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Ventriculoatrial Conduction Metrics for Classification of Ventricular Tachycardia With 1:1 Retrograde Conduction in Dual-Chamber Sensing Implantable Cardioverter Defibrillators

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Abstract: The introduction of dual-chamber sensing in implantable cardioverter defibrillators (ICDs) has greatly reduced the incidence of false detection due to supraventricular tachycardias. The remaining arrhythmias which serve to confound classification are supraventricular tachycardias (SVTs) with 1:1 anterograde conduction and ventricular tachycardias (VT) with 1:1 retrograde conduction. An algorithm has been designed and tested (28 patients) which employs ventriculoatrial (VA) conduction measurements to separate 1:1 VTs from 1:1 SVTs. A study was conducted to assess realistic VA interval boundaries for classification of arrhythmias with 1:1 retrograde atrial conduction. Intracardiac atrial and ventricular recordings of 7 passages of VT with retrograde conduction, 12 passages of atrioventricular nodal reentrant tachycardia (AVNRT), 3 passages of atrial tachycardia (AT), 8 passages of sinus tachycardia (ST), and 2 passages of orthodromic reentrant tachycardia (ORT) were analyzed. Automated real-time atrial and ventricular waveform recognition was performed on each passage and VA intervals were measured. Separation of VT with retrograde conduction from other 1:1 supraventricular tachycardias was effected by imposing discrete VA interval boundaries. VA boundaries of 80 ms to 234 ms classified 1:1 VT with 100% sensitivity (SENS) and 80% specificity (SPEC). In addition, the lower boundary completely classified AVNRT with 100% SENS and 100% SPEC, and all passages of ST were contained above the upper boundary. These findings could be of importance in algorithms for next-generation implantable cardioverter defibrillators which include two-chamber (atrial and ventricular) sensing and two-chamber interval measurements. **Key words:** ventricular tachycardia, retrograde, implantable defibrillators.

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Implantable cardioverter defibrillators (ICDs) have offered a life-saving alternative to drug or surgical treatment of potentially lethal arrhythmias. This technology has advanced to third-generation devices which have tiered-therapy choices: antitachycardia pacing, cardioversion, and defibrillation. The newest devices, now in clinical trials, contain dual-chamber sensing (atrial and ventricular) which has dramatically improved detection statistics. In dual-chamber sensing ICDs, detection of tachycardias is determined by atrial-to-atrial (AA) and ventricular-to-ventricular (VV) interval measurements. Upon detection of a fast cardiac rate, the ratio of A events and V events often gives evidence of origin of the arrhythmia, that is, the number of atrial events (As) greater than the number of ventricular events (Vs) denotes a supraventricular tachycardia while Vs greater than As denotes a ventricular tachycardia (1–2). A 1:1 ratio of As to Vs, however, is a confounding situation in which the origin and direction of conduction is indecipherable by the device. This phenomenon of 1:1 A to V relationship could reflect either a supraventricular tachycardia with 1:1 anterograde conduction or a ventricular tachycardia with 1:1 retrograde activation. It is important for the device to recognize a tachycardia with ventriculoatrial (retrograde) conduction due to the possible severity of this arrhythmia and the need for specific and appropriate therapy. Militianu et al. (3) confirmed the need for this classification given that about 20% of ICD recipients demonstrated retrograde conduction ability in a study they conducted.

Interval measurements are the primary means by which ICDs effect tachycardia detection and elicit therapeutic responses. Other more computationally intensive means can be used which include analysis of waveform morphology for recognition of abnormal conduction (4–10). However, simplicity of detection means remain a requirement given the power limitations of implanted battery-operated devices. Interval measurements can be used to derive some useful detection criteria such as sudden onset which helps to separate gradually increasing STs from VTs; however, this addresses only one specific type of 1:1 SVT when several are subject to false detection. The determination of AA and VV intervals is straightforward, yet AV and VA intervals, which are easily derived by the same digital logic, are ignored. It has been hypothesized that a simple additional step of incorporating VA interval measurements within the algorithmic logic of tachycardia detection could help to classify the ambiguous 1:1 cases.

This study was based on earlier findings (11,12) which examined artificially generated tachycardias via atrial and ventricular pacing and determined that VA interval boundaries could be used to classify retrograde activation. These studies did not, however, examine naturally occurring (nonpaced) retrograde activation. In a study on VA conduction, Schuilenburg (13) mentioned the concern that ventricular pacing may influence the properties of the ventricular-atrial conduction system. Thus, it is necessary to examine naturally occurring retrograde tachycardias before accurate discrimination can be performed. This study was undertaken to delineate the true boundaries that classify 1:1 VT with retrograde conduction by including nonpaced naturally occurring arrhythmias.

