Intramural Ventricular Recording and Pacing in Patients with Refractory Ventricular Tachycardia: Initial Findings and Feasibility with a Retractable Needle Catheter

Running title: AbdelWahab et al.; Needle Catheter EGMs and Pacing for Refractory VT

Amir AbdelWahab, MBBCh, MSc, MD1,2; William Stevenson, MD, FHRS3;
Kara Thompson, MSc, BSc4; Ratika Parkash, MD, FRCPC1; Christopher Gray, MD, FRCPC1;
Martin Gardner, MD, FRCPC, FHRS1; John Sapp, MD, FRCPC, FHRS1

1Heart Rhythm Service, Division of Cardiology, QEII Health Sciences Centre, Halifax, NS, Canada;
2Electrophysiology & Pacing Service, Department of Cardiovascular Medicine, Cairo University, Cairo, Egypt; 3Brigham and Women’s Hospital, Harvard Medical School, Boston, MA; 4Research Methods Unit, Department of Medicine, Dalhousie University, Halifax, NS, Canada

Correspondence:
Amir AbdelWahab, MBBCh, MSc, MD
Assistant Professor of Medicine, Dalhousie University
Heart Rhythm Service, QEII Health Sciences Centre
Room 2501 E Halifax Infirmary
1796 Summer Street
Halifax NS, B3H 3A7
Canada
Tel: 902.473.5023
Fax: 902.473.3158
Email: amir.abdelwahab@cdha.nshealth.ca

Journal Subject Codes: [22] Ablation/ICD/surgery
Abstract:

Background - Ablation of ventricular arrhythmias (VA) can be limited by intramural substrate not amenable to endocardial or epicardial ablation. Feasibility of irrigated needle ablation (INA) has been shown, but optimal means of identifying targets is not clear. We analyzed intramural needle electrograms (EGMs) in relation to endocardial EGMs.

Methods and Results - Eight sequential patients (mean age 56 yr) who had failed 1-4 prior ablations underwent INA were included. At selected sites, the needle was advanced into the myocardium. Bipolar and unipolar EGMs from the needle and catheter tip were analyzed. The needle was deployed at 75 sites with suspected intramural substrate among 2309 mapping sites. Intramural bipolar EGM amplitude and duration correlated closely with endocardial EGMs, but were greater in amplitude and duration (1.5±1.4 vs 0.6±0.5 mV and 131±66 vs 112±51 ms, p=0.001 for both). During sinus rhythm intramural late potentials (LPs) tended to be more common than endocardial LPs (53.6% vs. 35.7%, p=0.12). Intramural EGMs during VA preceded endocardial EGMs (-29±34 vs -15±21 ms, P=0.001). INA terminated VA at 12 of 28 sites with ablation during VA. Termination site needle EGMs tended to be earlier than non-termination sites (-54±37 vs -36±33 ms preQRS, p=0.15). Pace-mapping from the needle at 19 sites matched the VA at 18 and showed stim-QRS of 60±51 ms.

Conclusions - Recordings from intramural needle may be useful for selecting ablation targets during VT and for substrate mapping. Further study is needed to develop methods to guide selection of optimal sites for needle deployment and ablation.

Key words: ventricular tachycardia, intramural reentry, electrophysiology mapping, catheter ablation, needle ablation catheter, VT ablation, Refractory VT, intramural EGMs
Introduction

Catheter ablation is an important therapeutic option for ventricular tachycardia (VT), yet it remains ineffective in some patients despite technical advances including 3-dimensional mapping, irrigated radiofrequency ablation, the availability of epicardial mapping and ablation, and intracoronary ethanol ablation. A common limitation is the existence of reentry substrate that is beyond the reach of ablation with the use of standard techniques. Preclinical work has demonstrated that a catheter with an extendable/retractable electrically active needle can record intramural cardiac electrograms, pace, and create deep myocardial lesions. The addition of intramyocardial saline infusion, likely creating an interstitial virtual ablation electrode, permits the creation of large, deep myocardial lesions. Initial human experience suggested that some treatment-refractory VTs could be brought under control using this technique.

