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Research Article

Antitachycardic Therapy of ICD in Patients with Multiple Morphologies of Monomorphous Ventricular Tachycardia Refractory to Therapy

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The article presents a description of a clinical case of a patient with structural myocardial pathology (postinfarction cardiosclerosis) with recurrent paroxysmal sustained monomorphic ventricular tachycardia (VT) refractory to the nominal recommended ICD (implantable cardioverter defibrillator) settings; as well as discusses the shortcomings of existing standard algorithms for antitachycardia pacing (ATP) of implantable cardioverter defibrillators and potential ways to increase its efficiency. The refractoriness of recurrent paroxysms of ventricular tachycardia to ATP therapy increases the risk of repeated ICD shocks.

Despite the existence of universal recommendations for ICD programming and ATP therapy, there is a need in clinical practice for individualized ATP programming in patients refractory to nominal settings. Increasing the number of ATP series and changing algorithms enables to increase the efficiency of ATP up to 80–89%. Refractoriness to standard ATP settings may be also overcome by using alternative ATP pacing algorithms (Ramp, Burst-plus, or Ramp-plus instead of Burst), changing the pacing interval, ATP sequence duration, pacing type, and even adding 1–2 extra stimuli, as well as using data from the previous intracardiac electrophysiological heart test.

The presented clinical case of a patient with postinfarction cardiosclerosis and paroxysmal stable monomorphic VT (SM-VT) of several morphologies demonstrates that the arrhythmogenic substrate after myocardial infarction changes for a long time without new stenoses in large coronary arteries and without new episodes of acute coronary syndrome, as well as generates several different morphologies of VT from one scar (with different heart rates) and the effect on hemodynamics. The efficiency of early ATP pacing may differ for VT of various morphologies, which makes it reasonable to use alternative pacing algorithms (in addition to the standard Burst sequences recommended by the 2019 Consensus on ICD programming) and testing possible ATP algorithms during ablation of monomorphic VT, including during preventive VT ablation before ICD implantation.

Keywords: antitachycardia pacing; implantable cardioverter-defibrillator; monomorphic ventricular tachycardia; clinical case of VT refractoriness.

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Научная статья

Антитахикардитическая терапия ИКД у пациентов с несколькими морфологиями мономорфной желудочковой тахикардии, рефрактерной к терапии

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В статье приводится описание клинического случая пациента со структурной патологией миокарда (постинфарктный кардиосклероз) с рецидивирующей пароксизмальной устойчивой мономорфной желудочковой тахикардией (ЖТ), рефрактерной к номинальным рекомендуемым настройкам имплантируемых кардиовертеров-дефибрилляторов (ИКД); обсуждаются недоставки существующих стандартных алгоритмов антитахикардитической стимуляции (АТС) ИКД и потенциальные пути увеличения ее эффективности. Рефрактерность рецидивирующих пароксизмов желудочковой тахикардии (ЖТ) к АТС-терапии увеличивает риск повторных разрядов ИКД.

Несмотря на наличие «универсальных» рекомендаций по программированию ИКД и АТС-терапии, в клинической практике существует потребность в индивидуализированной программации АТС у пациентов, рефрактерных к номинальным настройкам. Увеличение числа серий АТС и смена алгоритмов позволяет увеличить эффективность АТС до 80–89 %. Рефрактерность к стандартным настройкам АТС может быть также преодолена путем использования альтернативных алгоритмов АТС-стимуляции (Ramp, Burst-plus или Ramp-plus вместо Burst), изменения интервала стимуляции, длительности АТС-последовательности, типа стимуляции и даже добавления 1–2 экстрастимулов, а также с использованием данных предшествующего внутрисердечного ЭФИ.

Представленный клинический случай пациента с постинфарктным кардиосклерозом и пароксизмальной устойчивой мономорфной ЖТ (УМ–ЖТ) нескольких морфологий демонстрирует, что аритмогенный субстрат после перенесенного инфаркта миокарда изменяется на протяжении длительного времени без новых стенозов в крупных коронарных артериях и без новых эпизодов ОКС, а также генерировать несколько различных морфологий ЖТ из одного рубца (с разной ЧСС) и влиянием на гемодинамику. Эффективность ранней АТС-стимуляции может отличаться для ЖТ различной морфологии, что делает целесообразным использование альтернативных алгоритмов стимуляции (помимо стандартных Burst последовательностей, рекомендованных Консенсусом 2019 г. по программированию ИКД) и тестирование возможных АТС-алгоритмов в процессе выполнения аблации мономорфной ЖТ, в том числе при проведении превентивной аблации ЖТ перед имплантацией ИКД.

Ключевые слова: антитахикардитическая стимуляция; имплантируемый кардиовертер-дефибриллятор; мономорфная желудочковая тахикардия; клинический случай рефрактерности ЖТ.

