A Prospective Study of Ripple Mapping the Post-Infarct Ventricular Scar to Guide Substrate Ablation for Ventricular Tachycardia

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**Background**—Post-infarct ventricular tachycardia is associated with channels of surviving myocardium within scar characterized by fractionated and low-amplitude signals usually occurring late during sinus rhythm. Conventional automated algorithms for 3-dimensional electro-anatomic mapping cannot differentiate the delayed local signal of conduction within the scar from the initial far-field signal generated by surrounding healthy tissue. Ripple mapping displays every deflection of an electrogram, thereby providing fully informative activation sequences. We prospectively used CARTO-based ripple maps to identify conducting channels as a target for ablation.

**Methods and Results**—High-density bipolar left ventricular endocardial electrograms were collected using CARTO3v4 in sinus rhythm or ventricular pacing and reviewed for ripple mapping conducting channel identification. Fifteen consecutive patients (median age 68 years, left ventricular ejection fraction 30%) were studied (6 month preprocedural implantable cardioverter defibrillator therapies: median 19 ATP events [Q1–Q3=4–93] and 1 shock [Q1–Q3=0–3]). Scar (<1.5 mV) occupied a median 29% of the total surface area (median 540 points collected within scar). A median of 2 ripple mapping conducting channels were seen within each scar (length 60 mm; initial component 0.44 mV; delayed component 0.20 mV; conduction 55 cm/s). Ablation was performed along all identified ripple mapping conducting channels (median 18 lesions) and any presumed interconnected late-activating sites (median 6 lesions; Q1–Q3=2–12). The diastolic isthmus in ventricular tachycardia was mapped in 3 patients and colocated within the ripple mapping conducting channels identified. Ventricular tachycardia was noninducible in 85% of patients post ablation, and 71% remain free of ventricular tachycardia recurrence at 6-month median follow-up.

**Conclusions**—Ripple mapping can be used to identify conduction channels within scar to guide functional substrate ablation. (Circ Arrhythm Electrophysiol. 2016;9:e004072. DOI: 10.1161/CIRCEP.116.004072.)

**Key Words:** ablation ■ cardioverter defibrillator ■ myocardial infarction ■ ventricular tachycardia

**Post-infarct reentrant ventricular tachycardia (VT) is dependent on channels of surviving myocardium within the infarct scar.**

Substrate-based ablation that eliminates all abnormal electrograms, including fractionated and late potentials within scar, can reduce long-term VT recurrence. However, detailed mapping studies of local electrograms can identify paths of activation within the scar, forming channels that are considered a more specific target for substrate ablation.

Ripple mapping (RM) is a method of 3-dimensional activation visualization that displays each electrogram component as a dynamic bar that protrudes from its 3-dimensional location on the surface geometry. The height of each bar correlates with the voltage amplitude of the electrogram at that time point. When multiple points are collected, activation is visually apparent from the direction of propagation of bar movement on the map. This is achieved without the need for manual annotation or setting a window of interest. Ripple activation maps can be superimposed on a conventional bipolar voltage map, thereby displaying the surface geometry with both voltage and activation simultaneously. RM is incorporated into CARTO3v4 (Biosense Webster) and has been

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applied prospectively to guide atrial tachycardia ablation in the scarred atrium.8

We have previously described how RM is able to visualize conducting channels of electrogram activation within scar using an offline system in a retrospective series of ventricular substrate maps.9 This showed that pacing sites with good pace maps and where entrainment mapping confirmed participation in VT collocated with the identified ripple mapping conducting channels defined by functional block. With hemodynamically stable ventricular tachycardia, ripple mapping revealed diastolic pathways contained within the confines of the conduction channels defined by functional block. In this feasibility study, limited scar ablation within conduction channels resulted in 70% of patients being free of ventricular tachycardia recurrence at 6 months.

Methods

Study Sample
Consecutive patients referred for VT ablation secondary to documented episodes of sustained VT or appropriate implantable cardioverter defibrillator (ICD) therapy post distant myocardial infarction were studied. All patients prospectively enrolled after providing written informed consent to participate in the research study. This study was approved by a local human research ethics committee.

