Present Status and Future Concepts for Arrhythmia Treatment with Multichamber Implantable Devices

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Summary

Rapid development of implantable cardioverter/defibrillators (ICD) extends their functionality to most universal devices. Phylax AV, world-wide first dual chamber ICD successfully implanted in pectoral position at Bakoulev Center, Moscow in April 1996, since then was implanted in more than 300 patients. New concepts for preventive arrhythmia therapy are now emerging that will provide dynamic therapeutic interventions, their strength and duration immediately adapted to the acute state of the cardiovascular system. It is therefore mandatory to continuously monitor the state of the cardiovascular system by suitable analysis of typical cardiac intervals and signals. Realization of these concepts of preventive therapy will reduce the necessity to terminate running arrhythmias drastically. Thus, future antiarrhythmia devices will resemble more a cardiac pacemaker than those cardioverter defibrillators known today.

Key Words

Dual chamber implantable cardioverter-defibrillator (ICD), heart arrhythmia, ventricular tachycardia, supraventricular tachycardia, antitachycardia pacing

Introduction

Since the first implantation of an cardioverter/defibrillator in 1980 [1], ICD therapy has seen a rapid development that is based on new therapeutic concepts and technological progress. Up to the early nineties, the predominant goal was the prevention of sudden cardiac death in patients with life-threatening ventricular tachyarrhythmias with the highest possible efficacy. Since then, the optimization of therapy efficiency and the improvement of the quality of life of the patients have become more and more important. In the following, the latter aspects in the management of malignant cardiac arrhythmia are considered. Progress in improvement of therapy efficiency and quality of life is being achieved by reducing the defibrillation threshold and by using antitachycardia pacing and dual chamber antitachycardia therapy. The logical extension of present concepts for the treatment of cardiac arrhythmia consists in a preventive closed loop therapy [2]. This idea comprises recognition of precursor states of arrhythmias and application of specific therapy controlled by the effect it exerts onto the arrhythmogenic substrate.

Role of the lead in defibrillation

From the very beginning, the lead concept played a crucial role for the development of ICD therapy because it largely determines the efficiency of the energy transfer from the device to the myocardium. Today, it is well appreciated that defibrillation requires the development of an adequate voltage gradient throughout a critical volume of the myocardium in order to excite the tissue and interrupt the multiple wavelets that sustain fibrillation [3-5]. It is obvious that the design of the electrode surface has to ensure that the voltage drop across the phase boundary is minimized. Theoretical considerations suggested to enlarge the active surface area by a fractal coating to achieve this goal, and indeed clinical results confirm the validity of this approach [6-8]. From a geometric point of view ideal electrode configuration should provide a uniform field distribution throughout the myocardium. The realization of this goal lead to the use of epicardial patch electrodes in the first ICDs. However, the perioperative mortality and morbidity associated with epicardial electrodes favored the usage of transvenous

leads with one shock coil in the right ventricle and the second shock coil in the superior vena cava in spite of the apparently inhomogeneous field distribution [9]. The availability of devices that are small enough for implantation in a pectoral position enabled an important improvement: A unipolar configuration with the use of a right ventricular shock coil and the housing as active electrodes enabled a more homogeneous defibrillation field and reduced defibrillation threshold (DFT) to mean values below 10 J [6].
However, this configuration is still not ideal with respect to the left ventricle. The establishment of a sufficient potential gradient in this region requires from a model point of view an excess voltage gradient throughout the right ventricle. Our personal experience with low-energy defibrillation indicate that this shortcoming may be solved by introducing a transvenous lead via the coronary sinus in a suitable coronary vein [10]. Inclusion of an electrode position in close vicinity of the left ventricle avoids the nonuniformity associated with an exclusively right ventricular electrode position and thus is expected to further reduce the defibrillation threshold by at least 30% [11].

