCLs) overtime.

METHODS

Data were analyzed from a nationwide registry including all patients with TOF and implantable cardioverter-defibrillator (ICD) since 2000. Patients with ≥ 1 VT episode with $VTCL \leq 250$ ms (240 beats/min) formed the rapid VT/VF group.

RESULTS

Of 144 patients (mean age 42.0 \pm 12.7 years; 104 [72%] men), 61 (42%) had at least 1 VT/VF episode, including 28 patients with rapid VT/VF (46%), during a median follow-up of 6.3 years (interquartile range 2.2–10.3 years). Compared with patients in the nonrapid VT group, those in the rapid VT/VF group were significantly younger at ICD implantation (35.2 \pm 12.6 years vs 41.5 \pm 11.2 years; $P = .04$), had more frequently a history of cardiac arrest

(8 [29%] vs 2 [6%]; P 5 .02), less frequently a history of atrial arrhythmia (11 [42%] vs 22 [69%]; P 5 .004), and higher right ventricular ejection fraction (43.3% +/- 10.3% vs 36.6% +/- 11.2%; P5.04). The median VTCL of VT/VF episodes was 325 ms (interquartile range 235–429 ms). None of the patients with a first documented nonrapid VT episode had rapid VT/VF during follow-up.

CONCLUSION

Patients with TOF and rapid VT/VF had distinct clinical characteristics. The relatively low variation of VTCL over time suggests a room for catheter ablation without a backup ICD in selected patients with well-tolerated VT.

Introduction

Tetralogy of Fallot (TOF) is the most common cyanotic congenital heart defect.¹ While long-term survival after repair is excellent,^{2,3} surgical scarring exposes patients to the occurrence of ventricular arrhythmias (VAs) and sudden cardiac death (SCD), which remains an important cause of death in this population.^{4–8}

In repaired TOF, VAs are mainly represented by monomorphic ventricular tachycardia (VT) related to reentrant circuits using anatomical isthmuses created by surgical scars.^{9,10} Implantable cardioverter-defibrillator (ICD) has been demonstrated to be highly effective in preventing arrhythmic death in high-risk patients, but the burden of long-term complications is considerable. Moreover, while high rates of appropriate ICD therapies have been demonstrated in large registries,^{11,12} VT may not be a surrogate of SCD and many patients experience clinically well-tolerated sustained VT episodes.¹³ In this context, catheter ablation has progressively emerged as an alternative in carefully selected patients. However, data on VT cycle length (VTCL) in TOF are scarce, and to our knowledge, the evolution of VTCLs over time has not been assessed so far. Whether patients with TOF presenting with rapid VT/VF (defined usually as life-threatening arrhythmias with VTCL \leq 250 ms, ie, \geq 240 beats/min) have a specific clinical profile is therefore unknown.

In this study, we used a population of patients with TOF monitored with an ICD to longitudinally assess the evolution of VTCLs. Our objectives were (1) to compare clinical characteristics of patients with rapid VT/VF with those without and (2) to assess the evolution of VTCLs over time, particularly the predictive value of the first documented VTCL during follow-up.

Methods

Study setting

The DAI-T4F registry is an ongoing French nationwide registry reporting the outcomes of patients with TOF and ICD.^{12,14} DAI-T4F ([ClinicalTrials.gov](https://clinicaltrials.gov/ct2/show/study/NCT03837574) identifier NCT03837574) was initiated in 2010 by INSERM, the French Institute of Health and Medical Research, and includes all patients with TOF implanted with an ICD in France after 2000 for the primary or

secondary prevention of SCD. Data collection was performed retrospectively for the 2000–2009 and prospectively from 2010 onward with annual follow-up for the entire cohort. Of the 167 French centers accredited for ICD implantation, 40 centers implanted at least 1 patient with TOF ([Online Supplemental Data 1](#)). Patients with unrepaired TOF, pulmonary atresia, absent pulmonary valve, atrioventricular canal defect, and double outlet right ventricle were excluded. Follow-up began at ICD implantation.

The DAI-T4F registry was declared to and authorized by the French data protection committee (Commission Nationale de l'Informatique et des Libertés), and the study was approved by the local institutional review boards. Data were centrally collected and analyzed at the Cardiovascular Epidemiology and Sudden Death Unit (Institut National de la Santé et de la Recherche Médicale [INSERM] Unit 970, Paris Cardiovascular Research Center, European Georges Pompidou Hospital, Paris, France). Written informed consent was obtained from all patients.

Data collection

Baseline (at ICD implantation) information included demographic characteristics, medical history, and details of TOF including date and types of previous cardiac operations. History of supraventricular arrhythmias, VAs, congestive heart failure, syncope, and cardiac arrest were also recorded. Findings from 12-lead electrocardiography and cardiac imaging (echocardiography with or without cardiac magnetic resonance = imaging) were also evaluated. When both echocardiography and magnetic resonance imaging were performed, magnetic resonance imaging–derived measures were considered. QRS fragmentation was previously defined.¹² The most recent data preceding ICD implantation were selected, with a maximum acceptable time interval of 1 year.

Secondary prevention was defined as ICD implantation after sustained VT/VF or aborted cardiac arrest. Of note, patients with inducible VT/VF during programmed ventricular stimulation without documented spontaneous sustained VA were considered as primary prevention.

A specific working group ensured systematic follow-up of patients at least once a year and more in case of clinical events, using electronic case report forms through regular contact with treating physicians or the patients themselves for additional information. Clinical events were centrally adjudicated by a blinded committee by reviewing all clinical data and device-stored electrograms when available (reviewed by at least 2 independent electrophysiologists). ICD programming was left to the discretion of the managing physician.