Methods

Recordings of atrial and ventricular electrograms were obtained during elective clinical cardiac electrophysiology studies. Patients gave informed written consent and were subsequently studied in a fasting postabsorptive state after sedation with 1 to 3 mg intravenous midazalom. After administering 1% lidocaine for local anesthesia, one 7F and two 6F side-arm sheaths (Cordis Corporation, Miami, FL) were positioned in the right femoral vein using the Seldinger technique. Three 6F quadripolar electrode catheters (USCI Division, C.R. Bard Inc., Billerica, MA) were introduced and advanced under fluoroscopic guidance. Each electrode catheter had four platinum electrodes with an interelectrode space of 1 cm. Electrograms were recorded on FM magnetic tape (9.525 cm per sec) or on digital audio tape from distal bipolar endocardial electrodes positioned in the right ventricular apex and from distal endocardial electrodes positioned in the high right atrium. Amplifier settings were 1 to 500 Hz and gains were held constant throughout the recordings. Electrograms were digitized at 1,000 Hz and processed by custom software on an Intel (Hillsboro, OR) 80486DX computer.

Analysis

In this study, the AA, VV, and VA interval measurements from passages of nonpaced 1:1 arrhythmias were examined. Seven passages of ventricular tachycardia (VT) with 1:1 retrograde conduction, 12 passages of atrioventricular nodal reentrant tachycardia (AVNRT), 8 passages of sinus tachycardia (ST), 2 passages of orthodromic reentrant tachycardia (ORT), and 3 passages of atrial tachycardia (AT) were analyzed from 28 patients (14). Four patients had 2 different tachycardias that were used in the study. Two of these had both an episode of ST and AVNRT, one had AT and ORT, and the last had two different VTs with retrograde conduction. Interval measurements were extracted using a real-time arrhythmia detection program developed in the Medical Computing Laboratory (Electrical Engineering and Computer Science Department, University of Michigan). This software is identical to that used by Stevenson et al. (11). The VA intervals of 15 cycles were averaged to produce a mean VA result for each passage. The mean VA interval values for all passages in this study were plotted and boundaries determined. Interval boundaries were chosen to maximize the inclusion of passages of VT with retrograde conduction while minimizing inclusion of all other 1:1 tachycardias represented within these boundaries.

Results

The boundaries determined in this study for detecting VT with retrograde conduction, differ significantly from those obtained in the earlier study (11). The mean VA intervals in the 7 passages of nonpaced ventricular tachycardia ranged from 85 ms to 169 ms during retrograde conduction. A majority of these passages (4/7) had mean VA intervals less than 132 ms (the lower boundary previously suggested) and thus would have been misclassified as SVTs under the previous algorithm. Table 1 lists the mean VA interval and cycle length for each passage considered in the study.

The AVNRT mean VA interval values were found to be shorter than those of VT with retrograde conduction in this study. Likewise, the sinus tachycardia mean VA interval values were found to be longer than those of VT with retrograde conduction in this study. This suggested that boundaries could indeed help to classify VT with retrograde conduction. Boundaries were experimentally derived at 80 ms and 234 ms. The upper boundary remains unchanged from the previous study since retrograde conduction with VA intervals close to 234 ms was demonstrated as a possible occurrence (via stimulation) even though none of the naturally occurring passages in this study had mean VA intervals that large. However, the lower boundary has been reduced from 132 to 80 ms to include all passages of naturally occurring VT with retrograde conduction considered in this study. A scatter diagram showing the mean VA interval value for each passage and the boundaries chosen to classify VT with retrograde conduction is shown in Figure 1.

Table 1. Mean Cycle Length and Mean VA Intervals of 1:1 Tachycardias

Rhythm	Patient #	Passage	Mean VA Interval (ms)	Cycle Length (ms)
ST	1	A201655	332	458
	2	A210500	422	558
	3	A197690	295	489
	4	A157705	428	573
	5	A135815	471	638
	6	A261330	378	522
	7	Z703115	311	446
	8	Z710100	374	480
AT	9	Z912900	203	349
	10	Z743651	208	317
	11	Z921820	191	333
ORT	11	Z921658	158	290
	12	Z791045	160	347
VT with retrograde	13	A217336	92	394
	14	A330228	106	400
	14	A330647	94	439
	15	A176870	154	424
	16	A316916	143	284
	17	A319137	85	560
	18	A326390	169	600
AVNRT	19	Z821505	21	445
	20	Z891009	19	289
	21	Z930455	36	332
	22	Z483700	65	466
	23	Z551400	20	351
	24	Z570700	55	375
	7	Z702400	44	320
	8	Z712240	26	351
	25	Z683_00	66	312
	26	Z750700	56	357
	27	Z780650	34	388
	28	Z800400	36	424

Patient identifier Zxxyyyy and Axxxyyy indicates patient number (xx or xxx) and tape location (yyyy or yyy). (Ann Arbor Electrogram Libraries, Ann Arbor, MI.)

A comparison of the mean VA intervals with respect to cycle length was made for each of the different arrhythmias. The additional consideration of cycle length in the diagnosis did not improve the efficacy of this algorithm thus the boundaries chosen to separate VT with retrograde conduction are independent of cycle length.

Discussion

The 1:1 retrograde conduction VA interval has a maximum ceiling above which only anterograde conduction seems to occur naturally and a lower bound beneath which retrograde conduction through the AV node is physiologically improbable.