Avoid shock delivery - antitachycardia pacing

Current efforts to improve ICD therapy focus on avoiding shock delivery whenever possible. The inclusion of antitachycardia pacing into the first 3rd generation ICDs in 1993 enabled for the first time an automatic non-shock treatment of recurrent sustained ventricular tachyarrhythmias [12,13] by the implantable defibrillator. This approach is based on the pioneering work of Wellens [14] and Josephson [15] who showed that sustained ventricular tachyarrhythmias can be safely and reproducibly terminated by programmed electrical stimulation of the heart in the catheterization laboratory.
Antitachycardia pacing (ATP) treats successfully between 80% and 90% of the VT episodes detected by the implantable cardioverter defibrillator. Thus, the therapy efficiency is enhanced by avoiding shock induced damage to the myocardium and reducing the energy consumption of the device. The patients, of course, benefit from every single shock that may be avoided since any shock release and particularly the permanent immanence of a shock delivery substantially limits his quality of life. It is generally accepted that the risk associated with acceleration of the arrhythmia and prolonged therapy duration may be safely controlled by limiting the maximum number of subsequent ATP deliveries.

Extension to atrial therapy

Being aware of the shortcomings of a ventricular-only ICD, it was our strong personal concern from our very earliest experiences with ICD therapy to extend detection and therapy delivery to the atria. Consequently, we committed ourselves to the development of a device providing AV discrimination and full atrial therapy resulting in the first implantation of a DDD controlled cardioverter/defibrillator in April 1996 [16]. The Phylax AV (Biotronik) for the first time closed the gap

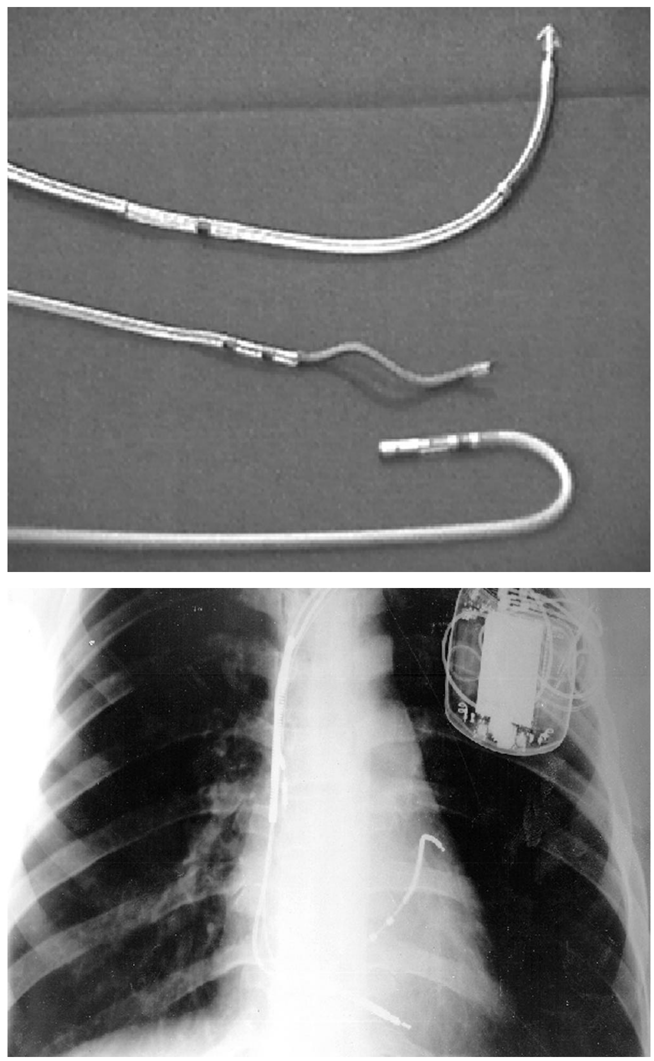

Figure 1. Electrodes for the dual-chamber ICD Phylax AV.