Intramural electrograms have been previously recorded in transplanted hearts and animal models of scar-related VT. This needle electrode is a single tube of the nickel titanium alloy nitinol. Unipolar electrograms can be recorded from the needle and bipolar electrograms can be recorded between the needle and the ring electrode 4.5 mm proximal to the tip of the catheter, which is intracavitary if orientation is perpendicular, producing a “semi-bipolar” recording. The needle also allows unipolar pacing and delivery of RF current. We have previously reported the clinical procedural data of this needle catheter in 8 initial patients. We sought to extend our report by comparing characteristics of human intramural electrograms with corresponding endocardial electrograms in these patients.
Methods

Study Population

Patients with recurrent VT, despite antiarrhythmic drug therapy and at least 1 attempt at catheter ablation, were offered catheter ablation with the use of an infusion-needle catheter as previously reported.\(^\text{13}\) All patients provided informed consent for use of this therapy, which was approved through the Special Access Program of Health Canada.\(^\text{18}\) The institutional research ethics board approved the review and reporting of cases.

Electroanatomical Mapping and Infusion Needle Ablation

Patients were brought to the electrophysiology laboratory in the fasting state. Multipolar electrode catheters and an intracardiac echocardiography catheter were placed from the femoral veins. Left ventricular access was gained via transeptal puncture and a deflectable sheath (Agilis large curl, St. Jude Medical, St. Paul MN), or via a retrograde aortic approach. Left ventricular substrate mapping was initially performed with a standard 3.5-mm irrigated tip mapping catheter and an electroanatomic mapping system (Carto; Biosense Webster, Diamond Bar, CA). VT was induced with programmed ventricular stimulation. After a voltage map was created, the standard mapping catheter was replaced with a needle-tipped ablation catheter (Figure 1). The deflectable catheter has a distal bipole with an extendable/retractable 27-gauge nitinol needle. The needle has an embedded thermocouple and has a central lumen through which saline can be infused. A position sensor within the tip is compatible with an electroanatomic mapping system (Carto; Biosense Webster, Diamond Bar, California). The needle depth can be adjusted and locked in the extended or retracted position. In its fully retracted position, it is entirely within the catheter tip, whereas, when fully deployed, it can extend 12 mm beyond the tip. An adjustable plunge activator on the handle permits the depth of extension to be preset and locks the needle in
position when deployed. The needle has a lumen that opens at its tip and allows for continuous infusion throughout the procedure. A pump (Thermocool; Biosense Webster, Diamond Bar, California) and three-way manifold permit injection before and throughout RF application. Infusion flow rate was set at 1 mL/min and was increased to 2 mL/min for 30 seconds before and during RF delivery.

During catheter manipulation, the needle was kept retracted and irrigated with ambient temperature 0.9% saline mixed with 2 U/mL heparin. Target sites were sought within areas of reduced bipolar or unipolar signal amplitude that were thought to be components of VT circuits based upon endocardial activation/entrainment mapping when possible, or substrate/pace-mapping. The catheter tip was placed at sites of interest with attempted orientation perpendicular to the endocardial surface. The needle was extended 7 to 9 mm into the myocardium. Intramural electrograms were recorded from the needle and pacing was performed (10 mA, 2-ms pulse width).

**Electrogram Acquisition and Filtering**

Recording and pacing were possible from both the external electrodes and from the needle. The recording system was configured to permit bipolar recordings between the needle and ring electrode (filtered 30–500 Hz), and between the needle and an inferior vena cava electrode (referred to as unipolar recordings) (filtered at 30–500 Hz, and separately displayed and filtered at 0.5–500 Hz) (Cardiolab, GE Healthcare). Bipolar and unipolar electrograms from the catheter tip were also recorded on the electroanatomic mapping system (Carto; filtered at 16-500 Hz and at 1-240 Hz respectively).

