Reprinted with permission from
PACING AND CLINICAL ELECTROPHYSIOLOGY, Volume 16, No. 1, January 1993 Part II

Real-Time Arrhythmia Identification from Automated Analysis of Intraatrial and Intraventricular Electrograms

CHIH-MING J. CHIANG, JANICE M. JENKINS, LORENZO A. DICARLO,*
DONGPING LIN, and PAI-CHI LI

From the Department of Electrical Engineering and Computer Science, School of Engineering, and the School of Medicine, University of Michigan, and the *Cardiac Electrophysiology Laboratory, St. Joseph Mercy Hospital of the Catherine McAuley Health Center, Ann Arbor, Michigan

CHIANG, C.-M. J., ET AL.: Real-Time Arrhythmia Identification from Automated Analysis of Intraatrial and Intraventricular Electrograms. *Implantable cardioverter defibrillators have dramatically improved survival rates for patients at risk of sudden cardiac death, but the occurrence of inappropriate shocks remains an unresolved problem. Various means for better tachycardia detection, chiefly morphological analysis, have been proposed to address this problem. A new computerized scheme entitled Two-Channel Rate-Morphology (2CRM) was introduced. It is a real-time arrhythmia detection algorithm that combines timing and morphology information from intraatrial and intraventricular electrograms for arrhythmia diagnosis. The program 2CRM applies an initial cycle-by-cycle coding scheme followed by contextual diagnosis of underlying rhythm. The program was tested on 36 distinct passages of two-channel intracardiac signals from 30 patients. The distribution of the arrhythmias are as follows: 4 atrial fibrillation, 6 atrial flutter, 6 supraventricular tachycardia, 10 ventricular tachycardia, and 10 ventricular flutter-fibrillation. Of the analyzed 3,417 individual cardiac cycles 3,135 (91.7%) were correctly identified. Contextual diagnosis reversed 123 single-cycle errors to obtain a performance of 3,258 correct out of 3,417 (95.3%). Utilizing an uninterrupted continuous correct contextual diagnosis as indicator of successful arrhythmia detection, 2CRM obtained an accuracy of 34 out of 36 passages (94.4%). (PACE, Vol. 16, January, Part II 1993)*

arrhythmia, intracardiac electrode, antitachycardia device, implantable defibrillator

Introduction

Implantable cardioverter defibrillators (ICDs) now exceed 25,000.[1] Newer generation devices offer tiered therapy selections that range from antitachycardia pacing protocols, low-level cardioversion, and higher level defibrillation. Despite the variety of choices that can be programmed, separation and classification of benign tachycardias from those requiring treatment remains problematic. Rate and rate-related measures are nonspecific, given the overlap that exists between rhythms. Our research work has demonstrated that pattern recognition of the raw signal can yield classification of normal and abnormal cardiac activation, in the atrium and in the ventricle.[2–5] Most of the morphological methods proposed to date fall into the time-domain template matching category, with the standard being correlation waveform analysis (CWA), shown to be effective in intracardiac electrogram analysis.[2,3]

Almost a decade ago, a two-channel strategy was developed for analysis of intracardiac electrograms without regard for morphological infor-

This work was partially supported by a grant from Medtronic Corporation and National Science Foundation Grants BCS-8909042 and EID-9023514.

Address for reprints: Chih-ming J. Chiang, M.S., Medical Computing Laboratory, Dept. of Electrical Engineering and Computer Science, The University of Michigan, Ann Arbor, MI 48109-2122.

Table II.

Two Channel Rate-Morphology Method Results

Patient Cases	Cardiac Cycles	Diagnosis	Isolated Errors	Contextual Corrections	Uninterrupted Contextual Success
1	146	A Flut	0	0/0	+
2	149	A Fib	2	0/2	+
3	211	A Flut	8	0/8	+
4	55	3:1 SVT	5	0/5	+
5	101	1:1 SVT	1	1/1	+
6	169	A Fib	13	0/13	+
7	163	A Flut (Fib)	5	0/5	+
8	143	A Flut	6	0/6	+
9	38	VT	7	3/7	+
10	57	VT	7	3/7	+
11	39	V Flut	5	4/5	+
12	67	V Flut (Fib)	9	4/9	+
13	92	V Fib	7	0/7	+
14	106	2:1 SVT	0	0/0	+
15	54	V Flut	5	3/5	+
16	145	1:1 SVT	0	0/0	+
17	150	1:1 SVT	11	0/11	−
18	169	A Fib	5	0/5	+
19	36	VT	12	9/12	+
20	197	2:1 SVT	0	0/0	+
21	130	A Flut	8	0/8	+
22	46	VT	10	7/10	+
23	74	VT	20	15/20	+
24	96	VT	16	11/16	+
25	45	V Flut	9	5/9	+
26	46	VT	10	5/10	+
27	34	VT	12	11/12	+
28	49	V Flut V Fib	14	1/14	−
29	44	VT retro	15	11/15	+
30	104	VT	22	14/22	+
31	57	V Flut	6	1/6	+
32	146	A Flut	4	0/4	+
33	86	A Fib	1	0/1	+
34	71	V Flut	6	1/6	+
35	50	V Fib	6	3/6	+
36	59	V Flut	5	1/5	+
36	3417		282	123/282	34