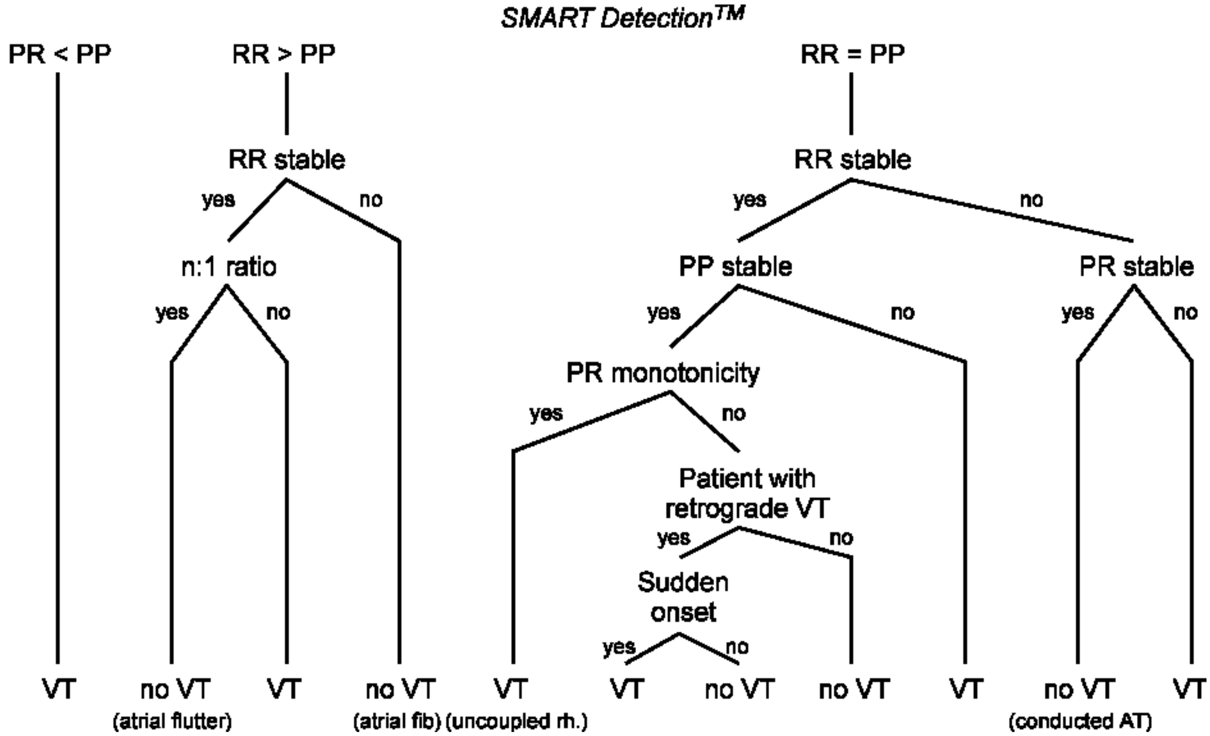

Figure 2. The diagram schematically visualizes the SMART algorithm.

of atrial sensing and pacing (Figure 1). This is the prerequisite for an algorithm for AV discrimination based on analysis of PP, PR and RR intervals and their stability (SMART algorithm) (Figure 2). It overcomes the lack of specificity of detection in ventricular-only ICDs which leads to approximately one third of inappropriate shock deliveries [17,18]. The basic idea for the SMART algorithm was a very simple assumption: the chamber with the higher rate is the origin of the arrhythmia.

Clinical data on dual-chamber ICD (Phylax AV) implantation

Phylax AV - first world-wide available universal ICD - was successfully implanted in pectoral position at Bakoulev Center, Moscow, on April 30, 1996. Clinical experience includes 329 patients (pts) to whom the dual chamber ICD (VVE-DDD) Phylax AV has been implanted (from April 1996 to July 1999) (Table 1). From 329 pts 48% had the SMART algorithm activated (SMART ON), but majority of them, 82%, had the indication for DDD pacing.

Our patient group with second generation of Phylax AV (DDE-DDD) devices includes 19 pts (17 male, mean age 56 ± 8 years). A lead with atrial and ventricular shock coils and ventricular pacing/sensing was used in 10 pts (SL-ICD, Biotronik), a similar lead without atrial shock coil was implanted in 9 pts (SPS and Kainox, Biotronik). The SMART algorithm for AV discrimination was validated intraoperatively and during follow-up. During testing and implantation (6 pts) a helix-shaped lead with one shock coil and two ring electrodes was used in the coronary sinus (CS) for atrial defibrillation and biatrial pacing option (Figure 1, 6). The DFT was measured to be 8.5 ± 3.8 J for ventricular shocks (RV vs. active housing), 1.2 ± 0.3 J in the atrium (RA vs. CS & active housing). The follow-up period is 23.3 months (ranging from 4 to 40 months), during which 104 tachycardic episodes have been detected. 32 atrial shocks were released during the follow-up (10 manual, 22 automatically). SMART algorithm sensitivity and specificity have been tested at the Bakoulev Center (104 clinical episodes) and with 67 patient files from the Ann Arbor electrogramm database, 100% sensitivity (Sv) and specificity (Sp) for

Phylax AV clinical data		
Number of implantations	329	
Gender	278 males / 51 female (84% / 16%)	
Age	10 - 88 years	
Mean age	60.8 ± 12.7 years	
CAD	67%	
NYHA*	I	40
	II	115
	III	58
	IV	8
DDD Indication	82%	
SMART ON	48%	

* (values missing: 108)

Table 1. Clinical data on patients with the ICD Phylax AV implanted.