Ventricular Scar Mapping
Patients were studied in the postabsorptive state under general anesthesia. Surface ECGs and bipolar electrograms were monitored continuously on a LabSystem Pro (Bard Electrophysiology, Lowell, MA), sampled at 1 kHz, and bandpass filtered at 30 to 500 Hz, with the notch filter switched off. Noise signal in the laboratory was recorded below 0.05 mV. A steerable quadripolar catheter was positioned in the right ventricular apex. The left ventricle (LV) was accessed via the transeptal approach (BRK Needle, St Jude Medical) under transesophageal guidance or retrograde from the aorta. Heparin boluses were administered intravenously to target an activated clotting time >300 seconds. The Hansen SenSet Robotic System (Hansen Medical Inc, Mountain View, CA) was used to support endocardial mapping and ablation as per operator preference.10 No epicardial mapping was performed. Detailed maps of the endocardial LV surface were obtained in sinus rhythm (or during right ventricular pacing if the patient was pacing-dependent) using a 3.5-mm tip SmartTouch Thermocool catheter (Biosense Webster). Interpolation was limited to a color threshold ≤5 mm, with an emphasis on fully defining the scar and border zone of the infarcted tissue. Normal bipolar endocardial voltage was defined as a peak-to-peak amplitude ≥1.5 mV and core scar as ≤0.5 mV, and border zone was between 0.5 and 1.5 mV.11 Electro-anatomic data were collected either point by point or using an automated point collection facility (ConfIdENSE Continuous mapping) as per operator preference. The automated system relied on filters for each beat based on a series of preassigned parameters. Criteria for including points were (1) a cycle-length stability within a 5% range of the R-R interval; (2) an electrode position stability within 2 mm; (3) gating to end expiration of the respiratory cycle; (4) a contact force above a minimum of 2 g (to avoid sites with insufficient contact). The multielectrode PentaRay catheter (2-6-2 mm spacing) was applied in the latter cases in this study. To ensure adequate surface contact, a tissue proximity filter which only collected points in proximity to the endocardial surface based on an impedance measurement algorithm of either dipole was applied.

VT Induction
VT induction was performed at 2 sites with 2 drive trains, with ≤3 extrastimuli decremented to ventricular refractoriness or 200 ms. If VT was inducible and sustained, a remap of the scar was performed. If an unstable VT was induced, it was terminated by overdrive pacing or defibrillation, and no further attempts to induce VT were performed.

Analysis of Ripple Map
Ripple bars of a typical bipolar electrogram from an area of functional myocardium within ventricular scar is shown in Figure 1A. The electrogram is composed of 2 components: a far-field component from the bulk of ventricular myocardium surrounding the scar (generally higher amplitude, lower frequency), followed by a delayed component from local tissue. Substrate mapping relies on differentiation of the local from far-field components. When multiple electrograms within the scar are reviewed using RM, 2 wavefronts may be seen: an initial wavefront occurs in tandem with bars in the surrounding healthy tissue and is presumed far field, followed by a delayed wavefront of presumed local activation (Figure 1B and Movie I in the Data Supplement). During the time the patient underwent VT induction, CARTO ripple maps were analyzed for RMCCs, defined as channels of sequentially moving adjacent bars representing local activation within scar, distinct from the initial wavefront (Figure 1C). No pacing maneuvers were performed to confirm the distinction between local and far-field components within the RMCC. Electrogram deflections <0.05 mV were hidden from the ripple map to reduce background noise, and the bars were clipped at 0.30 mV to allow low-voltage signals to be displayed more clearly. These parameters could be adjusted during analysis. Ripple maps were studied from the onset of QRS until the end of ventricular activation. Design lines were drawn on the anatomic shell to encircle the entire RMCC or clusters of late local activating ripple bars that activated simultaneously, and adjacent clusters were joined to form RMCCs. If the initial and delayed wavefronts were difficult to differentiate, maps were analyzed frame-by-frame or in reverse toward the onset of the QRS. Electrograms along each RMCC were then analyzed using the CARTO Ripple Viewer, which enabled multiple ripple bars to be selected and the corresponding electrograms to be displayed together. This was used to validate the RMCC design lines that had been drawn. Where VT was mapped, ripple maps were studied over the complete tachycardia cycle length to identify the location of ripple bar activation during the diastolic interval. Design lines were drawn to encircle the boundaries of this diastolic activation to highlight the diastolic pathway (Ripple Mapping Diastolic pathway [RMDP]).