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INTRODUCTION

Antitachycardia pacing (ATP) provides painless and most often safe relief of paroxysmal ventricular tachycardia (VT) in patients with implantable cardioverter-defibrillators (ICDs). The introduction of ATP therapy technology in ICDs in 1987 [2] was a significant step in the treatment of patients with VT. Currently, ATP is included in all international recommendations for ICD programming. However, with the accumulation of experience, shortcomings of ATP therapy have been revealed, and the efficiency of ATP algorithms in arresting rapid VT with a cycle length (CL) < 300 ms, proposed by the 2019 Consensus [3], is only 50%, and acceleration of VT can occur in 10% of cases receiving ATP therapy [4, 5]. The efficiency of ATP may decrease to an even greater extent in patients with multiple VT morphologies, which is more often observed in patients with structural pathology (after myocardial infarction) with a complex arrhythmogenic substrate. When ATP therapy is ineffective, the ICD uses maximum power discharge to arrest the persistent paroxysm of VT. Frequent discharges of ICD result in reduced quality of life [6] and increased mortality [7] in patients with ICDs. To eliminate the refractoriness of VT, in addition to the ICD algorithms recommended in the 2019 Consensus, antiarrhythmic therapy can increase (increase in drug doses and combination of antiarrhythmic drugs), the use of VT source ablation and individualized ATP programming, including that based on data obtained in performing intracardiac electrophysiological study (EPS) during endocardial catheter ablation (CA) of VT.

An ideal ATP algorithm should include automatic and customizable ATP for each VT in real time, taking into account the heart rate (HR), VT QRS complex morphology, and response to the previous series of ineffective ATP pacing. Such an algorithm can be created using artificial intelligence and implemented in the ATP ICD therapy program, which can be a further step in the improvement of ICD technology.

Case description

- Anamnesis: Patient (62 years old), diagnosed with postinfarction coronary heart disease (2015, non-Q-MI), cardiosclerosis. Condition after stenting of the circumflex branch of left coronary artery (2015). AV blockade 3 degree (since 2017). Implantation of pacemaker (2017) H1. (NYHA1). Arterial hypertension 2 degree, risk 4. Dyslipidemia.
- At the time of non-Q-AMI in 2015, the patient underwent stenting of the circumflex branch of the left coronary artery in 2015, with the achievement of complete revascularization. During 2015–2017, the patient did not have complaints during the intake of the recommended adequate therapy.
- In 2017, the patient developed a transient grade 3 AV block; as a result, a two-chamber electric cardiac pacemaker (ECP) was implanted, and the necessary pharmacotherapy was continued for 2 years with high adherence.
- Therapy (2017–June 2021): aspirin 75 mg/day, metoprolol 50 mg/day, ramipril 10 mg/day, and rosuvastatin 20 mg/day. During the unscheduled programming of the ECP (June 2021), sustained monomorphic VT was detected (HR, 188 beats per minute [bpm]; duration 8 min, stopped spontaneously). The patient requested unscheduled programming for this episode of palpitations, which was accompanied by a presyncope state. Coronary angiography (June 2021) revealed that the stent was passable. Hemodynamically insignificant stenoses of the coronary arteries were noted (up to 20%). ECHO-CG (2021) showed an end-diastolic dimension of 51 mm, end-systolic dimension of 34 mm, and left ventricular ejection fraction (V) of 59%. There was regurgitation on the mitral and tricuspid valves of 1 degree. Because of a device-detected (ECP) paroxysm of sustained VT, the patient underwent ECP replacement with an ICD (07.2021; Evera DR). When programming the ICD, the standard ICD settings recommended by the 2019 Consensus were used.

Therapy after icd implantation

Treatment. After ICD implantation, the dose of metoprolol was increased to 100 mg/day (amiodarone was not prescribed because this paroxysm was the only detected paroxysm of VT). The rest of the therapy was unchanged (aspirin 75 mg/day, ramipril 10 mg/day, and rosuvastatin 20 mg/day).

During the period from July 2021 to June 2022, the patient did not notice any cardiac arrhythmias, and no paroxysms of sustained VT were registered during the control programming in the course of pharmacotherapy (every 3 months). However, from June 2022, the patient began to notice sustained episodes of palpitations (up to several tens of minutes) without presyncopal and syncopal conditions, which were not detected on repeated ECG and 24-h ECG monitoring at the primary healthcare facility, until the patient was admitted to the district hospital with a stable paroxysm of monomorphic VT with HR of 155 bpm (total duration > 30 h). Intravenous administration of amiodarone did not lead to the relief of VT. As a result, procainamide was administered intravenously, which caused VT relief.

ATP therapy for this episode of VT was not initiated by the ICD because the established lower VT detection interval (in accordance with the 2019 Consensus guidelines) was set to 20 bpm less than the previously verified (2021) episode of sustained monomorphic VT (SM-VT), i.e. 167 bpm (which turned out to be higher than HR during sustained VT paroxysm, i.e., up to 155 bpm). According to the patient, until admission to the district hospital, he experienced weekly episodes of palpitations with an HR of 145–160 bpm. Coronary angiography performed at the primary healthcare facility (August 2022) did not differ from that previously performed in 2021 (the stent was passable, and hemodynamically insignificant stenoses of the coronary arteries were noted up to 20%).

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For further treatment, the patient was transferred to a level 4 center of medical care (State Republican Research and Practical Center "Cardiology").

Control programming of ICD Control (September 2022): from July to August 2022, ICDs were detected:

- One episode of sustained monomorphic VT (SM-VT) = 166 bpm (duration, 1 h 3 min; VT monitor mode without ATP therapy/no ICD discharge).
- One episode of SM-VT = 166 bpm (31 h 5.5 min; VT monitor mode without ATP therapy/no ICD discharge).
- One episode of sustained SM-VT with HR of 182–188 bpm; ATP therapy SM-VT with three attempts of ATP therapy without effect. After that, VT paroxysm was stopped by an ICD discharge (in accordance with the programmed algorithm).