VT/VF discrimination been revealed. For no 1:1 conduction SVT, AF, Affl Sv was 100%, Sp 95%; for double tachyarrythmias VT/VF + AFib/AFl Sv was 92%, and Sp 100% [19] (Tables 2-3).

The subtle problems involved in the case of equal atrial and ventricular rates require analysis of the stability of the respective intervals. To overcome the most challenging case, i.e. the discrimination between retrograde conducted VT versus supraventricular tachycardia, the use of an active discrimination method was investigated. It consists in applying ventricular stimulation at slightly decreasing coupling intervals. Our data show, that the resulting shortening of the PP intervals in the case of ventricular origin of the arrhythmia provides excellent detection specificity without reducing sensitivity.

During intraoperative testing of the active discrimination algorithm [20,21], 22 episodes of clinical ventricular or supraventricular tachycardia were induced. Another 20 VT episodes were simulated by stimulating the right ventricle at a cycle length indentical to the patient's intrinisic VT cycle length. For comparison, the atrium was stimulated at the same cycle length in order to simulate a SVT. The clinical episodes were detected by the algorithm with a VT sensitivity of 100% and specifity of 88%. For the paced episodes, both sensitivity and specifity were 100%.

The first Phylax AV with this active discrimination method implemented was implanted in two patients at the Bakoulev Institute in April 1998 [21] (Figure 3-5). This device furthermore offers full atrial therapy and thus is very close to the vision of a tiered therapy dual chamber ICD to treat concurrent atrial and ventricular arrhythmias as it is required in 10 to 35 % of patients [16,22]. Atrial antitachycardia pacing and atrial defibrillation enable specific and reliable therapy of supraventricular arrhythmias. In particular, the delay between detection of atrial fibrillation and therapy delivery can be distinctly reduced [10]. Therefore, atrial remodeling [23] and thromboembolic risk associated with sustained fibrillation are reduced by prompt therapy delivery.

	Algorithm	Experience (pts)	Therapy
Defender™ 9001, 9201 (Ela Medical)	+	> 200	-
Phylax AV™ (Biotronik)	+	> 300	+
Ventak AV, AV III DR (CPI/Guidant)	+	> 70	-
Res-Q™ Micron (Intermedics)	+/-	26	-
Jewel™ 7218, 7223, GEM 7227 (Medtronic)	+	+	-
Jewel™ AF, 7250, GEM DR 7271 (Medtronic)	+	> 500	+

*1995 - 1999

Table 2. World-wide experience on dual chamber ICD implantation (1995-1999).

ICD type	AV discrim. Algorithm	Sensitivity (SVT)	Specifity (VT / VF)
DefenderTM 9001, 9201 (Ela Medical)	+	93%	100%
Phylax AVTM (Biotronik)	+	95%	100%
Ventak AV (CPI/Guidant)	+	89%	100%
Res-QTM Micron (Intermedics)	+/-	-	-
JewelTM II, 7218, 7223 (Medtronic)	+	88-96%	76% / 100%
JewelTM AF, 7250 (Medtronic), GEM DR	+	92%	99%

Table 3. Specificity and sensitivity of different ICD algorithms to discriminate supraventricular (SVT) and ventricular tachycardia (VT).

Preventive closed loop therapy

The biggest potential for further progress in arrhythmia therapy will certainly stem from the maintenance of an appropriate heart rate that takes into account balance of the cardiovascular system. Especially, in patients with low ejection fraction and limited cardiac function, the required cardiac output has to be provided with optimal efficiency. The detrimental effect of VVI stimulation on the cardiac output has been shown as early as 1967 by Nager and coworkers [24]. On the other hand, AV synchronous pacing increases the cardiac output [25] and thus also may improve cardiac function substantially in patients with severely diseased hearts. Furthermore, it is generally appreciated that DDD pac-