WHAT IS KNOWN
- The post-infarct ventricular scar is characterized by low-voltage multicomponent electrograms which are difficult to interpret.
- Ripple mapping is a novel visualization technique that displays each electrogram as a dynamic bar on the cardiac surface and has been used in an offline retrospective series to demonstrate evidence of conduction channels within the ventricular scar.

WHAT THE STUDY ADDS
- Ripple mapping incorporated into the CARTO 3-dimensional navigation system can be used to locate conduction channels within ventricular scar to guide ablation in real time.
- With hemodynamically stable ventricular tachycardia, ripple mapping revealed diastolic pathways contained within the confines of the conduction channels defined by functional block.
- In this feasibility study, limited scar ablation within conduction channels resulted in 70% of patients being free of ventricular tachycardia recurrence at 6 months.
Figure 1. A. Ventricular electrogram (EGM). A bipolar EGM (400 m/s sweep speed) collected within ventricular scar is displayed. The EGM contains 2 components. The initial component is a likely far-field signal (either epicardial or surrounding healthy tissue). The second component likely represents delayed local activation (late potential). Six time frames from the Ripple map are displayed (1–3 occur during far-field signal; 5–6 occur during the local signal). The Ripple bar for each time point is seen, overlying a CARTO voltage isochrone. (Continued)
Radiofrequency Ablation

Ablation was delivered within each RMDP where VT was mapped, followed by all RMCCs identified. Discrete clusters of late-activating ripple bars were also ablated because they were considered an endocardial component of an epicardial RMCC. Ablation was performed with a 3.5-mm externally irrigated tip catheter. Each radiofrequency delivery was temperature-controlled to 50°C, with a power limit of 30 W for 60 seconds (17/mL/min) or 50 W for 30 seconds (30 mL/min) as per operator preference, with a target contact force of 10 to 20 g aiming for the local signal to diminish. No other ablation was performed within this protocol.

End Points

Postprocedural VT Inducibility

Post-ablation ventricular stimulation was used to assess VT inducibility as a marker of immediate ablation efficacy. Patients were defined as either noninducible or inducible for VT.

Follow Up

ICD interrogations were conducted at 1, 3, 6, and 12 months, and arrhythmia logs were retrieved. End points were defined by time to first VT episode recurrence (first ATP or shock therapy or sustained VT captured within a monitor zone or 12-lead ECG).

Table 1. Patient Demographics

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CABG indicates coronary artery bypass graft; CRT-D, cardiac resynchronization therapy with defibrillator; LQ, lower quartile; LVEF, left ventricular ejection fraction; ICD, implantable cardioverter defibrillator; PCI, percutaneous coronary intervention; and UQ, upper quartile.
previous 6 months or last VT ablation included 19 ATP events (4–93) and 1 shock (0–3).

Map Collection
Details of LV map collection are summarized in Table 2. Ventricular scar maps in the first 12/15 cases (80%) were collected with a SmartTouch catheter supported by the Hansen Sensei Robotic System. The latter 3/15 (20%) maps were collected using the PentaRay. Voltage maps were collected in an RV-paced rhythm in 9/15 (60%) patients (pacing-dependent/operator preference). Chamber geometry and electro-anatomic data were collected simultaneously (median chamber area of 258 cm² [235–298], median 714 points per map [55–1107], median mapping time of 79 min [63–90]). Detailed mapping was performed within scar (median 540 points per map [365–742]; median 6.6 point per cm² [5.3–8.7]; median scar area 77cm² [62–120]). Scar represented median 29% (26%–37%) of the total endocardial surface area.