**Electrogram Selection for analysis**

The needle was extended within the myocardium at sites where endocardial mapping raised
clinical suspicion of deeper culprit substrate because activation time, pace-mapping, or entrainment suggested it was close to the VA origin. Electrograms were recorded from sites where the needle was deployed within the myocardium and were included for analysis. For sites where RF energy was delivered more than once, the electrogram was analyzed prior to the first RF application. Fractionation was defined as: the number of positive and negative peaks of the recorded bipolar electrogram. Late potentials were defined as: electrograms on bipolar recordings that occurred after the end of the surface QRS complex during sinus or paced rhythm. Intramural to endocardial conduction time was defined as: the difference between needle EGM to QRS and endocardial EGM to QRS at the same site.

Unipolar pacing from the needle was performed between the needle and the inferior vena cava electrode at 10 mA with a pulse width of 2 ms.

**Statistical Analysis**

Continuous variables were expressed as mean ± standard deviation and were tested for distributional properties (such as normal, log normal) using Kolmogrov-Smirnov test, histograms and probability plots (QQ plots). Correlations between continuous variables were assessed using maximum likelihood estimation to account for multiple measurements on the same subject. Generalized linear mixed models (GLMM) were used to compare intramural and endocardial electrogram outcomes. Unstructured covariance structure was used to account for correlation between needle site and clustering of observations on same subject. GLMM were used to compare outcomes at termination sites and different scar zones. Unstructured covariance structure was used to account for correlation between observations within the same subject. Outcomes were modeled using either a normal, lognormal, binomial (categorical data), negative binomial (count data) or poisson (count data) distribution using PROC GLIMMIX. Significance
was defined as P<0.05. Statistical analysis was performed using SPSS, version 21.0 (IBM) and SAS software, version 9.3 (SAS Institute).

Results

Study population

Electrograms were analyzed in 8 patients with recurrent VT (6 male), age 54 (limits, 13–70). Ventricular function was reduced in all patients (ejection fraction 29±11%) associated with nonischemic cardiomyopathy in 6 patients and ischemic heart disease in 2 patients. All patients had recurrent VT despite antiarrhythmic drug combinations including amiodarone. All patients had undergone previous endocardial catheter ablation attempts (mean, 2; limits, 1–4), and 4 patients had undergone an ineffective epicardial procedure.

Procedures

Patients had 1 to 7 inducible or spontaneous monomorphic ventricular arrhythmias (median, 2). In 7 patients, some intramural mapping with the needle electrode was possible for at least 1 VT (VT was not reproducibly inducible in 1 patient). In each of these, a VT was identified with earlier intramural signal than the adjacent endocardial activation time, but mapping during VT was limited because of hemodynamic intolerance and the inducibility of multiple VT morphologies, or lack of reproducible inducibility. In 6 patients, at least 1 VT was terminated with intramural needle infusion and ablation. Details of acute and long-term procedure outcomes as well as associated complications have been previously reported.13

Endocardial electrograms were collected from 2309 sites; the needle was deployed at a total of 75 sites with suspected intramural substrate (Median 10 deployment sites/patient, range 4-14), 1st-3rd quartiles (6.75-11.5). The rhythm during deployment at these sites was VT in 35, PVCs in 12, sinus in 25 and biventricular paced rhythm in the remaining 3 sites. Intramural semi-
bipolar electrogram amplitude and duration correlated closely with corresponding endocardial bipolar electrograms with correlations of 0.615 and 0.774 respectively, but were 2.5 times greater in amplitude (1.5±1.4 mV vs. 0.6±0.5 mV, p=0.001) and 16% greater in duration (131±66 ms vs. 112±51 ms, p=0.001) as shown in Table 1. Intramural EGMs recorded during ventricular arrhythmias at sites where the needle was deployed preceded the corresponding endocardial EGMs (EGM-QRS of -29±34 ms vs. -15±21 ms, P=0.001) consistent with closer proximity to the arrhythmia exit (Figure 2). However both endocardial and intramural EGMs were similar in terms of unipolar amplitudes and degree of EGM fractionation (Table 1). Among 28 sites mapped during sinus rhythm or ventricular pacing, late potentials were more common on intramural EGMs compared to endocardial EGMs (54% vs. 36%) although not statistically significant, p=0.12 (Figure 3).