Study population

In the DAI-T4F registry population, patients with VT during follow-up but without information on VTCL for any VT episode were excluded. The remaining patients with or without VT during follow-up were included in the present analysis. VTCLs were centrally collected from outpatient clinical visit reports, printed device interrogation reports from patient files, or telemonitoring data. Maximum efforts were made to collect VTCL for each VT episode. Among patients with VT/VF during follow-up with ≥ 1 VTCL available (n 561), the VTCL was missing in at least 1 other VT/VF episode in 12 patients (20%). The median number of missing VTCLs was 1 (interquartile range [IQR] 1–10). The VTCL of the

initial VT episode during followup was missing in 8 patients. The number of missing VTCLs per study patient is available in [Online Supplemental Table 1](#).

Definitions and outcomes

VT was defined as any VT lasting ≥ 30 seconds and/or triggering appropriate ICD intervention.

Rapid VT/VF was defined as mean VTCL during the recorded VT episode ≤ 250 ms. When the outpatient clinical visit report indicated “VF” without further information on VTCL, a value of 200 ms was allocated to the VTCL of the episode. Patients with VT/VF during follow-up were separated into 2 groups—rapid VT/VF or nonrapid VT/VF—according to whether they experienced at least 1 episode of rapid VT/VF during follow-up, whereas patients without VT/VF during follow-up formed the no VT/VF group. In order to analyze the evolution of VTCLs over time in each ICD carrier with at least 2 VT episodes with documented VTCL, DVTCL was calculated in milliseconds, representing the difference between 2 consecutive VTCLs ($VTCL [n + 1] - VTCL [n]$). In case of a missing VTCL among the succession of VT episodes, DVTCL was calculated between the 2 consecutive VT episodes with a documented VTCL.

Statistical analyses

This report was prepared in compliance with the Strengthening the Reporting of Observational Studies in Epidemiology checklist for observational studies.¹⁵ Categorical data were reported as number and percentage. Continuous variables were reported as mean \pm SD or median (IQR) for normally and non-normally distributed data, respectively. The normality of the distribution of a continuous variable was assessed using the Shapiro-Wilk test. Comparisons used the χ^2 or Fisher exact test for categorical variables and Student t test or Mann-Whitney-Wilcoxon test, when appropriate, for continuous variables, according to their distribution. Survival curves were built using the Kaplan-Meier method. The time-to-event intervals were the time from ICD implantation to the first VT episode and the age at first VT, setting date of birth as t_0 in the latter. Censoring occurred in the event of loss to follow-up, heart transplantation, or death. The log-rank test was used to compare the Kaplan-Meier curves of the 2 groups. Cox proportional hazards models were used to identify factors associated with rapid VT/VF. Variables with probability values ≤ 0.10 in univariable analyses were considered in multivariable models, with final selection based on most favorable goodness-of-fit measures (Bayesian information criterion). Missing data were no more than 5%, except for previous palliative shunt (15.6%), pulmonary regurgitation severity (14.9%), right ventricular ejection fraction (RVEF) (21%), systolic pulmonary artery pressure (SPAP) (43.1%), and QRS duration and fragmentation (7.8%). Statistical analyses were performed using R software version 3.6.3 (R Project for Statistical Computing, Vienna, Austria), and schematics were created by GraphPad Prism version 9.3.0 (GraphPad Software, San Diego, CA).

Results

Study population

Of the 165 patients included in the DAI-T4F registry, 82 (50%) experienced at least 1 VT/VF episode during follow-up and 83 (50%) did not (no VT/VF group). Among the former, 61 patients (74%) had at least 1 documented VTCL. The 21 patients with VT during follow-up but no information on VTCL for any VT episode were excluded from the present study. The study population therefore consisted of 144 patients (mean age at ICD implantation 42.0 \pm 12.7 years; 104 [72%] men) (Figure 1). Of the 61 patients with VT during follow-up and \geq 1 documented VTCL, 28 (46%) had at least 1 episode of rapid VT (rapid VT/VF group) and 33 (54%) did not (nonrapid VT group).

Comparisons of patients' characteristics

The characteristics of patients at the time of ICD implantation in the rapid VT/VF group, as compared with patients in the nonrapid VT and in the no VT/VF groups, are summarized in Table 1.

Compared with patients in the nonrapid VT group, those in the rapid VT/VF group were significantly younger at the time of ICD implantation (35.2 \pm 12.6 years vs 41.5 \pm 11.2 years; $P = .04$), had more frequently a history of cardiac arrest (8 [29%] vs 2 [6%]; $P = .02$), and had less frequently a history of atrial arrhythmia (11 [42%] vs 22 [69%]; $P = .004$). Patients in the rapid VT/VF group also had higher RVEF (43.3% \pm 10.3% vs 36.6% \pm 11.2%; $P = .04$) and lower SPAP (37.0 \pm 12.3 mm Hg vs 47.8 \pm 14.0 mm Hg; $P = .02$) than did patients in the nonrapid VT group.

Compared with patients in the no VT/VF group, those in the rapid VT/VF group were significantly younger at corrective operation (5 years; IQR 2–11 years vs 7 years; IQR 4–13 years; $P = .02$) and at ICD implantation (35.2 \pm 12.6 years vs 44.6 \pm 12.2 years; $P = .001$).