VT Induction
VT was noninducible in 2/15 (13%) patients from the start. In 10/15 patients, VT was either nonsustained or poorly tolerated, requiring termination with overdrive pacing or defibrillation. VT was mapped in only 3/15 (20%) patients, enabling detailed review as a ripple map (1205±1026 electrograms) to characterize the RMDP. No entrainment was performed in VT, but ablation was delivered within the mapped RMDP. In all patients, after the first VT was induced, no further attempts to induce VT were performed till after RMCC ablation.

Ripple Mapping Within Ventricular Scar
RMCCs were identified in all patients, and 3 patients also had induced VT mapped. Figure 2A illustrates the RMCCs identified in patient 9 using the raw data shown in Movie IIA in the Data Supplement. The 2 RMCCs (enhanced with design lines) are seen as late-activating channels separate from the initial wavefront. The direction of activation is readily apparent, and the channel is seen without any manual annotation or point tagging. In this example, the RMCCs are broad and cover a relatively large area of the scar. In Figure 2B and Movie IIB, the corresponding VT circuit is shown as a ripple map, and local diastolic activation is clearly differentiated from systolic activation. The entire RMDP is seen with varying diameter along its length. Ablation within the RMDP interrupted the VT circuit. In some cases, the RMCCs were difficult to see during forward play and needed step-by-step reverse play.
Figure 3A summarize the 3 RMCCs identified from Movie IIIA in the Data Supplement in patient 5. The RMCCs were seen closer to the conventional scar border on the bipolar voltage map. Isolated clusters of very late--activating ripple bars that do not seem connected to the RMCCs identified are also apparent, and it is assumed that these arose from channels that are deep to the endocardium. In Figure 3B and Movie IIIB in the Data Supplement, the diastolic component of the induced VT is shown. The complete RMDP was not seen because of either insufficient point collection or non-endocardial components to the circuit. Despite this, the RMDP, there seems to be a central refractory core in this circuit within the scar. A single ablation lesion within the RMDP interrupted VT.

Centripetal pattern of activation into the scar core has also been described previously, and Movie IVA in the Data Supplement from patient 13 demonstrates an example of this with a ripple map. Figure 4A illustrates how this pattern might occur with regions of functional tissue activated by any number of RMCCs. This map was collected with the PentaRay (2599 points). By playing the RM backwards and encircling each patch of simultaneously activating tissue, interconnecting RMCCs were gradually built up. Figure 4B summarizes the final RMCC locations. Remapping of the scar post RMCC ablation to look for elimination of activation...
along RMCCs was also performed in this case and presented in the Video in the Data Supplement. Figure 4C and Movie IVB in the Data Supplement show the corresponding VT map. In this example, there was a narrow RMDP, which opened into a broad region of diastolic activation before the systolic activation occurred. Ablation within the RMDP interrupted VT.

Details of RMCC characterization within all study patients are presented in Table 3. A median of 2 RMCCs were identified within each scar. The median RMCC length was 60 mm (40–80). Electrograms were sampled for analysis every 10 mm along each RMCC. The median amplitude of the initial component (presumed far field) was significantly greater than that of the delayed component (presumed local; initial component 0.44 mV [0.25–0.68]; delayed component 0.20 mV [0.13–0.30]; \(P<0.001\)). The median conduction velocity within the RMCC was 55 cm/s. Radiofrequency ablation was delivered along each RMCC (median 18 lesions per RMCC [9–22]). Further ablation (median 6 lesions [2–12]) was performed within isolated clusters of late-activating ripple bars, considered an endocardial component of an epicardial RMCC.