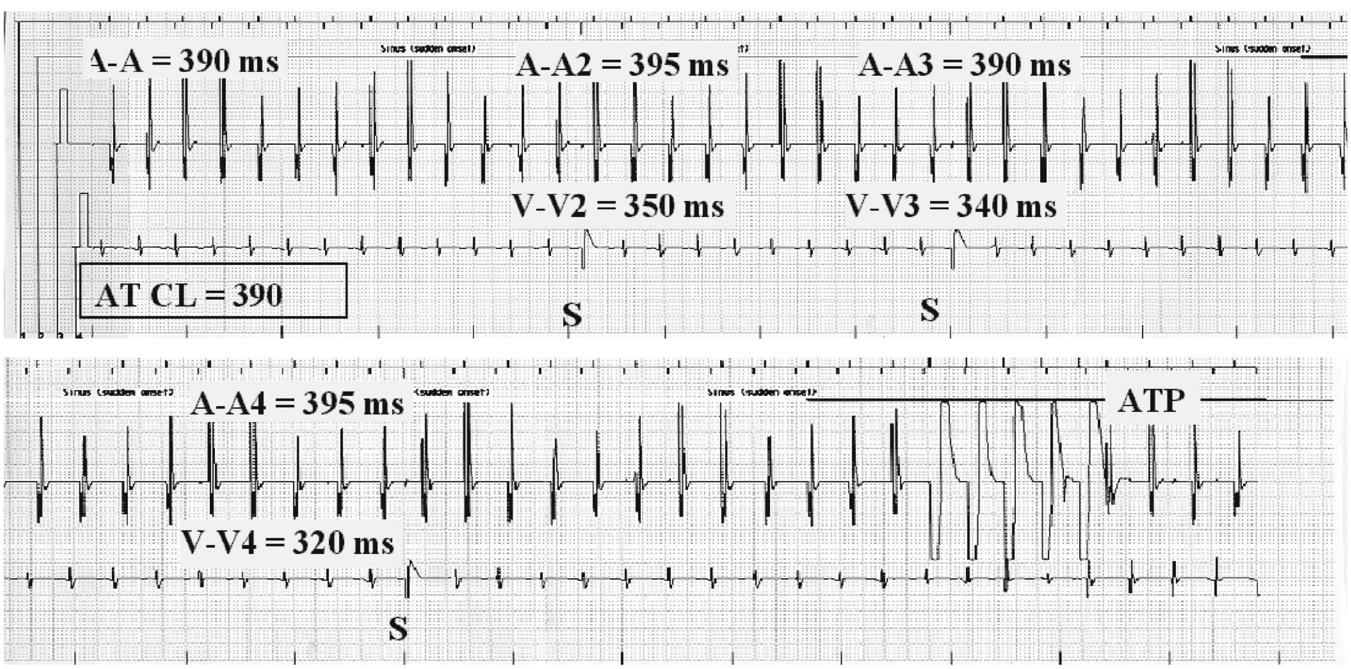

Figure 3. Atrial and ventricular EGMs of the patient with atrial tachycardia (cardiac cycle length CL = 390 ms and A:V = 1:1. Active discrimination algorithm is initiated automatically releasing singular ventricular test pulses with decreasing event-pulse intervals: V-V2 = 350ms, V-V3 = 340 ms, V-V4 = 320 ms. As far as the atrial CL is not changed for more than 5 ms, the device delivers atrial ATP.