Rapid VT/VF and VTCLs during follow-up

The median follow-up time after ICD implantation was 6.3 years (IQR 2.2–10.3 years), without significant difference between the rapid VT/VF group and the nonrapid VT group ($P = .70$), but was significantly shorter in the no VT/VF group (4.1 years; IQR 1.1–8.7 years; $P = .0003$).

There was no significant difference in time from ICD implantation to first VT between the rapid VT/VF (median 2.3 years; IQR 0.27–5.7 years) and the nonrapid VT (2.5 [0.6–5.4] years) group (log-rank, $P = .58$) (Figure 2A). Age at first VT was significantly lower in the rapid VT/VF group (median 39.0 years; IQR 30.3–50.2 years) than in the nonrapid VT group (median 46.6 years; IQR 37.1–56.1 years) (log-rank, $P = .04$) (Figure 2B).

Overall, 171 VT episodes with available VTCLs in 144 patients were documented during follow-up. The median number of VT episodes per patient was 2 (IQR 1–3) (Online Supplemental Table 1). The median VTCL across all patients and episodes was 325 ms (IQR 235–429 ms). The median VTCL of the first VT episode was 295 ms (IQR 200–335 ms).

(Figure 3A). The distribution of VTCLs across all VT episodes pooled together is shown in Figure 3B.

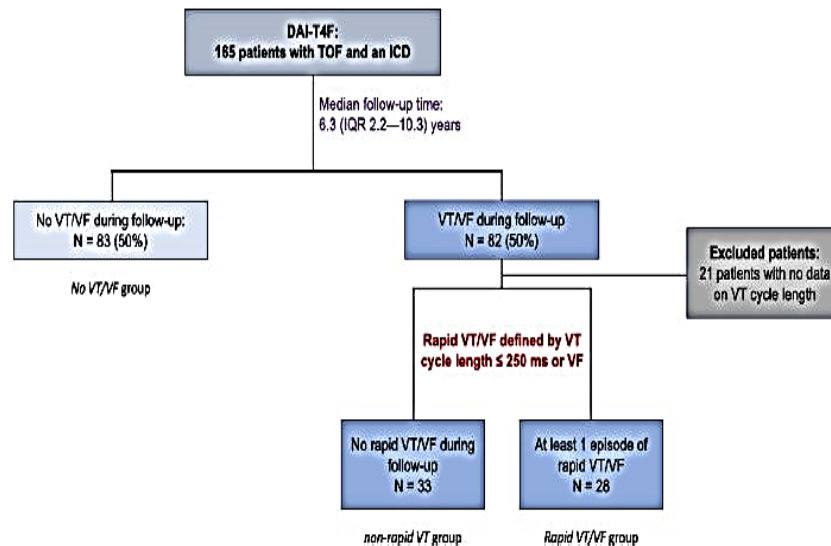


Figure 1 Flowchart of selected patients within the DAL-T4F registry and composition of groups. ICD = implantable cardioverter-defibrillator; IQR = interquartile range; TOF = tetralogy of Fallot; VF = ventricular fibrillation; VT = ventricular tachycardia.

The evolution of VTCLs across VT episodes in patients individually is shown in Figure 4. Patients in whom the first documented episode had a VTCL of ≤ 250 ms did not experience any rapid VT/VF during follow-up.

Overall, 28 patients had ≥ 2 VT episodes with available VTCLs. In those patients, the median VTCL of the first VT episode was 298 ms (IQR 236–335 ms) (Figure 5A). The median time between each VT episode was 182 days (IQR 38–792 days). The VT episode with the minimal VTCL among the subsequent VT episodes had a median VTCL of 300 ms (IQR 238–330 ms). The difference of VTCL between the fastest VT episode (excluding the first) and the first VT episode ranged from 2105 (faster) to 65 ms (slower) (median 0; IQR 29.0 to 0). Δ VTCLs for each patient with ≥ 2 VT episodes with documented VTCLs are shown in Figure 5B. Δ VTCLs ranged from 2162 (faster) to 220 ms (slower) (median 0; IQR 29.5 to 3.5). The maximal negative Δ VTCL (2162 ms; from 492 to 330 ms) occurred in a patient with a first VT with a VTCL of 300 ms.

Fifteen patients (11%) died during follow-up: 9 died of advanced heart failure, 2 of refractory VF (who belonged to the rapid VT/VF group), 2 of sepsis, 1 of stroke, and 1 of cancer.

Table 1 Clinical characteristics of the study population at ICD implantation

Characteristic	Nonrapid VT (n = 33)	Rapid VT/VF (n = 28)	No VT/VF (n = 83)	P (rapid VT/VF vs nonrapid VT)	P (rapid VT/VF vs no VT)
Male sex	22 (66)	23 (82)	59 (71)	.2	.4
Age at corrective operation (y)	7.5 (3–14)	5 (2–11)	7 (4–13)	.08	.02
Prior palliative shunt	16 (55)	10 (38)	33 (49)	.2	.3
No. of cardiac operations	1 (1–2.8)	1 (1–2)	1 (1–2.5)	.2	.4
Age at ICD implantation (y)	41.5 ± 11.2	35.2 ± 12.6	44.6 ± 12.2	.04	.001
Body mass index (kg/m ²)	24.5 ± 3.9	23.8 ± 4.0	25.1 ± 4.2	.6	.2
History of cardiac arrest	2 (6)	8 (29)	11 (13)	.02	.06
History of syncope	14 (42)	11 (39)	30 (36)	.8	.8
History of atrial arrhythmia	22 (69)	11 (42)	36 (44)	.04	.8
History of congestive heart failure	0	1 (4)	8 (12)	.3	.3
History of nonsustained VT	5 (15)	4 (14)	16 (19)	.9	.8
ICD implantation for secondary prevention	25 (76)	19 (68)	44 (53)	.5	.2
Positive programmed ventricular stimulation	12 (71)*	7 (58) [†]	19 (66) [‡]	.5	.7
LVEF (%)	53.6 ± 9.8	51.5 ± 12.4	48.7 ± 10.3	.5	.4
RVEF (%)	36.6 ± 11.2	43.3 ± 10.3	40.8 ± 11.3	.04	.4
SPAP (mm Hg)	47.8 ± 14.0	37.0 ± 12.3	40.8 ± 11.8	.02	.3
At least moderate pulmonary regurgitation	15 (50)	12 (48)	36 (51)	.8	.5
QRS duration (ms)	178.8 ± 32.8	170.0 ± 30.9	164.7 ± 31.1	.3	.5
QRS fragmentation	25 (78)	14 (56)	31 (43)	.07	.2
Corrected QT interval [§] (ms)	474.9 ± 46.9	471.7 ± 47.0	471.2 ± 43.6	.8	1.0