The number of episodes of VT with an HR < 150 bpm in the last 3 months was not known because the lower detection threshold for VT in the monitor mode was set to > 150 bpm. Such recurrent episodes of slow VT occurred because the patient (according to him) noted periodic episodes of palpitations with a frequency of 140–145 bpm with preserved hemodynamics. Moreover, the presence of reciprocal or supra-VT was ruled out because of the presence of degree 3 AV blockade (since 2017). Paroxysms of atrial fibrillation and atrial flutter were also absent in the device memory.

Analysis of atp fragments for treatment of the episode of sustainable vt with hr of 182–188 BPM

The results of the analysis of fragments of ATP therapy demonstrated effective imposition of ATP pacing from the distal pole of the defibrillating electrode, with post-pacing interval at the time of ATP termination > VT cycle (but < 2 VT intervals), which indicated the entry of the ATP pacing sequence into the VT cycle (VT entrainment), but the inability of ATP therapy to arrest the paroxysm because of the inability to cause a bidirectional block in both directions in the vulnerable isthmus of VT. Thus, the ATP pacing cycle used was too long to achieve a critically short and effective refractory period (ERP) in the VT reentry cycle.

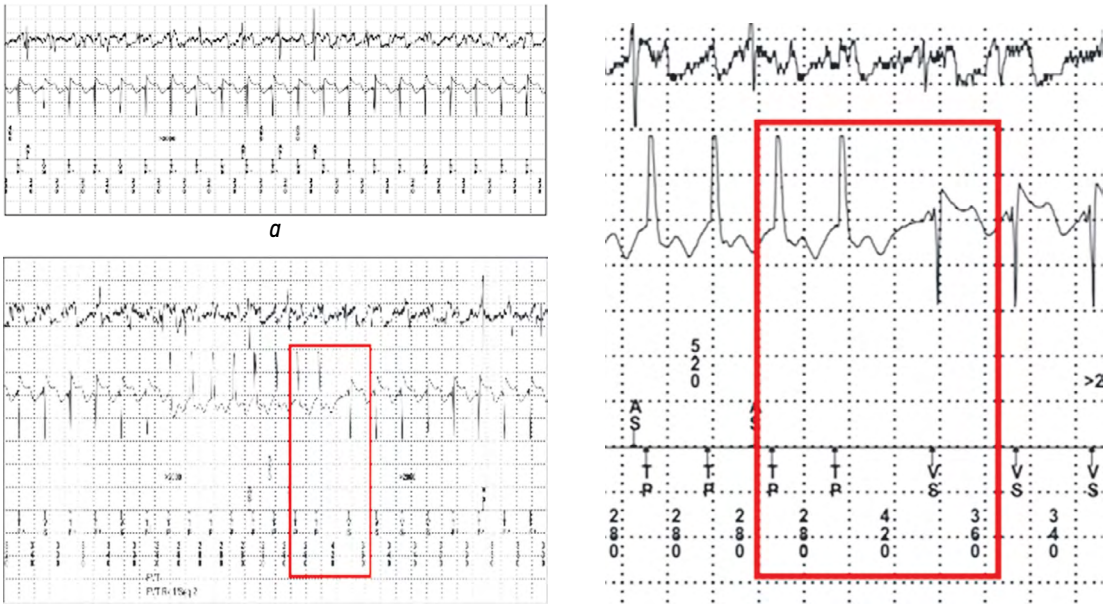


Fig. 1. ICD detects VT with a cycle of 330 ms (*a*), delivers a series of ATP pacing (*b*), whereas the analysis of the ICD endogram indicates effective pacing, with post-pacing interval of 420 ms. ATP has entered a VT cycle which is at a distance of (420–330)/2 = 45 ms from the ICD stimulation electrode. However, VT persists at the same rate

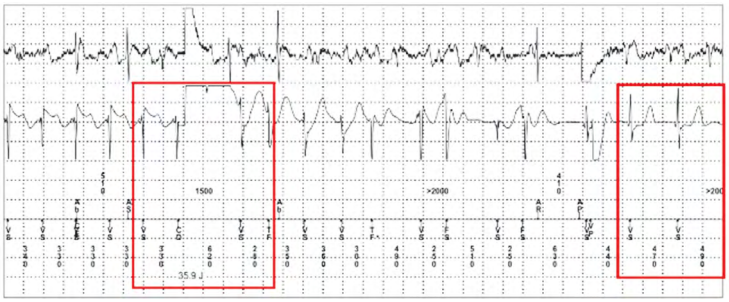


Fig. 2. Owing to the lack of effect of ATP pacing, the ICD delivers a discharge and stops VT