**Pacing from the needle catheter**

Unipolar pacing from the needle catheter was successfully performed at 19 sites, 18 of which matched or nearly matched the targeted VA. The mean stim-QRS duration was 60±51 ms (limits 0 – 192 ms) (Figure 4). Entrainment from the needle catheter during VT was successfully performed at 5 sites (Figure 5).

**Termination Sites**

Needle ablation was attempted during VA at 28 sites and terminated the arrhythmia at 12 sites (43%). Sites with VA termination during needle RF ablation did not show any significant differences when compared to non-termination sites in terms of endocardial EGM characteristics (Table 2). However, there was a trend for earlier intramural bipolar EGMs with longer intramural to endocardial conduction time at termination sites. (Table 2) No significant differences were observed in bipolar and unipolar needle EGM amplitudes, EGM duration or degree of EGM fractionation.
fractionation. There was lower average temperatures (55±3.8 °C vs. 57±1.5 °C, p=0.15) and higher delivered power (17.5±5.1 W vs. 13±6.9 W, p=0.08) at termination sites (Table 2) although not statistically significant. The average time to termination was 11±7 s.

**Scar definition based on Electrogram Voltage**

Needle deployment sites were defined as normal myocardium (n=5) if they had normal endocardial unipolar and bipolar EGM amplitudes (>8.3 mV and >1.5 mV respectively on the electroanatomic mapping system); transmural scar (n=41) if they had reduced unipolar and bipolar EGM amplitudes (≤8.3 mV and ≤1.5 mV respectively); epicardial/intramural scar (n=12) if they had reduced unipolar EGM and preserved bipolar EGM amplitudes (≤8.3 mV and >1.5 mV respectively).19 (Table 3) Needle unipolar and semi-bipolar EGMs had lower amplitude at sites of transmural scar compared to normal myocardium or epicardial/intramural scar sites (Table 3). During ventricular arrhythmias, sites of transmural scar tended to have earlier endocardial and needle EGMs compared to the other two types of sites.

**Discussion**

This is the first detailed analysis of electrograms recorded from an intramural needle during catheter mapping and ablation in humans. We found that recordings from the needle were feasible, often had features that can be used to determine if the site may be desirable for ablation and to define scar. Pacing from the needle is also possible and can be used for pace-mapping and entrainment mapping.

There are several important considerations in interpreting this data. Importantly the needle is a single solid piece of nitinol capable of extending up to 11 mm into the myocardium. It does not contain additional isolated microelectrodes on its surface. Hence the recordings are expected to be different from those of plunge microelectrodes that have been used.
intraoperatively and in animal models.\textsuperscript{14-16} We analyzed both unipolar recordings and semi-bipolar recordings (between the needle and the ring electrode of the catheter). Semi-bipolar recordings have the potential for better rejection of far-field recordings than unipolar recordings and would be expected to be less affected by wavefront direction, compared to bipolar recordings.\textsuperscript{20} In some cases, however the ring electrode may be in contact with myocardium if the catheter is not perpendicular to the myocardium. Although we focus attention on the intramural nature of the needle recordings, the most proximal portion of the needle is at the endocardial surface. It should also be recognized that the depth of the needle beneath the endocardial surface varies not only with the length of the needle, but with the angle of the needle with respect to the endocardial surface. It is also possible that in some cases the needle could be deployed with a gap between the dome electrode and the endocardium such that a portion of the needle is in the blood pool.