Values are presented as mean ± SD, median (interquartile range), or n (%).

ICD = implantable cardioverter-defibrillator; LVEF = left ventricular ejection fraction; PVS = programmed ventricular stimulation; RVEF = right ventricular ejection fraction; SPAP = systolic pulmonary artery pressure; VF = ventricular fibrillation; VT = ventricular arrhythmia.

*Among 17 patients with PVS performed.

[†]Among 12 patients with PVS performed.

[‡]Among 29 patients with PVS performed.

[§]According to the Bazett formula.

Factors associated with VT and rapid VT/VF during follow-up

Age at ICD implantation (hazard ratio [HR] per year increase 0.96; 95% confidence interval [CI] 0.93–1.00; $P = .02$) and history of cardiac arrest (HR 3.38; 95% CI 1.80–6.33; $P < .001$) were significantly associated with rapid VT/VF during follow-up in univariable analyses, whereas only history of cardiac arrest was independently associated with rapid VT/VF in multivariable analyses (Table 2). QRS duration ≥ 180 ms (HR 2.33; 95% CI 1.38–3.94; $P = .002$) and QRS fragmentation (HR 3.38; 95% CI 1.80–6.33; $P < .001$) were significantly and independently associated with VT (rapid or not) during follow-up.

Discussion

The DAI-T4F nationwide registry presents long-term followup of a large cohort of patients with TOF followed longitudinally with an ICD. The main findings of this study addressing rapid VT are as follows: (1) patients with rapid VT/VF have distinct characteristics at ICD implantation as compared with those with nonrapid VT, (2) patients with an initial slow VT do not exhibit rapid VT/VF during follow-up, and (3) VTs in TOF exhibit a low variation of VTCL over time according to the first documented episode.

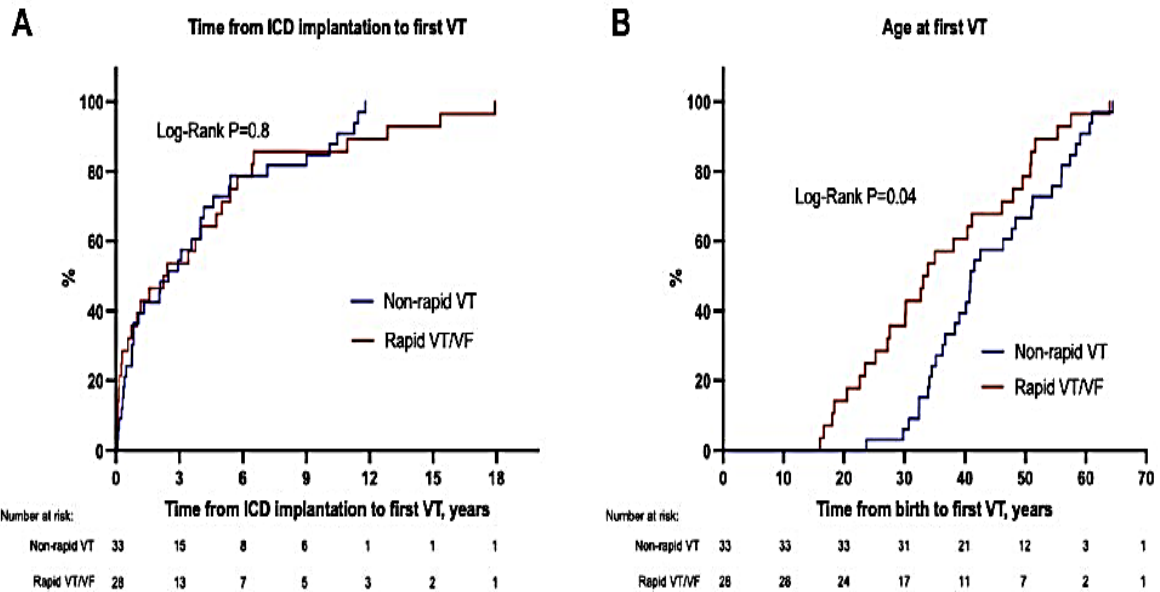


Figure 2 Kaplan-Meier curves representing the time from ICD implantation to the first documented VT episode (A) and the age at first VT (B) in the nonrapid VT group (blue) and in the rapid VT/VF group (red). Date of the first documented VT episode before ICD implantation was considered as the date of first VT in patients implanted for secondary prevention. Abbreviations as in Figure 1.