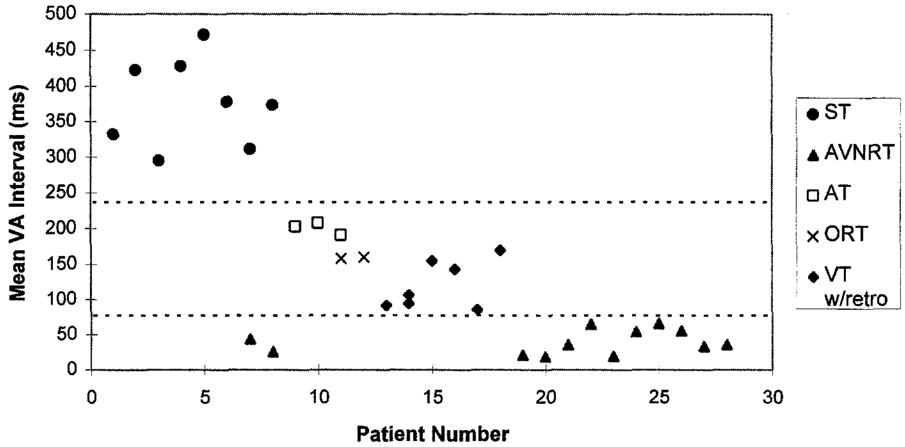

Fig. 1. Scatter plot of mean VA interval (15 cycles) for patients with 1:1 tachycardias of 5 types: sinus tachycardia (ST), atrioventricular nodal reentrant tachycardia (AVNRT), atrial tachycardia (AT), orthodromic reentrant tachycardia (ORT), and ventricular tachycardia with retrograde conduction (VT w/retro). Four patients had two separate 1:1 tachycardias: patients 7 and 8 each had both ST and AVNRT, patient 11 had AT and ORT, and patient 14 had two distinctly different VTs with retrograde conduction. Ordinate gives mean VA interval (in ms) and abscissa indicates patient number. Dotted lines indicate upper and lower decision boundaries for recognition of VT with retrograde conduction.

This suggests VT with 1:1 retrograde conduction can be identified and separated from many of the 1:1 SVT arrhythmias based on the VA interval alone.

The identification of VA intervals which define 1:1 ventricular tachycardias with retrograde atrial activation has been previously described in an experimental study by Stevenson et al. (11). In that study, episodes of 1:1 arrhythmias were stimulated via atrial and ventricular pacing. However, the study did not include naturally occurring (nonpaced) arrhythmias. This current study was intended to examine naturally occurring (nonpaced) VA measurements and derive a realistic modification of the boundaries for VA conduction time previously suggested. In this population of VT with naturally occurring retrograde, VA intervals fell below the lower bound suggested previously in the majority of cases. Thus, the region of VA intervals in which VT with retrograde conduction can occur is much broader than previously suggested. The VA interval boundaries which this study derived for correct delineation of VT with 1:1 retrograde are 80 ms to 234 ms as opposed to the previously published 132 ms to 234 ms (11). This may seem a minor adjustment; however, a majority of the naturally occurring retrograde conducting passages in this limited study would have been misclassified under the previous boundary settings.

In this study, passages of VT with retrograde conduction were classified with a 100% sensitivity (by experimental design) and gave an 80% specificity. This demonstrates that the important life-threatening constraint of avoiding false negatives is met, but with the inherent tradeoff of some false positives. The false positives in this study are due to passages of ORT and AT which have mean VA intervals similar to those of VT with retrograde conduction. However, it is important to note that given current detection algorithms, all of the non-retrograde SVT arrhythmias and all of the AVNRT tachycardias would have invoked false therapy. The new algorithm reduces the number of false positives in this study by 80%.

The benefits of more specific classification are many. Most importantly, the patient is not at risk of having a ventricular arrhythmia induced by a false shock administered unnecessarily to a 1:1 supraventricular tachycardia. Also appropriate and low energy therapy can be administered in many cases of 1:1 ventricular tachycardia with retrograde because these typically fall into the slow tachycardia zone amenable to pacing or cardioversion. The use of less aggressive therapy addresses the patient comfort problem and offers a partial solution to the battery depletion problem of numerous unwanted false shocks. Although using mean VA interval boundaries as a discriminant of confounding 1:1 tachycardias will not bring perfection to the device, it is an important step in the improvement of ICD discrimination of SVTs and VTs.

Limitations

This study investigated naturally occurring retrograde conduction in a limited sample of patients.

Robust confidence intervals will require a larger patient set for confirmation. In the Medical Computing Laboratory data base of over 400 patient recordings, examples of retrograde conduction constitute fewer than 5% of all arrhythmia passages. However, we continue to acquire new data which will permit more rigorous testing of these boundaries. The boundaries chosen in this study may need further modification in the face of a larger patient set. They serve to demonstrate, however, the value of this measurement for improved detection.

In addition, the use of the mean VA interval boundaries for classification is not designed to be a classifier of 1:1 tachycardias in and of itself, but rather to be combined with modern arrhythmia detection techniques (primarily rate) to improve the overall detection of 1:1 tachycardias in dual-chamber ICDs.

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