Clinical Outcome
This has been summarized in Table 4. At the end of the procedure, no VTs were inducible in 11/13 (85%) patients, where VT was induced from the start (VT occurred in the remaining 2 cases only with a more aggressive programmed stimulation for induction). There were no complications during the procedures, but 1 patient died a week later from worsening heart failure, and no ventricular arrhythmic episodes were identified on postmortem device interrogation. In those patients already

Figure 3. (Movie IIIA+IIIB): Analysis of Ripple mapping (RM) within ventricular scar to guide substrate ablation (patient 5). The map was collected in sinus rhythm. Scar (<1.5 mV) was identified on the anterior wall (66 cm², 300 points). A, Ripple bars were seen to propagate from the septum to the lateral wall. The map is presented in reverse. A cluster of late activating bars +130 ms post QRS onset is seen within basal scar and corresponds to late potentials traveling from the lateral wall to the septum, representing RMCC1. RMCC2 is encountered +115 ms post QRS onset, this time traveling mid scar from septal–lateral LV. RMCC3 is seen +80 ms post QRS onset traveling down the lateral wall from base-apex. In the presented time frame, bars are seen along each RMCC because the corresponding late signals are at different time points away from the isoelectric line. Our approach to substrate ablation is presented, with ablation delivered along all RMCCs and at late activating clusters. B, Ventricular tachycardia (VT) was induced (cycle length 440 ms) and mapped. Three time points within the diastolic period are presented. RM tracked diastolic signals traveling around a counterclockwise loop within the scar. RMCC indicates Ripple mapping conducting channel.
on long-term Amiodarone, it was continued. Patients were followed up for a median of 6 months. Ten of 14 (71%) patients remain free of VT recurrence. VT recurred in 4 patients—within 1 month (Patients 11 and 12), at 2 months (Patient 13), and at 6 months (Patient 3) post ablation. Of note, despite VT noninducibility immediately post procedure, patient 12 presented again with ICD storm, and importantly, during redo ablation, the RMCCs identified during the index case had not been completely eliminated.

Postprocedural Analysis

By merging the 3 RMDP and RMCC maps, it was possible to understand the relationship between these. Figure 5 confirms that the RMDP (length 61±17 mm, area 5±0.3 cm², diastolic component 0.27±0.18 mV) always appeared within the area of an RMCC (length 60±23 mm, area 5.4±3 cm², delayed component 0.21±0.17 mV). Interestingly, Figure 6 demonstrates how the lines of block bordering the RMDPs in patient 9 were formed of myocardium with no signal during VT but of conducting myocardium during sinus rhythm (0.22±0.1 mV) indicating functional block. These areas of functional block were within the RMCC borders (20±13% of total RMCC area), not at the scar border zone.

Figure 1 in the Data Supplement illustrates how the location of most RMCCs did not correlate with voltage channels because voltage was usually annotated to the largest electrogram component rather than the local signal within...
the RMCC. All remaining ventricular scar maps within this study are presented as Figure II in the Data Supplement, with the location and direction of RMCC activation highlighted. The location of the scar within the ventricle did not influence the frequency, location, or size of an RMCC within the scar.

### Discussion

In this study, we describe our early experience of ripple mapping the post-infarct ventricular scar to identify channels of local activation. These conducting channels (RMCCs) collocated with the VT diastolic pathway (RMDP; mapped in 3 patients, with ablation interrupting VT in each case), and ablation of these RMCCs rendered 85% of patients noninducible for VT and 70% free from ICD therapy at 6 months.

### Table 3. RMCC Characteristics

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<th>Length, mm</th>
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LQ indicates lower quartile; RMCC, Ripple mapping conducting channel; and UQ, upper quartile.