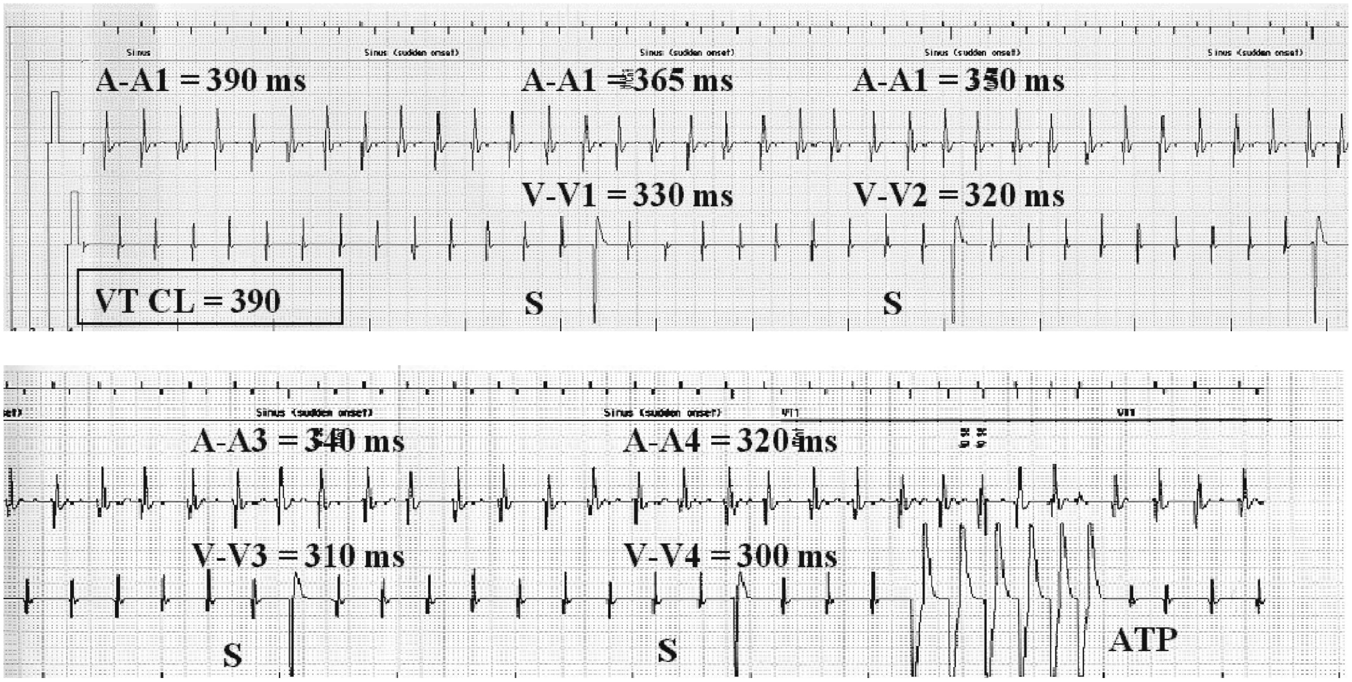

Figure 4. Atrial and ventricular EGMs of the patient with atrial tachycardia (cardiac cycle length CL = 390 ms and A:V = 1:1. Active discrimination algorithm is initiated automatically releasing singular ventricular test pulses with decreasing event-pulse intervals: V-V2 = 350 ms, V-V3 = 340 ms, V-V4 = 320 ms. As far as the atrial CL is changed for more than 60 ms, the device delivers ventricular ATP.

ing exerts a protective effect against the risk of atrial fibrillation and mitral or tricuspidal valve damage associated with a loss of atrioventricular synchrony and retrograde atrial excitation. The overall benefits of AV synchronous pacing are perceived in the most distinct manner if the increased mortality rates of VVI versus AAI/DDD pacing are considered: Witte et al. [26] found, that in a paired population of 1242 patients the survival rate after 8 years of follow-up was 79% in the VVI group and 91% in the AAI/DDD group. Therefore, the availability of DDD pacing in implantable cardioverter/defibrillators is an important step towards an optimized tachyarrhythmia therapy and an improved quality of life.

However, the next step must be to take into account the observation that arrhythmia genesis is closely associated to anomalies in the repolarization behavior and in the conduction velocity of electrical excitation propagation through the heart. Simultaneous stimulation of right and left atrium using a coronary sinus electrode today is widely accepted for prevention of atrial fibrillation in patients with interatrial conduction block [10] (Figure 6). A more generalized approach will have to include in addition to this example of a static change in substrate properties also the dynamic changes that may trigger arrhythmias. The fluctuations of autonomic tone have been recognized since long to be deeply involved into arrhythmia genesis. Generally speaking, vagal activity exerts a protective influence in diseased hearts, however, in normal hearts vagally mediated atrial fibrillation has been observed [27,28]. New concepts for preventive therapy will have to account for the dynamic character of the mechanisms of arrhythmia genesis. This means that they have to provide dynamic therapeutic interventions that adapt strength and duration immediately to the acute state of the cardiovascular system. It is therefore mandatory to continuously monitor the state of the cardiovascular system by suitable analysis of typical cardiac intervals (PP, PR, RR, total atrial activation time, etc.) or signals (MAP, VER, AER, etc.). Realization of this concept of preventive closed loop therapy will reduce the necessity to terminate running arrhythmias drastically. Thus, future antiarrhythmia devices will resemble more a cardiac pacemaker than those cardioverter defibrillators known today.