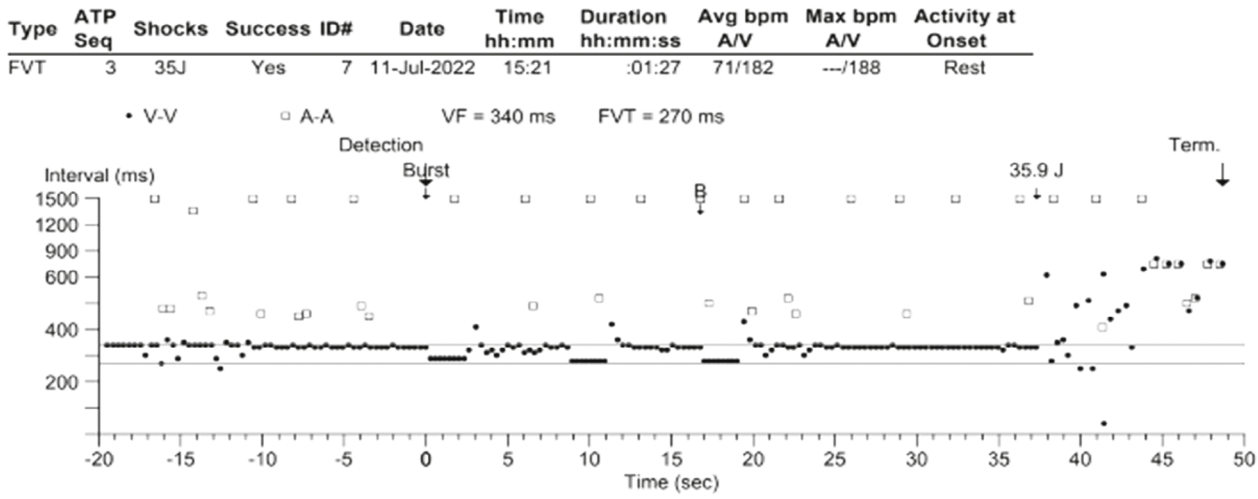


Fig. 3. Summary of the detected and arrested VT episodes. The total duration from the onset of the paroxysm to its arrest was 1 min 27 s. The episode of SM-VT with HR of 182–188 bpm was detected by ICD. To stop the ICD-detected VT, three attempts were made to arrest VT using ATP, starting from a cycle of 88% of the detected VT cycle. Thus, for the VT cycle of 330 ms, the first sequence of ATP Burst-1 is plotted with a cycle of 330 × 0.88 = 290 ms. The imposition was effective, and there were no signs of loss of capture. ATP "entered a VT cycle" but did not stop VT and was not effective. As VT persists, the ICD delivers the next series of cycles 10 ms shorter, i.e. 280 ms and then 270 ms. The duration of the post-stimulation interval (return cycle 1 of VT) ranged from 410 to 420 ms, which indicated the effective imposition of ATP pacing and the absence of loss of capture. However, this cycle of ATP pacing was too long to induce VT arrest (by creating a blockade in both directions of the VT reentry chain). Owing to the lack of VT arrest, the ICD delivered a discharge and stopped VT

Revealing the cause: analysis of ATP therapy fragments in device memory

A fragment of the programming protocol with VT detection, ATP therapy, and subsequent cardioversion is presented.

Owing to the inefficiency of ATP therapy and antiarrhythmic therapy (metoprolol + amiodarone), the patient underwent EEPS, arrhythmia substrate mapping, and ablation of the sources of detected VT.

EEPS results

- The patient underwent EEPS, using the EPS of the AXIOM Sensis XP system. From two different points of the right ventricle, using a quadripolar electrode installed in the right ventricle (RV), and a multi-programable Micropace stimulator, frequent and programable (with two extra pacings) stimulation was performed (including against the adrenaline infusion). However, inducing VT by pacing from the RV was not possible.
- Given the repeated episodes of sustained monomorphic VT with a suspected source in the left ventricle (LV), left ventricular substrate mapping was performed. In the region of the high sections of the anterior–lateral and lateral walls of the LV, a zone of low amplitude and fractionated signals (a zone of non-transmural scar) was revealed, along the edge of which early- and mid-diastolic potentials were also detected in sinus rhythm (at a distance of 1.0–1.5 cm from the annulus of the mitral valve (MV). When pacing mapping from this zone of the LV, the stimulated QRS complex matched 90%–95% with the morphology of the previously detected VT (during paroxysm at the outpatient stage). With programmed pacing from this zone against the intravenous infusion of adrenaline, paroxysmal stable VT of two different morphologies was reproducibly induced in the patient with a high percentage coincidence of induced VT with QRS of clinical VT (coincidence percentage of VT No.1 close to 100%). The HR of the two induced sustained monomorphic VT (SM-VT) was 155–165 bpm, which was accompanied by intact hemodynamics (blood pressure = 110/60 mm Hg).

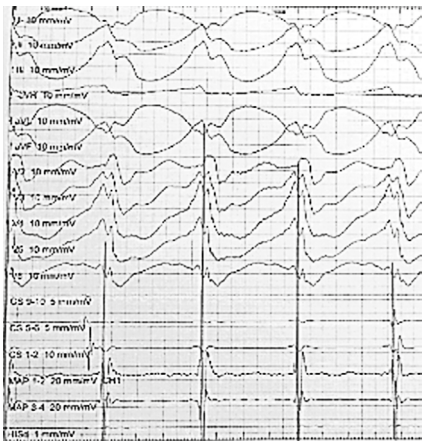
In addition, with programmed stimulation from the LV against adrenaline infusion, two slower non-sustained VTs (145 and 155 bpm; lasting 8–15 s) were induced, which differed in morphology from VT No. 1 and VT No. 2 and stopped spontaneously.