All approaches to substrate-based ablation of ventricular scar use 3-dimensional mapping to characterize the likely location of channels that might support VT. Voltage mapping displays scar as areas below a threshold of 1.5 mV, allowing encirclement of the scar border zone or complete scar homogenization to isolate or eliminate all potential channels without defining them specifically.\textsuperscript{11,14} Adjustment of the voltage threshold has been used to identify channels of preserved myocardium within scar, but because voltage is annotated to the electrogram peak, these regions are usually formed of far-field signal.\textsuperscript{15} Manual tagging of abnormal potentials or manual adjustment of activation time using color-coded isochronal activation maps can highlight local activation through scar, but are challenging with high-density point collection, and annotation as a single activation time is suboptimal at sites with fractionated or multiple late
Conclusions

We describe a technique using CARTO ripple map for mapping the functional substrate of post-infarct scar. We were able to identify conduction channels that contain the diastolic isthmus of VT. Further studies are needed to elucidate if RM can be used to target alternative end point such as channel abolition to improve outcomes.
Figure 5. Ripple mapping conducting channel (RMCC) and ventricular tachycardia (VT) isthmus colocalization. A, The RMCC substrate map (left) and VT map (right) from Figure 2 (patient 9) are displayed in identical orientations (sync views). To demonstrate the location of the VT isthmus in relation to the RMCCs, the VT map has been opened directly on the RMCC map. The CARTO system merges the colors represented by the voltage map. The VT isthmus is seen to colocalize within the RMCC. B, VT was mapped in the 3 cases presented (patients 9, 5, and 13). The VT map was opened on its corresponding RMCC map, and the VT isthmus is outlined in blue and the RMCC in white. The VT isthmuses collocate within the corresponding RMCCs, reinforcing the functional significance of the RMCCs identified.

Figure 6. Functional lines of block bordering the Ripple Mapping Diastolic pathway (RMDP). The lines of block bordering the RMDP (white outline) mapped in ventricular tachycardia (VT) from Patient 9 (described in Figure 2 and Figure 5) were analyzed in greater detail. The area of the RMDP is contained within the edge of the Ripple mapping conducting channel (RMCC; blue outline) mapped in paced rhythm. The area immediately outside the RMDP border, but contained within the RMCC, was formed of myocardium that has signal during pacing but without any diastolic potentials during VT, confirming this is an area of functional block.
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Disclosures
Imperial Innovations hold Intellectual Property relating to Ripple Mapping on behalf of Drs Kanagaratnam and Linton, who have also received royalties from Biosense Webster. Drs Kanagaratnam, Linton, Jamil-Copley, Luther, and Lim have received consulting fees with respect to Ripple Mapping from Biosense Webster. The other authors report no conflicts.

References
A Prospective Study of Ripple Mapping the Post-Infarct Ventricular Scar to Guide Substrate Ablation for Ventricular Tachycardia
Vishal Luther, Nick W.F. Linton, Shahnaz Jamil-Copley, Michael Koa-Wing, Phang Boon Lim, Norman Qureshi, Fu Siong Ng, Sajad Hayat, Zachary Whinnett, D. Wyn Davies, Nicholas S. Peters and Prapa Kanagaratnam

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SUPPLEMENTAL MATERIAL

Supplemental Figure 1: RMCCs cannot be identified by voltage thresholding (pt. 7)

The location of the RMCC identified within scar has been drawn as a double white design line and the accompanying EGMs along the RMCC displayed in the Ripple Viewer. Yellow and pink design lines highlight the scar border and scar core zones. Voltage maps annotate the peak amplitude within an electrogram which is usually a far field component. Reducing the voltage threshold shows no correlation between the voltage channels seen and the RMCC.

Supplemental Figure 2: Ventricular scar maps with RMCCs

The remaining 12 voltage maps from each case within this study are presented with the location of each RMCC highlighted as a design lines for ease of display. The scar threshold is set below 1.5mV. EGMs along an RMCC within each map have been highlighted using the Ripple Markings tool, and displayed in the CARTO Ripple Viewer (400mm/sec) with LII body surface QRS at the top. The EGMs demonstrate increasing activation timing along their path and an arrow depicts the direction of activation along each RMCC.
Supplemental Figure 1: RMCCs cannot be identified by voltage thresholding (pt. 7)
Supplemental Figure 2: Ventricular scar maps with RMCCs
Supplemental Video 1: RMCC

The Ripple Map of the five sampled endocardial points presented in figure 1b are played at full and slow speed. Two distinct wave-fronts of activation can be seen. In order to distinguish the delayed wavefront from the initial wavefront, the map is studied frame by frame in reverse. The “earliest ripple bar” corresponds with the “latest” delayed potential, and subsequent “earlier” late activating bars can be tracked down the geometry allowing an RMCC to be constructed in reverse. Corresponding bars from the initial wavefront are clearly distinguished as a second wavefront.