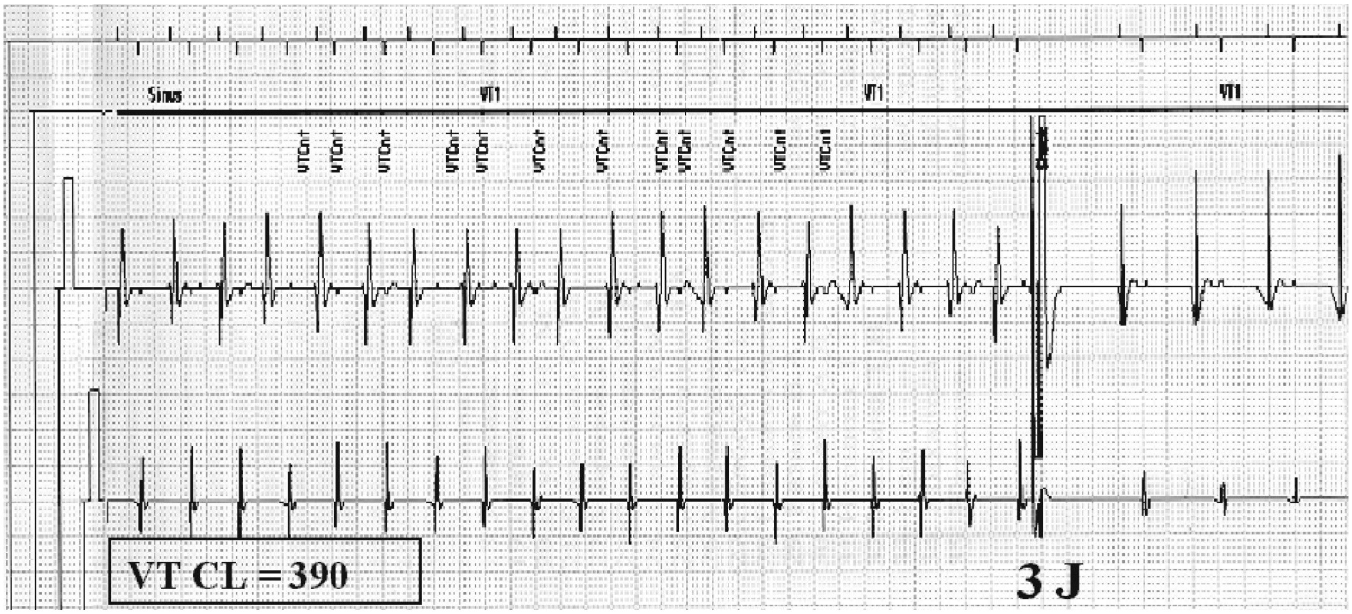

Figure 5. The therapy course continued from Figure 4. Ventricular ATP occurs to be not effective and the 3J shock is delivered to terminate successfully the VT paroxysm.

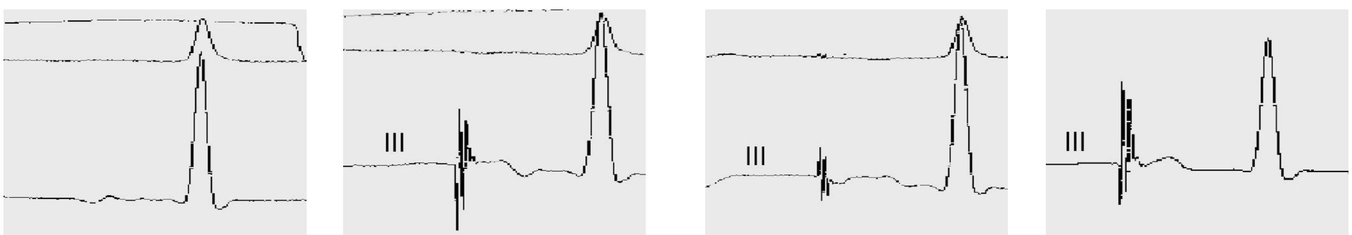

Figure 6. ECG of standard I, II and III leads. As pacing mode is switched from right atrial (HRA st) to biatrial (HRA/CSd st) the P wave duration is decreased from 200 to 85 ms, respectively.

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