Given the preserved hemodynamics, in addition to substrate mapping in sinus rhythm, activation mapping of both SM-VT was performed using the Carto 3 system. The sources of "exit" of the two indicated VTs (zones of the earliest activation) were at a distance of 1.5 cm from each other and coincided with the extended zone of low amplitude and fractionated potentials in sinus rhythm. In this area, extended ablation was performed (scar homogenization with a power of 30 W and ablation time of 25 min) until the elimination of diastolic potentials. The affected area was connected to the MV ring by an additional ablation line. According to the ablation results, non-inducibility of both SM-VT was achieved (with frequent and programmed [up to two extra pacings] stimulation from the RV and LV, including

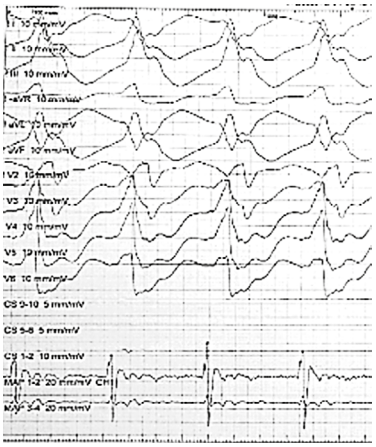
against adrenaline infusion. Thus, a positive clinical effect was achieved.

The presence of SM-VT of multiple morphologies increases the potential risk of recurrent VT after successful ablation compared with VT of a single morphology. Therefore, immediately before performing ablation during intracardiac EEPS, the efficiency of future antitachycardiac ATP protocols was tested in the X-ray operating room with stimulation from a quadripolar catheter placed in the area of the defibrillating ICD electrode. This aimed to establish the cause of the inefficiency of the previously used ATP therapy of ICD (before ablation) and test alternative ATP protocols (for customized ICD programming after ablation).

As a result of ATP simulation of ICD protocols in an X-ray operating room, typical ATP therapy using a series of burst

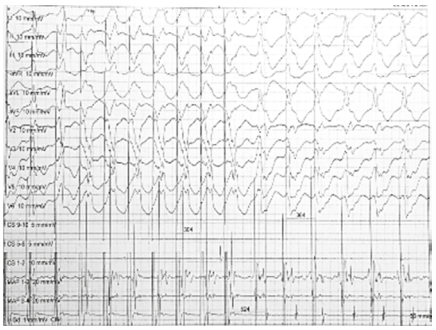


VT No. 1 (basic, clinical); heart rate = 164 bpm; CL = 360–365 ms.

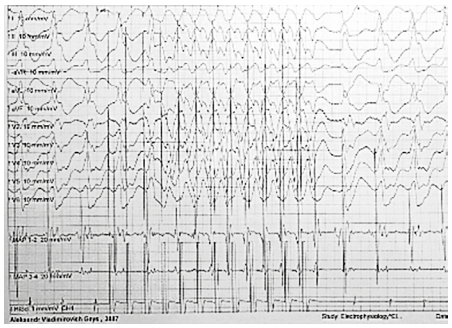


VT No. 2 (sustained monomorphic, induced on EEPS); heart rate = 160 bpm; CL = 370–375 ms

Fig. 4. SM-VT induced during EEPS of two main morphologies



a



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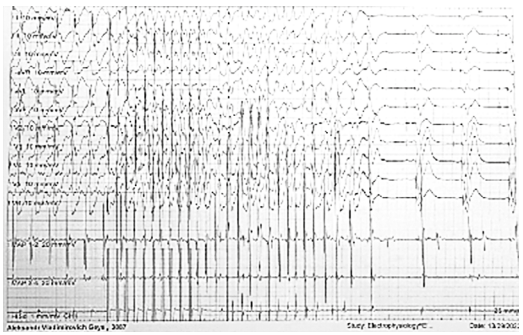

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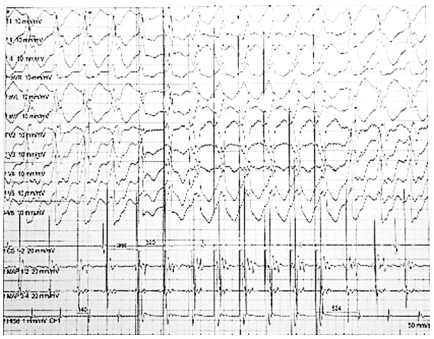

d

Fig. 5. *a* — Typical burst pacing from the right ventricular (RV) lead (88% of the SM-VT cycle). After ATP termination, VT continues with the same cycle of 365 ms. *b* — Typical burst pacing from the RV lead (83% of the SM-VT cycle). VT changed slightly the morphology and continues with the same cycle of 365 ms. *c* — "Aggressive" antitachycardic burst pacing from the RV lead (approximately 55% of the SM-VT cycle of 200 ms) with no effect. VT was maintained with the same cycle. *d* — "Aggressive" antitachycardiac burst pacing from the RV lead with a very short interval on the verge of an effective ventricular refractory period (approximately 52% of the SM-VT cycle of 190 ms). At the end of ATP stimulation, VT accelerates to 280–290 bpm and transforms into polymorphic VT (short fragment), with spontaneous arrest

stimulations, according to the recommendations of the 2019 Consensus, was deemed ineffective (Fig. 5).

The analysis of the results of intraoperative ATP with ultra-frequent stimulation demonstrated the following:

1. The ERP of the ventricles in sinus rhythm was 210 ms.
2. The ERP of the ventricles against long-term VT was < 190 ms.
3. The ERP of the ventricles with long-term VT was much shorter than the cycle of previously established antitachycardic ICD pacing in episodes of ineffective ATP at the outpatient stage (shortest pacing interval of 270 ms).