In cohorts of patients with TOF, the DAI-T4F study provided a unique opportunity to analyze the continuous monitoring offered by the ICD to assess the evolution of VTCLs over time. VAs are common in repaired TOF recipients, and the annual rate of appropriate ICD therapy in primary prevention ranges from 7.1% to 7.7%,^{11,12} rates comparable with those of the Multicenter Automatic Defibrillator Implantation Trial II study on ischemic heart disease for primary prevention. ¹⁶ Monomorphic VTs account for >.80% of VAs in TOF and rely on macroreentrant circuits occurring in the right ventricle (RV).¹⁷ Dense scars, created by surgical incision of the RV outflow tract, and prosthetic patches transecting the pulmonary annulus or used for ventricular septal defect repair, create anatomical isthmuses bounded by unexcitable tissue that serve an ideal bed for macroreentrant arrhythmias. ^{9,18} There are few studies assessing longitudinal variations of VTCLs in other disease model, as this objective essentially requires a large population of ICD carriers. In ischemic heart disease, a study including 17 patients with repeated programmed ventricular stimulation immediately after myocardial infarction and during long-term follow-up showed a high reproducibility of VT induction but poor preservation of VTCL.¹⁹ In this work, VTCLs exhibited remarkable stability over time, with a median Δ VTCL of 0 ms and a small dispersion of its distribution. This contrasting finding may be explained by the difference in the nature of the arrhythmogenic substrate between the 2 heart diseases. Myocardial infarction-related scar is heterogeneous and may harbor several channels. Surviving myocytes at the border zone can exhibit functional block. These phenomena may account for a greater VTCL variability. In TOF, macroreentrant circuits are determined by fixed anatomical boundaries, and they do not use scar as providers of critical isthmuses, but rather as boundaries, whose dimensions do not vary significantly over time.⁹ Also, VT ablation failure and late recurrence have been associated with difficulty in transecting anatomical isthmuses and achieve durable block rather than substrate extension.^{9,18} Overall, the specific substrate in TOF likely explains the small longitudinal variability of VT rate.

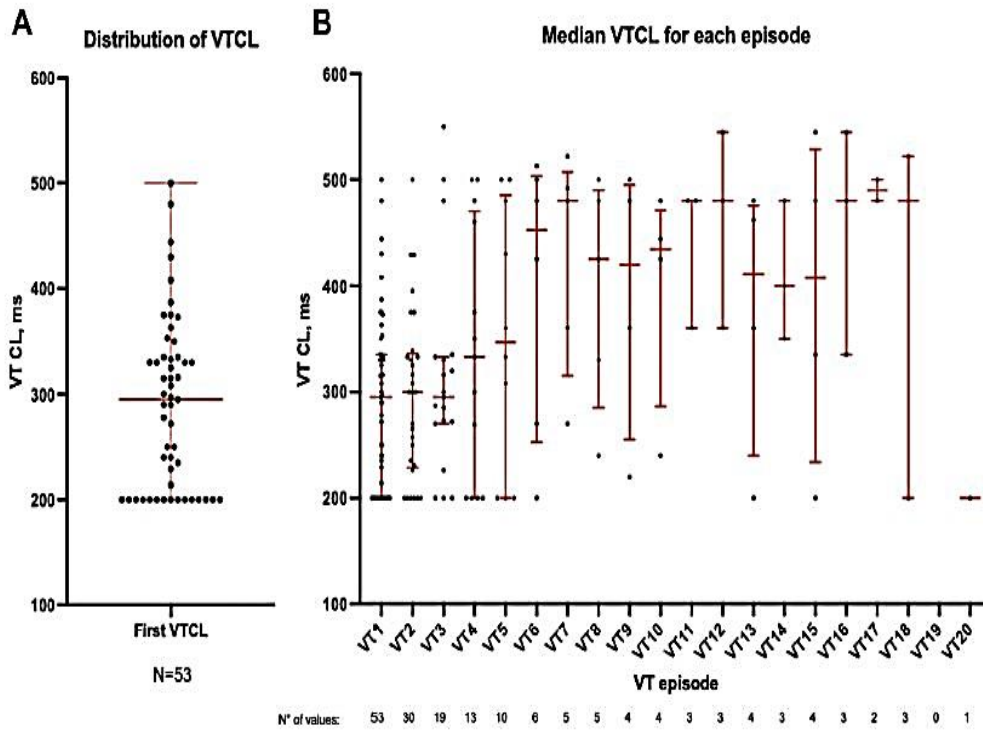


Figure 3 A: Distribution of VTCLs in the 53 patients with an available VTCL at the first VT episode. B: Distribution of VTCLs for each VT episode during follow-up. VTCL = ventricular tachycardia cycle length; other abbreviations as in Figure 1.