**Intramural Scar Electrograms**

Identification of regions of scar, consisting of fibrosis with some surviving myocardial cells, is an important component of identifying the substrate for reentrant scar related arrhythmias, and is generally sought based on analysis of electrogram amplitude. A bipolar electrogram amplitude < 1.5 mV is a robust indicator of scar.\textsuperscript{3} MRI studies in patients with non-ischemic cardiomyopathy and VT suggest that midmyocardial scars account for 27%-100% of total scars, mostly in the septum, inferior and lateral walls.\textsuperscript{21} At some of these sites, only 2 mm of viable endocardium was sufficient to generate signal amplitude >1.5 mV.\textsuperscript{21} It is likely that deep extensions of myocardial scar are frequent contributors to recurrent arrhythmias after catheter ablation.\textsuperscript{22}

In this study, we observed that intramural semi-bipolar electrogram amplitude was significantly greater than that of corresponding endocardial bipolar electrograms. This may be
caused by the extension of the needle through a greater volume of myocardium, and consequent greater far-field contribution to the signal, or perhaps by characteristics specific to the needle electrode. Determination of whether an intramural signal amplitude can be used to identify scar requires further study; most sites sampled during this clinical experience were within or near areas of low endocardial signal amplitude. It seems likely that a combined analysis of endocardial bipolar and unipolar electrogram with the needle electrogram may facilitate definition of intramural components of the arrhythmia substrate.

Predictors of VA Termination

In this clinical series, needle deployment with or without intramural RF delivery was performed at sites which were suspected to be important arrhythmogenic substrate. When possible, intramural activation mapping was performed during VAs. Sites where ablation terminated arrhythmias tended to be activated earlier relative to both QRS onset and endocardial activation time, although neither difference was statistically significant (Table 2). No other electrogram characteristics were clearly associated with termination of VA, although there was a trend to greater mean RF power delivered at termination sites while mean temperature tended to be slightly lower at termination sites, suggesting slightly larger lesion size in association with termination. While these differences were not statistically significant, they may represent two mechanisms of unsuccessful ablation—insufficient lesion size and non-culprit targets.

Limitations

This is the initial data from our feasibility study in a small number of patients. A number of factors can potentially affect the electrograms recorded as discussed above. We did not investigate pacing threshold, which may also be a useful indicator of the nature of fibrosis and surviving myocardium. Only one patient did not have an ICD and had a pre-procedure MRI. We
did not have the original images available to analyze. In the other patients, confirmation of scar
distribution in the mid-myocardium or epicardium by delayed enhancement MRI was not
performed because of the presence of an ICD.

Criteria for identifying the optimal sites for needle deployment are not yet well defined.
We attempted to identify the endocardial region that seemed closest to the arrhythmia origin
based on endocardial mapping findings, including substrate mapping, entrainment and
electrogram timing and characteristics, and deployed the needle in that region. In addition, we
could not identify any specific characteristics of endocardial EGMs that can predict intramural
EGMs characteristics. Further studies in larger numbers of patients may allow us to better predict
sites where needle deployment is likely to identify a suitable ablation target.

Conclusions
Electrograms obtained from this intramural needle show similar features to endocardial signals in
regions of potential arrhythmia substrate. Sites with suspected intramural substrate had early
activation relative to the endocardium; sites with earlier intramural activation times and greater
RF power delivery tended to be more likely to terminate ventricular arrhythmias. The needle can
be repeatedly deployed. These findings indicate that intramural recording can potentially be
used to guide ablation. Electrogram amplitude is greater than that seen in bipolar recordings
from the overlying endocardium, indicating that parameters to define scar will need to be defined
specifically for this electrode and recording method. The combination of needle and endocardial
recordings at a site may help refine identification of intramural substrate.

Acknowledgments: Catheters were provided free of charge by Biosense Webster.

Conflict of Interest Disclosures: Dr AbdelWahab has received fellowship support from
Biosense Webster from 2006 to 2008 and has a current trainer agreement with Biosense Webster, both are unrelated to this study. Dr Stevenson is a coholder of a patent for the needle catheter that is consigned to Brigham and Women’s Hospital. Dr Sapp is a coholder of a patent for the needle catheter, rights assigned to Brigham and Women’s Hospital, is a consultant to Biosense Webster, and reports research funding from Biosense Webster unrelated to this study.