This fact was probably the reason for the inefficiency of ATP in this patient at the outpatient stage, which required changing the ATP settings for ICD therapy, which differ from those recommended by the 2019 Consensus.

Efficiency of ATP therapy during 3 months after ablation

During the follow-up period of 3 months, the patient had 2 episodes of VT with a heart rate of 168 bpm, which required the use of ATP stimulation. In both cases, Burst-pacing with a cycle length of 88% of the VT cycle (recommended by the 2019 Consensus) was ineffective. Both paroxysms of VT were effectively stopped by ATP pacing with a shorter coupling interval, namely paroxysm 1 from the series 1 with a coupling interval of 81% of the VT cycle, and the paroxysm 2 from the sequence 2 (30 ms shorter than 81% of the VT cycle), which confirmed the greater efficacy of a short pacing interval for slow VT in this patient, revealed during endocardial electrophysiological study. There were no ICD shocks during the follow-up period.

DISCUSSION

The setting protocols for ATP therapy for ICD have not changed significantly over the past 20 years, except for one important addition, that is, the lengthening of the VT detection time. Studies have shown that lengthening the time of VT detection from 18 to 30 of 40 VT intervals before applying ATP pacing or an ICD discharge can reduce reliably and significantly the number of ICD discharges [9]. This effect is achieved mainly by preventing unreasonable therapy of non-sustained VT. After obtaining similar results in several studies, a long VT detection interval has now become the standard for programming ATP therapy for ICD [10], although this prolongs the overall duration of VT paroxysm from its onset to arrest.

The experience of the arrhythmology department in the treatment of patients with paroxysmal VT with structural pathologies of the heart indicates that the main etiological cause of SM-VT directed for ablation in the Republican Scientific and Practical Center "Cardiology" was coronary heart disease (77.1%; 54 of 70 patients), and 62.9% of them had a history of myocardial infarction. In 60.0% of the cases, the posterobasal and posterolateral left ventricular wall was the VT substrate; and in 9 (12.9%) cases, multiple localizations of VT substrates were noted. Such an uneven distribution of localizations can be due to both the "survivor error" (high probability of being stopped for SM-VT from the posterolateral wall of the LV) and the anatomical or electrophysiological aspects of the myocardium of this zone, predisposing to maintaining SM-VT with preserved hemodynamics.

According to the ICD programming data, 104 VT episodes not stopped by ATP were detected in the monitored patients, which was accompanied by a total of 144 ICD discharges. Multiple localizations of VT substrates were registered in 30% of these cases. Patients were programmed according to the standard recommendations in the 2019 Consensus. Changes in programming parameters were made during the follow-up based on previous ineffective ATP therapy and the endocardial EPS (EEPS) protocol during the CA VT procedure.

The 2019 Consensus guidelines for optimal programming of ICDs recommend the use of ATP for the treatment of VT up to a high HR. The number of pulses in series and the number of series were not clearly defined. Ramp ATP and low-power cardioversion are not recommended. The nominal recommendation of the 2019 Consensus for all ICD manufacturers is "conservative" initial burst ATP therapy for monomorphic VT paroxysm after a long interval of VT detection (typically 30 of 40 ICD-detected VT complexes). The conservative start of ATP therapy implies a stimulation cycle length of 85–88% in the first series of burst stimulation (of the 8 stimulating complexes). If the first ATP sequence is ineffective for rapid VT (range, > 200–220 bpm), automatic cardioversion (up to five high-power discharges) is usually recommended.

For slow and medium HR VTs (up to 188 bpm), several sequences of burst ATP therapy can be performed (usually with 10-ms increments, i.e. each subsequent series of pacing shortens the pacing cycle by 10 ms). The number of pacing series is not specified in the 2019 Consensus guidelines; however, in practice, the number of sequences rarely exceeds 3–4 pacing series, after which the ICD is usually programmed to deliver cardioversion (usually with a maximum power discharge). An analysis of the CareLink ICD database (> 100,000 patients) demonstrated that only approximately 50% of patients with ICD had ≥3 ATP sequences programmed [11].

Frequent discharges of ICDs result in reduced quality of life [6] and increased mortality [7] in patients with ICDs. In routine clinical practice, many physicians use 1–2 series of ATP stimulation, after which cardioversion is programmed, despite convincing data confirming that increasing the number of stimulation series with a gradual shortening of the ATP stimulation cycle increases the efficiency of ATP therapy and reduces the number ICD discharges.

For example, the hypothesis that an increase in the number of series of ATP pacing leads to an increase in

the efficiency of ATP was, in particular, tested in the Shock-Less study (4112 patients). This study compared the total number of ICD discharges between two groups of patients, (1) nominal ICD programming parameters such as programming on ⩽ 3 ATP series (VT zone) and ⩽1 ATP sequence (in rapid VT zone) (nominal group), and (2) patients programmed to receive additional ATP sequences in VT (> 3) or rapid VT (> 1) zones [12]. In this study, 4359 VT episodes occurred in 591 patients over a mean follow-up of 19.6 ± 10.7 months.