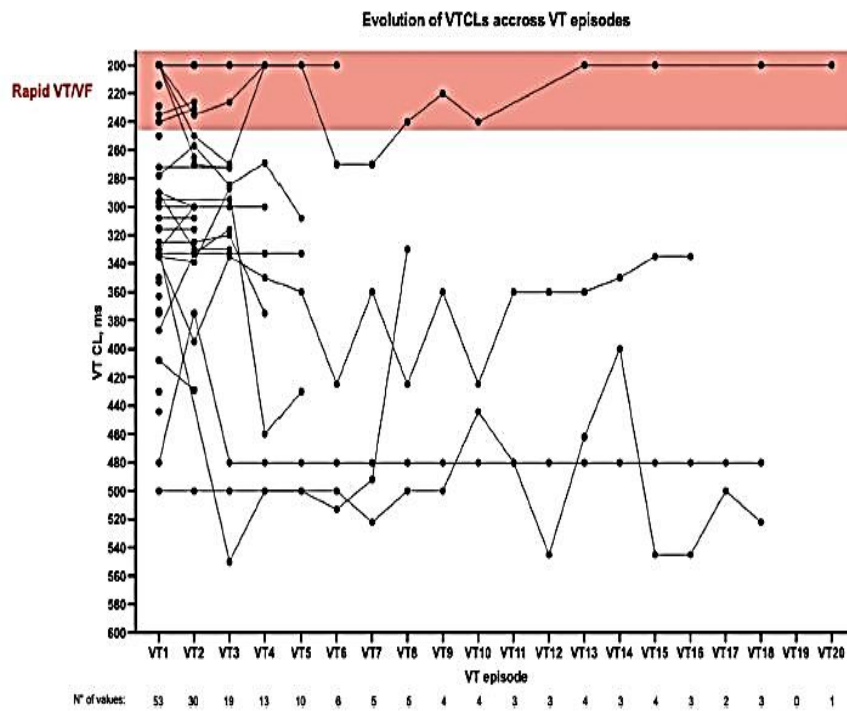


Figure 4 Evolution of VTCLs across all VT episodes and study patients. No patient with first nonrapid VT had rapid VT/VF at any further VT episode. Abbreviations as in Figures 1 and 3.

Rapid VT has been used as a surrogate for SCD in cohorts of patients carrying an ICD.²⁰ In TOF, despite a scarce number of studies reporting VTCLs, VTs exhibit faster VTCLs than other types of reentrant arrhythmias. In a recent experience of VT ablation in TOF, the median VTCL of induced VTs was 267 +/- 95 ms,¹⁸ and in a large previous multicenter registry including patients with TOF and ICD, the median VTCL was 282 ms (IQR 227–330 ms).¹¹ The electrophysiological properties affecting VTCL in macroreentrant VTs are the wavelength and conduction velocity within the circuit. In a recent study revisiting the determinants of VTCL in macroreentries, the size of the outer loop has been found to be the main determinant of VTCL, well before conduction velocity within the critical isthmus.²¹ In TOF, outer loops are determined by the extent of the RV scar. In particular, the presence of a RV incision or a transannular patch leads to slower VT with a later precordial transition.²² In our study, patients with rapid VT/VF were younger at the time of surgical repair and at the time of ICD implantation than those with nonrapid VT. They also had higher RVEF and lower SPAP. These findings suggest that patients with rapid VT/VF may have less extensive RV scarring than do those with nonrapid VT, allowing for smaller circuits and consequently more rapid VAs. This observation does not infer that young patients with repaired TOF and preserved RV function have a higher prevalence of VAs. In fact, old age at repair, transannular repair, wide QRS complex, and altered RV function, characteristics that we found more frequent in the nonrapid VT group, have been consistently associated with VAs and SCD.^{4,5,23} Furthermore, in a large multicenter cohort of repaired TOF, Gatzoulis et al⁴ found that patients who experienced SCD had a significantly narrower QRS than did those with VT. Also, up to two-thirds of patients with repaired TOF who experience SCD have preserved cardiac function.^{6,24}

Based on favorable outcomes after catheter ablation of VAs in patients with TOF, the recent American and European guidelines propose stand-alone catheter ablation therapy—without a backup ICD—in carefully selected patients with well-preserved hemodynamics and well-tolerated monomorphic VT as a class IIb recommendation.^{25,26} With stable VTCLs over recurrent episodes and without rapid VT/VF found in patients with an initial nonrapid VT, our findings support this approach. In the absence of rapid and potentially life-threatening VAs during follow-up, the risk of nonrapid VT recurrence, which can be managed by catheter ablation, has to be balanced with the major burden of long-term complications associated with ICDs well-documented in this young population.^{11,12} The results of this study can help clinicians in predicting the VTCL of potential future VAs on the basis of a first episode. However, identification of reliable predictors specific to rapid VT/VF (that we demonstrated to be different from overall VT) is complex and remains a major issue, particularly in a primary prevention setting. The history of cardiac arrest, independently associated with rapid VT/VF, reminds us that SCD can be the first arrhythmic event in patients with repaired TOF.