References:


**Table 1:** Characteristics of intramural electrograms in comparison with corresponding endocardial electrograms at needle deployment sites

<table>
<thead>
<tr>
<th></th>
<th>Endocardial (n=75)</th>
<th>Intramural (n=75)</th>
<th>P value$^\dagger$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bipolar amplitude (mV)</strong></td>
<td>0.6±0.5</td>
<td>1.5±1.4</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>0.5 (0.3, 0.9)$^\S$</td>
<td>1.0 (0.7,2.1)$^\S$</td>
<td></td>
</tr>
<tr>
<td><strong>Unipolar amplitude (mV)</strong></td>
<td>1.8±1.3</td>
<td>1.7±1.2</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>1.4 (1.0, 2.3)$^\S$</td>
<td>1.3 (0.7, 2.2)$^\S$</td>
<td></td>
</tr>
<tr>
<td><strong>Bipolar EGM duration (ms)</strong></td>
<td>112±51</td>
<td>131±66</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>96 (79, 142)$^\S$</td>
<td>103 (84, 173)$^\S$</td>
<td></td>
</tr>
<tr>
<td><strong>EGM to QRS during VA (ms)</strong></td>
<td>-15±21</td>
<td>-29±34</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>EGM fractionation (number of peaks)</strong></td>
<td>7.3±3.6</td>
<td>7.5±3.1</td>
<td>0.53</td>
</tr>
<tr>
<td><strong>Late potentials†</strong></td>
<td>10 (35.7%)</td>
<td>15 (53.6%)</td>
<td>0.12</td>
</tr>
</tbody>
</table>

EGM: Electrogram, ms: millisecond, mV: millivolt, VA: Ventricular Arrhythmias including VT and PVCs. Bipolar electrograms were filtered 30-500 Hz, Unipolar electrograms 0.5-500 Hz

* Among 47 sites recorded during ventricular arrhythmias

† Among 28 sites mapped during sinus rhythm or ventricular pacing

‡ Generalized Linear Mixed Models (log-normal for the first 3 variables; normal, Poisson and binomial for the last 3 respectively)

§ Median (Quartile 1, Quartile 3) are reported for continuous variables not meeting normality assumption
**Table 2:** Characteristics of local electrogram at VA termination sites during Irrigated needle RF application

<table>
<thead>
<tr>
<th></th>
<th>Termination site (n=12)</th>
<th>Non-termination site (n=16)</th>
<th>P value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endocardial EGM to QRS (ms)</td>
<td>-24±16</td>
<td>-22±24</td>
<td>0.51</td>
</tr>
<tr>
<td>Endocardial Bipolar amplitude (mV)</td>
<td>0.7±0.9</td>
<td>0.7±0.3</td>
<td>0.31†</td>
</tr>
<tr>
<td></td>
<td>0.4 (0.2, 0.8)§</td>
<td>0.6 (0.4, 0.9)§</td>
<td></td>
</tr>
<tr>
<td>Endocardial Unipolar amplitude (mV)</td>
<td>1.9±1.2</td>
<td>1.5±0.9</td>
<td>0.84‡</td>
</tr>
<tr>
<td></td>
<td>1.2 (1.0, 2.8)§</td>
<td>1.3 (0.9, 2.0)§</td>
<td></td>
</tr>
<tr>
<td>Endocardial EGM duration (ms)</td>
<td>118±65</td>
<td>121±50</td>
<td>0.96‡</td>
</tr>
<tr>
<td></td>
<td>96.5 (81.5, 130.5)§</td>
<td>116.5 (79.5, 165.0)§</td>
<td></td>
</tr>
<tr>
<td>Endocardial EGM fractionation (number of peaks)</td>
<td>6.4±2.6</td>
<td>7.5±2.7</td>
<td>0.41‡</td>
</tr>
<tr>
<td>Needle EGM to QRS (ms)</td>
<td>-54±37</td>
<td>-36±33</td>
<td>0.15</td>
</tr>
<tr>
<td>Intramural to Endocardial conduction time (ms)</td>
<td>-30±30</td>
<td>-15±28</td>
<td>0.17</td>
</tr>
<tr>
<td>Needle Semi-Bipolar amplitude (mV)</td>
<td>1.6±1.3</td>
<td>1.4±1.0</td>
<td>0.63†</td>
</tr>
<tr>
<td></td>
<td>1.0 (0.6, 2.3)§</td>
<td>0.9 (0.7, 1.6)§</td>
<td></td>
</tr>
<tr>
<td>Needle Unipolar amplitude (mV)</td>
<td>1.9±1.3</td>
<td>1.4±0.9</td>
<td>0.81†</td>
</tr>
<tr>
<td></td>
<td>1.5 (1.1, 3.3)§</td>
<td>1.3 (0.7, 2.0)§</td>
<td></td>
</tr>
<tr>
<td>Needle EGM duration (ms)</td>
<td>180±105</td>
<td>136±66</td>
<td>0.19‡</td>
</tr>
<tr>
<td></td>
<td>142.5 (88.5, 299.5)§</td>
<td>120.5 (78.5, 191.0)§</td>
<td></td>
</tr>
<tr>
<td>EGM fractionation (number of peaks)</td>
<td>7.6±3.2</td>
<td>8.3±3.0</td>
<td>0.93‡</td>
</tr>
</tbody>
</table>