Compared with the nominal group in the Shock-Less study, patients with additional ATP programming had a 39% reduction in the number of ICD discharges caused by detected VT episodes (0.46 episodes per patient-year vs. 0.28 episodes per patient-year; occurrence rate ratio [RR] 0.61, $p < 0.001$). Moreover, the number of ICD discharges for fast VT reduced by 44% (0.83 episodes per patient-year vs. 0.47 episodes per patient-year; RR 0.56; $p < 0.001$). A decrease in the number of ICD discharges was noted both in the groups with primary prevention of sudden cardiac death (SCD) (IRR 0.68; 95% confidence interval (CI) 0.51–0.90; $p = 0.007$) and secondary prevention of SCD (IRR 0.51; 95 % CI 0.35–0.72, $p < 0.001$). Thus, programming more than the nominal number of ATP sequences in VT zones (and even rapid VT) is associated with a lower rate of ICD discharges.

The key efficacy parameter is pacing with an ATP cycle duration short enough to achieve block in both directions of the VT reentry wave (or delivering a single extra pacing during the vulnerable period of VT reentry), but not the number of ATP series per se.

Thus, if ATP stimulation with a sufficiently short cycle is immediately chosen, it will stop the VT paroxysm from the first exposure. An increase in the number of ineffective ATP series leads to the prolongation of the VT paroxysm, and this, paradoxically, reduces ATP efficiency.

Several clinical studies have shown that even prolonging the detection time from 18 to 30/40 VT complexes leads to a decrease in the efficiency of ATP therapy, especially for rapid VT. Specifically, in the ADVANCE 3 study, a reduction in the efficiency of ATP therapy by up to 50% for rapid VT was noted [4].

Probably, prolonged paroxysm leads to the development of electrical myocardial remodeling, which is expressed in a shortening of the ERP of the myocardium and vulnerable VT isthmus, which in turn reduces the efficiency of slow, conservative series of ATP stimulation. The longer the time to effective therapy (a short ATP cycle is sufficient), the lower the efficiency of ATP and the higher the frequency of ICD discharges.

Thus, it is necessary to maintain a balance with a sufficiently long initial detection of VT (to prevent unreasonable treatment of non-sustained VT that can stop independently) and the application of effective ATP with a sufficiently short pacing cycle (stopping VT by achieving blockade in vulnerable VT isthmus). However, the ATP pacing cycle should not be excessively short to avoid warming up of VT, its acceleration, and/or transformation into polymorphic VT or ventricular fibrillation.

The presented clinical case reflects the shortcomings of the standardized approach to ICD programming recommended by the 2019 ICD programming consensus. A long detection interval in combination with a "conservative" start of ATP stimulation (88% of the length of the VT cycle), a slow sequential shortening of the ATP stimulation cycle (minus 10 ms) with a limited number of ATP stimulation sequences (4 stimulation series) does not allow stopping slow VTs that have a short ERP in the vulnerable isthmus of the reentry of VT, which does not allow for bidirectional blockade in both directions of the VT cycle (Fig. 6).

In the demonstrated clinical case, the cycle of clinical and EPS-induced VT was 365 ms. When applying the 2019 Consensus recommendations after a long VT detection interval (30 of 40 complexes, which corresponds to a detection duration of ≈ 11 sec), after the inefficiency of series 1 of ATP (88% of the SM-VT cycle, i.e. 321 ms), the device will gradually shorten the stimulation cycle (by 10 ms).

Thus, if additional three bursts of burst pacing are programmed, then the ICD will sequentially reach the length of the ATP pacing cycle of 321–311–301–291 ms, after which, with continued VT, it will deliver an ICD discharge. The total time to the restoration of sinus rhythm is approximately 46.7 s (≈ 11 s for detection, 27.7 s for delivering a series of four ineffective burst ATP pacing, and 8 s for charging the ICD before delivering a discharge). In this case, as follows from the above case, the length of the cycle of the ineffective ATP pacing 4 of ICD of 290 ms was much longer than the pacing cycle during EEPS that arrested VT during EEPS (190 ms). The paroxysm duration before an effective impact (ICD discharge after 46.7 s) was sufficient to cause electrical remodeling and reduce the efficiency of ATP pacing in a patient.

Possible methods to overcome refractoriness to ATP stimulation:

1. Use antiarrhythmic therapy that increases the length of the action potential and ERP of the myocardium in vulnerable VT isthmus (antiarrhythmic drugs of classes 1A, 1C, and III).

2. Use a more "aggressive" starting percentage of burst pacing (e.g., with 81% of the VT cycle length).

3. Use a larger number of sequences with a slow decrement (step of 10 ms), which may lead to a several-fold increase in the risk of VT acceleration and its transformation into ventricular fibrillation with an increase in the number of ATP series of > 6 [13].

4. Use a faster decrement between successive series of burst pacing (decrement step of 30 ms instead of that nominal of minus 10 ms recommended by the Consensus), at least for patients with slow and medium-fast VT with a history of episodes of ineffective ATP pacing, accompanied by potentially preventable ICD discharges.

5. Use ATP sequences such as burst plus or ramp plus, where, in addition to a series of 6–8 pacing of the same

a *b*

Pic. 6. *a* — ATP pacing with an insufficiently short pacing cycle produces blockade in one direction but does not achieve blockade in the antegrade propagating reentry wave. S1 stimulation "enters the VT cycle" (VT entrainment), but does not stop VT. *b* — S1 pacing "enters the VT cycle" and given the short interval, achieves blockade of impulse propagation in both directions (stops VT)

length, 1–2 extra pacings with a shorter coupling interval is added. Unfortunately, these algorithms are not available from all manufacturers.