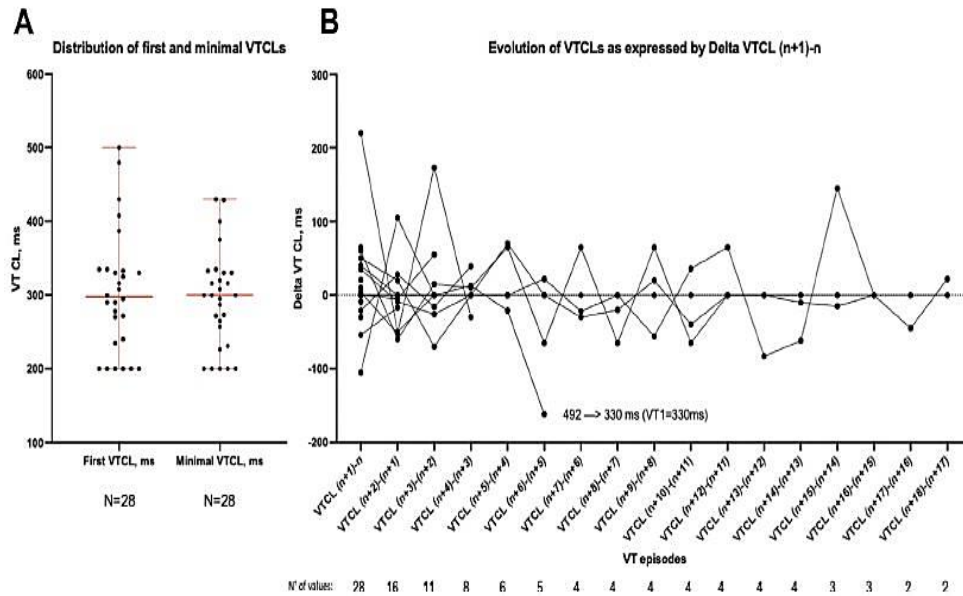


Figure 5 VTCLs in patients with at least 2 documented VTCLs. **A:** Distribution of the VTCL of the first VT episode (median 298 ms; IQR 236–335 ms) and of the VTCL of the VT episode during follow-up with the shortest VTCL (median 300 ms; IQR 238–330 ms). **B:** Evolution of VTCLs between 2 consecutive VT episodes represented by the distribution of Δ VTCLs (VTCL [n + 1] – VTCL [n]). IQR = interquartile range; other abbreviations as in Figures 1 and 3.

Table 2 Variables associated with VT/VF and rapid VT/VF during follow-up (Cox regression)

Variable	Univariable			Multivariable		
	HR	95% CI	P	HR	95% CI	P
VT/VF overall (n = 61)						
Age at corrective operation (per year increase)	0.99	0.96–1.03	.64			
Age at ICD implantation (per year increase)	0.99	0.97–1.01	.51			
History of cardiac arrest	1.05	0.53–2.08	.89			
History of atrial arrhythmia	0.99	0.53–1.83	.97			
History of nonsustained VT	0.98	0.57–1.70	.95			
Positive PVS*	1.17	0.54–2.51	.70			
LVEF (per % increase)	1.01	0.99–1.01	.38			
RVEF (per % increase)	0.98	0.99–1.04	.22			
QRS duration \geq 180 ms	2.33	1.38–3.94	.002	1.80	1.05–3.09	.03
QRS fragmentation	3.38	1.80–6.33	<.001	2.89	1.52–5.51	.001
Rapid VT/VF (n = 28)						
Age at corrective operation (per year increase)	0.94	0.88–1.01	.11			
Age at ICD implantation (per year increase)	0.96	0.93–1.00	.02	0.97	0.94–1.00	.08
History of cardiac arrest	2.65	1.16–6.06	.02	2.31	1.17–6.54	.02
History of atrial arrhythmia	0.72	0.33–1.58	.45			
History of nonsustained VT	0.85	0.29–2.47	.77			
LVEF (per % increase)	1.00	0.97–1.03	1.00			
RVEF (per % increase)	1.02	0.98–1.06	.28			
QRS duration \geq 180 ms	1.55	0.70–3.43	.28			
QRS fragmentation	2.10	0.87–5.04	.10	2.17	0.89–5.25	.09

*Among 31 patients with PVS performed.

CI = confidence interval; HR = hazard ratio; ICD = implantable cardioverter-defibrillator; LVEF = left ventricular ejection fraction; PVS = programmed ventricular stimulation; RVEF = right ventricular ejection fraction; VF = ventricular fibrillation; VT = ventricular arrhythmia.

Study limitations

First, the main limitation of the present study is that its conclusions rely exclusively on VTCL, without clinical correlations. While VTCL has been repeatedly used as a surrogate for life threatening arrhythmias, hemodynamical tolerance can depend on underlying cardiac

function and slow VT can degenerate into VF. The difference in clinical characteristics of patients with rapid VT/VF as compared with those without suggests that VTCL has a physiological relevance. Second, 21 patients with VT but no available VTCL were excluded; the number is significant and warrants caution on the main finding of the study. Third, the morphology of VT episodes recorded by the ICDs, in particular the monomorphic or polymorphic nature of the rapid VT episode, was not retrieved. Fourth and importantly, a longitudinal assessment of VTCL variations did not include changes in pharmacological treatment or catheter ablation procedures, from which one would expect a significant impact on VTCL. While this is clearly a major limitation, it does not hamper the main finding of the study, which is that patients with an initial nonrapid VT did not present rapid VT later on. Fifth, we did not collect data on the type of ICD intervention and therefore the efficacy of antitachycardia pacing for rapid or nonrapid VT. Last, patients who died of SCD without ICD implantation were not included, which may conduct to underrepresentation of rapid VT in the study population.

Conclusion

In this nationwide cohort of patients with TOF and ICD, patients with rapid VT had distinct clinical characteristics compared with those with no or nonrapid VT. The low variation of VT rate demonstrated over time should be considered in sudden death prevention strategies and supports the emerging approach based on catheter ablation without a backup ICD in selected patients with well-tolerated VT.

Acknowledgments

The list of DAI-T4F Investigators is provided in [Online](#)

References

1. Marelli AJ, Mackie AS, Ionescu-Ittu R, Rahme E, Pilote L. Congenital heart disease in the general population: changing prevalence and age distribution. *Circulation* 2007;115:163–172.
2. Smith CA, McCracken C, Thomas AS, et al. Long-term outcomes of tetralogy of Fallot: a study from the pediatric cardiac care consortium. *JAMA Cardiol* 2019; 4:34–41.
3. Wu M-H, Wang J-K, Chiu S-N, et al. Long-term outcome of repaired tetralogy of Fallot: survival, tachyarrhythmia, and impact of pulmonary valve replacement [published online ahead of print June 30, 2022]. *Heart Rhythm*. <https://doi.org/10.1016/j.hrthm.2022.06.032>.
4. Gatzoulis MA, Balaji S, Webber SA, et al. Risk factors for arrhythmia and sudden cardiac death late after repair of tetralogy of Fallot: a multicentre study. *Lancet* 2000;356:975–981.
5. Khairy P, Aboulhosn J, Gurvitz MZ, et al. Arrhythmia burden in adults with surgically repaired tetralogy of Fallot: a multi-institutional study. *Circulation* 2010; 122:868–875.