**RF Parameters**

- **RF Time (s)**: 52±28, 53±26 (0.74)
- **RF Maximum Temp (°C)**: 62±2.5, 62±1.7 (0.79)
- **RF Maximum Power (W)**: 25±6.5, 22±8.6 (0.31)
- **RF Average Temp (°C)**: 55±3.8, 57±1.5 (0.15)
- **RF Average Power (W)**: 17.5±5.1, 13±6.9 (0.077)

EGM: Electrogram, ms: millisecond, mV: millivolt, VA: Ventricular Arrhythmias including VT and PVCs, W: Watt

* Generalized Linear Mixed Models (†log-normal; ‡negative binomial; normal for the rest)

§ Median(Quartile 1, Quartile 3) are reported for continuous variables not meeting normality assumption
Table 3: Intramural EGM characteristics at different scar zones classified based on Electroanatomic system (Carto) Unipolar and Bipolar recordings (with thresholds of 8.3 mV and 1.5 mV respectively\textsuperscript{19}).

<table>
<thead>
<tr>
<th></th>
<th>Normal myocardium</th>
<th>Transmural scar</th>
<th>Epicardial/ Intramural scar</th>
<th>P value$^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Sites n=5 n=41 n=12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Needle Unipolar amplitude (mV)</td>
<td>3.5±1.6 3.2 (2.3, 4.2)$^§$</td>
<td>1.1±1.0 0.8 (0.5, 1.2)$^§$</td>
<td>2.1±1.4 1.6 (0.8, 3.7)$^§$</td>
<td>0.001$^†$</td>
</tr>
<tr>
<td>Needle Semi-Bipolar amplitude (mV)</td>
<td>2.6±1.6 2.0 (1.9, 2.1)$^§$</td>
<td>1.1±1.0 0.7 (0.4, 1.2)$^§$</td>
<td>2.6±2.1 1.9 (1.1, 3.8)$^§$</td>
<td>0.001$^§$</td>
</tr>
<tr>
<td>Needle EGM duration (ms)</td>
<td>96±12 93 (89, 105)$^§$</td>
<td>157±72 142 (98, 200)$^§$</td>
<td>107±55 93 (87, 108)$^§$</td>
<td>0.22$^†$</td>
</tr>
<tr>
<td>Needle EGM fractionation (number of peaks)</td>
<td>8.4±3.9</td>
<td>7.4±3.4</td>
<td>7.8±3.4</td>
<td>0.81$^‡$</td>
</tr>
</tbody>
</table>