The first column contains the patient cases, and the second the total number of cycles analyzed in each passage. The third column is the true underlying rhythm of the passage. The fourth column contains the number of single cycle diagnostic errors out of the total cycles analyzed (2nd column). The fifth column gives the number of corrections made by the contextual diagnosis to override errors in single cycle diagnosis (4th column). The last column indicates success (+) or failure (−) of the program on each passage based upon an uninterrupted contextual diagnosis as the measure of success. A = Atrial, V = Ventricular, Fib = Fibrillation, Flut = Flutter, T = Tachycardia, SV = Supraventricular, + = Success, − = Failure.

program was tested and validated on an 80386-based personal computer (Dell Computers, Austin, TX, USA) with a 25 MHz clock speed.

Results

Recordings were made from 36 patients who had one or more of six distinct arrhythmias. There were 3,417 cycles processed in total. Of these cycles, 3,135 (91.7%) were accurately diagnosed in the initial stage of single-cycle analysis. Contextual diagnosis reversed 123 of the single-cycle errors to obtain a performance of 3,258 correct out of 3,417 (95.3%). Using a continuing correct diagnostic stream as the criterion for successful arrhythmia identification, i.e., an isolated erroneous diagnostic statement did not interrupt the overall correct diagnosis, the success rate was 34/36 passages or 94.4%. Table II gives the detailed results of each passage.

Discussion and Future Work

Prior to this study, no real-time tachycardia algorithm for implantable devices has been implemented or available that incorporates atrial as well as ventricular activation rates, morphologies, and AV relationships to provide accurate discrimination. Yet dual-chamber pacemakers have been available for decades and the feasibility of two-chamber arrhythmia detection and analysis is certainly within reach. This work was based on the hypothesis that future generation ICDs will have dual chamber sensing and pacing capabilities, just like present pacemakers.

Several major limitations of the algorithm still exist and can be appreciated by careful assessment of errors. During passages of ventricular tachycardia, flutter, and fibrillation, a cardiac cycle will occasionally be misdiagnosed as an aberrantly conducted sinus beat. This is due to a mistaken association of an atrial depolarization with a subsequent ventricular depolarization. This remains the most serious problem in two-channel analysis, i.e., limitations of implied associations of A and V. In the two patient cases that failed the continuous contextual diagnosis, one supraventricular tachycardia and the other ventricular fibrillation, wrong atrioventricular association incidents caused repeated single-cycle errors that interrupted correct contextual diagnosis.

Among the possible improvements to be made in future models of arrhythmia analysis is the inclusion of our recently developed fast algorithms for morphological analysis,[4,5] which dramatically reduce computational requirements. Further improvement of contextual diagnosis, such as emphasizing contextual logic particularly in the presence of sustained high rate in either chamber, could eliminate the intermediate steps and lead to quick convergence. Our presentation here is meant to demonstrate that morphological classification offers a substantial improvement over rate-only methods and provides a mechanism for increasing specificity of diagnosis, particularly in the separation of benign tachycardias from those requiring electrical therapy. The two-channel system, 2CRM, is intended to address the problem of inappropriate delivery of shock therapy,[8,9] and facilitate the therapeutic choice in devices with tiered therapy options.

References

1. AICD Advances, Cardiac Pacemakers, Inc., 1992.
2. Lin D, DiCarlo L, Jenkins J. Identification of ventricular tachycardia using intracavitary ventricular electrograms: Analysis of time and frequency domain patterns. PACE 1988; 11:1592–1605.
3. Throne R, Jenkins J, Winston S, et al. Discrimination of retrograde from anterograde atrial activation using intracardiac electrogram waveform analysis. PACE 1989; 12:1622–1630.
4. Throne R, Jenkins J, DiCarlo L. The bin area method: A computationally efficient algorithm for analysis for ventricular and atrial intracardiac electrograms. PACE 1990; 13:1286–1297.
5. Throne R, Jenkins J, DiCarlo L. A comparison of four new time-domain techniques for discriminating monomorphic ventricular tachycardia from sinus rhythm using ventricular waveform morphology. IEEE Trans Biomed Eng 1991; 38:561–570.
6. Arzbaecher R, Bump T, Jenkins J, et al. Automatic tachycardia recognition. PACE 1984; 7(II):541–547.
7. Jenkins J, Wu D, Arzbaecher R. Computer diagnosis of supraventricular and ventricular arrhythmias. Circulation 1979; 60:977–987.
8. Chapman P, Troup P. The automatic implantable cardioverter-defibrillator: Evaluating suspected inappropriate shocks. J Am Coll Cardiol 1987; 7: 1075–1078.
9. Cohen T, Chien W, Lurie K, et al. Implantable cardioverter defibrillator proarrhythmia: Case report and review of the literature. PACE 1991; 14:1326–1329.