6. Koyak Z, Harris L, Groot JR de, et al. Sudden cardiac death in adult congenital heart disease. *Circulation* 2012;126:1944–1954.
7. Wu M-H, Lu C-W, Chen H-C, Chiu S-N, Kao F-Y, Huang S-K. Arrhythmic burdens in patients with tetralogy of Fallot: a national database study. *Heart Rhythm* 2015;12:604–609.
8. Shade JK, CartoskiMJ, Nikolov P, et al. Ventricular arrhythmia risk prediction in repaired tetralogy of Fallot using personalized computational cardiac models. *Heart Rhythm* 2020;17:408–414.
9. Kapel GFL, Sacher F, Dekkers OM, et al. Arrhythmogenic anatomical isthmuses identified by electroanatomical mapping are the substrate for ventricular tachycardia in repaired tetralogy of Fallot. *Eur Heart J* 2017;38:268–276.
10. Rivas-G_andara N, Dos-Subir_a L, Francisco-Pascual J, et al. Substrate characterization of the right ventricle in repaired tetralogy of Fallot using late enhancement cardiac magnetic resonance. *Heart Rhythm* 2021;18:1868–1875.
11. Khairy P, Harris L, Landzberg MJ, et al. Implantable cardioverter-defibrillators in tetralogy of Fallot. *Circulation* 2008;117:363–370.
12. Waldmann V, Bouzeman A, Duthoit G, et al. Long-term follow-up of patients with tetralogy of Fallot and implantable cardioverter defibrillator—the DAIT4F nationwide registry. *Circulation* 2020;142:1612–1622.
13. Vehmeijer JT, Koyak Z, Leerink JM, et al. Identification of patients at risk of sudden cardiac death in congenital heart disease. The PRospEctiVE study on implaNTable cardiOverter defibrillator therapy and suddeN cardiac death in Adults with Congenital Heart Disease: PREVENTION-ACHD. *Heart Rhythm* 2021;18:785–792.
14. Bessière F, Gardey K, Bouzeman A, et al. Impact of pulmonary valve replacement on ventricular arrhythmias in patients with tetralogy of Fallot and implantable cardioverter- defibrillator. *JACC Clin Electrophysiol* 2021;7:1285–1293.
15. von Elm E, Altman DG, Egger M, et al. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *BMJ* 2007;335:806–808.
16. Moss AJ, Zareba W, Hall WJ, et al. Prophylactic implantation of a defibrillator in patients with myocardial infarction and reduced ejection fraction. *N Engl J Med* 2002;346:877–883.
17. Zeppenfeld K. Ventricular tachycardia in repaired congenital heart disease. *Herzschrittmacherther Elektrophysiol* 2016;27:131–136.
18. Laredo M, Frank R, Waintraub X, et al. Ten-year outcomes of monomorphic ventricular tachycardia catheter ablation in repaired tetralogy of Fallot. *Arch Cardiovasc Dis* 2017;110:292–302.
19. Schoenfeld MH, McGovern B, Garan H, Ruskin JN. Long-term reproducibility of responses to programmed cardiac stimulation in spontaneous ventricular tachyarrhythmias. *Am J Cardiol* 1984;54:564–568.
20. Cadrin-Tourigny J, Bosman LP, Nozza A, et al. A new prediction model for ventricular arrhythmias in arrhythmogenic right ventricular cardiomyopathy. *Eur Heart J* 2019;40:1850–1858.

21. Nishimura T, Upadhyay GA, Aziz ZA, et al. Circuit determinants of ventricular tachycardia cycle length: characterization of fast and unstable human ventricular tachycardia. *Circulation* 2021;143:212–226.
22. Brouwer C, Kapel GFL, Jongbloed MRM, Schaliij MJ, de Riva Silva M, Zeppenfeld K. Noninvasive identification of ventricular tachycardia-related anatomical isthmuses in repaired tetralogy of Fallot: what is the role of the 12-lead ventricular tachycardia electrocardiogram. *JACC Clin Electrophysiol* 2018;4:1308–1318.
23. Ghai A, Silversides C, Harris L, Webb GD, Siu SC, Therrien J. Left ventricular dysfunction is a risk factor for sudden cardiac death in adults late after repair of tetralogy of Fallot. *J Am Coll Cardiol* 2002;40:1675–1680.
24. Diller G-P, Kempny A, Liodakis E, et al. Left ventricular longitudinal function predicts life-threatening ventricular arrhythmia and death in adults with repaired tetralogy of Fallot. *Circulation* 2012;125:2440–2446.
25. Stout KK, Daniels CJ, Aboulhosn JA, et al. 2018 AHA/ACC Guideline for the Management of Adults With Congenital Heart Disease: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Circulation* 2019;139:e698–e800.
26. Baumgartner H, De Backer J, Babu-Narayan SV, et al. 2020 ESC Guidelines for the management of adult congenital heart disease: the Task Force for the management of adult congenital heart disease of the European Society of Cardiology (ESC). Endorsed by: Association for European Paediatric and Congenital Cardiology (AEPC), International Society for Adult Congenital Heart Disease (ISACHD). *Eur Heart J* 2021;42:563–645.