6. Use "intelligent" ATP stimulation algorithms that automatically adjust to the parameters of the previous ineffective series of ATP stimulation (shortening the stimulation cycle, adding or decreasing the number of pacing in the series, adding 1 or 2 extra pacings with automatic adjustment of the changing auto number and length of the extra pacing cycle, etc.).

To prevent repeated ICD discharges in the patient described above after effective VT ablation of two morphologies, we made the following corrections to the standard settings of ATP ICD therapy (in case of VT recurrence):

1. As the initial therapy for VT, a "conservative" start of ATP therapy was retained (88% of the length of the VT cycle to reduce the risk of accelerated VT/transformation into ventricular fibrillation):

- Initial series of ATP pacing with a starting cycle of 88% (only two sequences with 10-ms steps were retained), which may be sufficient in the case of recurrent VT after the modification of the arrhythmogenic substrate because of ablation.

The number of pulses in the series was reduced to six pacings because the post-pacing interval of 410–420 ms indicates that four ATP cycles of a given length are sufficient to reach the pacing wave to the VT reentry circle; and + 2 pacings are left for other VT morphologies.

2. If the step 1 of the ATP pacing algorithm is ineffective, the step 2 of the ATP therapy algorithm includes the following:

- A series of stimulations with a starting cycle of 81% of the length of the VT cycle (6 pacing in each sequence).
- Decrement step–minus 30 ms, retained + 3 sequences in 30-ms steps (which for VT with an initial frequency of 164 bpm enables achieving quickly the length of the stimulation cycle of 206 ms (56% of the length of the VT cycle) after step 3 of the decrement and to shorten to the maximum the time to achieve the ERP (i.e., moment of potential efficiency of ATP pacing, approaching the ERP of the ventricles of 200–210 ms even against adrenaline infusion).
- The total duration from the onset of VT paroxysm to its relief by series 4 of ATP with a decrement of 30 ms will be 30.7 s (instead of 46.7 s), which is 34.3% shorter than the initial duration of the ineffective series of ATP, which ended with an ICD discharge.
- A faster shortening of the pacing cycle to an effective one will prevent rapid electrical remodeling ("warming up") of VT.

3. If step 2 is ineffective, the algorithm proceeds to step 3, that is, the programmed "conservative" Ramp plus:

- A series of stimulations with a starting cycle of 88% (instead of the nominal 75%) of the length of the VT cycle (six pacing in each sequence), plus
- Two nominal extra pacings with a length of 69% and 66% of the length of the VT cycle.

4. If steps 1–3 are ineffective, cardioversion with maximum energy of discharge is performed (steps 4–6).

The general opinion of the authors of the recommendations on ICD programming and analysis of the literature suggests that the risk of VT transformation is higher with the use of

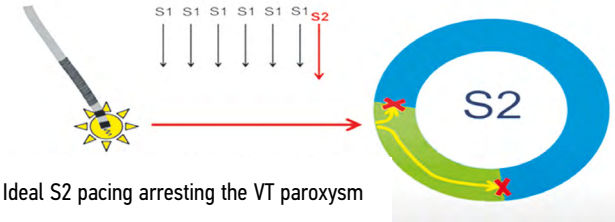

Fig. 7. After entering the reentry cycle, the application of the S2 pacing with a sufficiently short coupling interval "closes" the impulse propagation in both directions (due to the entry of vulnerable VT isthmus into the tissue refractoriness period)

more aggressive ramp and ramp plus sequences of ATP therapy (with a short initial coupling interval of 75%)[14] and [15]. Therefore, in the 2019 Consensus, ATP therapy should be started with a "conservative" burst (88%).

The concept of extra pacing (S2 and S3 [if necessary] assumes that the initial series of impulses with a fixed duration of the stimulation cycle [S1 pacing of 4–8 impulses] enter the VT cycle [VT entrainment; therefore, there is no need for an excessively short coupling interval for S1 (which, if excessively shortened, will more possibly accelerate VT).

VT relief was achieved by a single (or double) extra pacing S2, applied with a short enough coupling interval to "close" the electrically excitable vulnerable VT isthmus on the verge of ERP "gateway" or VT isthmus. Preliminary analysis performed on a simulator based on the database of remote ICD monitoring indicates an increase in the efficiency of this approach by 15%–20% compared with the standard burst ATP stimulation [16].

CONCLUSIONS

1. The clinical case presented clearly demonstrates that the arrhythmogenic substrate after myocardial infarction changes over a long period of time, and it may take several years for its "maturation". The arrhythmogenic substrate can continue to evolve after the identified episode 1 of VT without new stenoses of large coronary arteries and without new episodes of acute coronary syndrome, as well as generate several different VT morphologies from the same scar (with different heart rates) and influence on hemodynamics.

2. In case of insufficient efficiency of ATP pacing and/or repeated ICD shocks caused by the inefficiency of ATP aimed against monomorphic VT, it is advisable to use alternative pacing algorithms (in addition to the standard Burst sequences recommended by the 2019 Consensus on ICD programming).

3. It is reasonable to test possible ATP algorithms during ablation of monomorphic VT (when performing endocardial electrophysiological study), for example, when performing preventive ablation of VT before implantation of ICD as first line therapy for recurrent sustained monomorphic VT.

4. Newly developed ICDs and ATP therapy algorithms are in dire need of the introduction of artificial intelligence elements, especially for patients with multiple VT morphologies.

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