During VA n=1 n=24 n=7

|                      |                   |                 |                             |             |
| Endocardial EGM to QRS (ms) | 0  | -25±22 | -3±23 | 0.064 |
| Needle EGM to QRS (ms) | -16 | -43±38 | -15±35 | 0.22 |

Needle pacing sites n=2 n=12 n=3

|                      |                   |                 |                             |             |
| Needle Stim-QRS (ms) | 0 60 (46, 76)$^§$ | 20±35 0 (0, 60)$^§$ | 0.29$^†$ |

$^*$ Generalized Linear Mixed Models ($^†$log-normal; $^‡$negative binomial; normal for the rest)
$^§$ Median(Quartile 1, Quartile 3) are reported for continuous variables not meeting normality assumption
Figures Legends:

**Figure 1:** Picture of the needle ablation catheter with its needle retracted (Top right) and extended (Bottom right). The left fluoroscopy image shows the needle catheter advanced to the left ventricle through a trans-septal sheath and its needle deployed in the inferior septum. Contrast injected through the needle confirms intramyocardial location (*) prior to irrigated RF delivery.

**Figure 2:** Upper right panel shows an AP view of an endocardial bipolar voltage map of the left ventricle. White tags are needle deployment sites. Brown tags are needle ablation sites. Recordings from two needle deployment sites at the superior border of a septal scar, are shown in the lower panels with the endocardial (Endo Bi) and needle semi-bipolar (Ndl Bi) ventricular EGMs during VT. In the lower right panel the needle EGM onset starts before the endocardial EGM and QRS onset by 21 ms. In the lower left panel the needle EGM precedes the endocardial EGM and QRS onset by 60 ms. Needle ablation at this site resulted in immediate termination of the VT (upper left panel).

**Figure 3:** Needle semi-bipolar (Ndl Bi) and unipolar (Ndl Uni) and endocardial bipolar (Endo Bi) and unipolar (Endo Uni) recordings during sinus rhythm from a sites at a low voltage scar margin are shown. A distinct sharp late potential (*) was seen only on the needle EGMs with a corresponding rounded far-field signal on the endocardial recordings.

**Figure 4:** The center panel shows a right anterior oblique view of a bipolar endocardial voltage
map of the left ventricle showing a basal septal scar. White markers are needle deployment sites; brown markers are needle ablation sites. Two sites where pacemapping from the needle (Needle PM) matched a VT QRS morphology suggesting the exit location are indicated and the pacemapping shown in the right and left panels along with the VT. The left panel shows a long stim-QRS delay of 105 ms with 12/12 pacematch to VT#4. The right panel shows close pacematch to VT# 3 with stim-QRS delay of 68 ms.

**Figure 5:** Entrainment of VT by pacing from the needle (left panel) with in-circuit response (PPI=VT CL) and QRS fusion consistent with an outer loop site near the exit. Irrigated RF delivery through the needle at this site resulted in variation in the VT cycle length and termination in 5.2 sec without a change in VT QRS morphology suggesting a possible direct effect on the reentrant circuit (right panel). VT was not reinducible after ablation. Abbreviations are as in prior figures. CL, cycle length; PCL, paced cycle length; Abl, ablation.
Intramural Ventricular Recording and Pacing in Patients with Refractory Ventricular Tachycardia: Initial Findings and Feasibility with a Retractable Needle Catheter
Amir AbdelWahab, William Stevenson, Kara Thompson, Ratika Parkash, Christopher Gray, Martin Gardner and John Sapp

Circ Arrhythm Electrophysiol. published online July 8, 2015;
Circulation: Arrhythmia and Electrophysiology is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2015 American Heart Association, Inc. All rights reserved.
Print ISSN: 1941-3149. Online ISSN: 1941-3084

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circep.ahajournals.org/content/early/2015/07/08/CIRCEP.115.002940

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation: Arrhythmia and Electrophysiology can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation: Arrhythmia and Electrophysiology is online at:
http://circep.ahajournals.org//subscriptions/