A second Ripple Map of 4 adjacent fractionated electrograms sampled within endocardial scar is presented. Activation is seen to descend down the anatomy. Multiple oscillations of Ripple bars are seen at each site, corresponding with each deflection of the sampled electrogram.
Supplemental Video 2a: Clear direction of RMCC activation (pt. 9)

The CARTO Ripple Map of the case depicted in figure 2 is seen. To guide the viewer, at the beginning of the video, the location/dimension/path of each RMCC is marked on the map using the design line tool, and tracked using the mouse arrow. The Ripple Map is initially played at full speed from the onset of the QRS to the T wave over a bipolar voltage setting of 0.5-1.5mV. Having multiple colors on the endocardial shell can be distracting when observing Ripple bars, so the voltage setting is adjusted to 1mV-1.5mV. When the Ripple Map is played at slow speed, an initial wavefront of bars are seen to propagate along the anterior wall from the apex to the basal LV. These bars occur in tandem to bars in the surrounding healthy tissue and considered far field activation. A delayed wavefront of smaller Ripple bars follows this initial wavefront and considered local activation.

The map is then studied in reverse from the T wave backwards. The Ripple map is presented frame by frame, and as each bar is seen, the corresponding electrogram signal is highlighted. Occasional noise artifact is identified and is ignored. A channel of late potentials is seen along the septal wall (RMCC 2), and lateral wall (RMCC 1).

Supplemental Video 2b: RM Diastolic Pathway

The Ripple Map in VT is played in the same orientation as above. The map is played at full and slow speed. Systolic activation travels from LV base to apex. The RM diastolic pathway (RMDP) is outlined with a white design line. During the diastolic period, clusters of Ripple bars are seen to ascend the map, contained within the design lines. The corresponding electrograms along this channel can be seen as time progresses in the Ripple EGM Viewer.
Supplemental Video 3a: Analysis of RM within ventricular scar to guide substrate ablation (pt. 5)

The CARTO Ripple Map presented in figure 3 is played at full speed overlying a bipolar voltage of 1.5mV-1.5mV. At this setting, the colors within border-zone tissue are of no distraction to the Ripple Map. The map is subsequently played more slowly to appreciate areas of late activating Ripple bars. RM is subsequently studied in reverse from the T wave backwards. Bars highlighting areas of late activation are seen with their corresponding electrogram. The construction of 3 RMCCs is presented. Two clusters of late activating sites (+170ms, +150ms post QRS onset) without increasing activation delay were also encountered (not shown in the figure).

Supplemental Video 3b: RM Diastolic Pathway

The Ripple Map of the VT circuit is presented at full and slow speed. The map is then studied frame by frame through the diastolic period to carefully characterize the diastolic pathway.
Supplemental Video 4a: RMCCs in close proximity with probable path of activation towards the center of the scar (pt. 13)

The Ripple Map presented in figure 4b is played at full speed overlying a bipolar voltage setting of 0.5mV-1.5mV. At this setting, the colors within border-zone tissue are of no distraction to the Ripple Map. The map is subsequently played more slowly to appreciate areas of late activating Ripple bars. RM is subsequently studied in reverse from the T wave backwards. Bars highlighting areas of late activation are seen with their corresponding electrograms. Design lines have been drawn around each area of late activation. Bars appear to arise in clusters, but without an immediately obvious path of activation through the scar. Clusters adjacent to each other have been highlighted in the same color (pink, yellow, brown) and used to determine the location and path of each RMCC within the map. Our approach to substrate ablation targeting these RMCCs is presented. Post substrate ablation, a dense remap of the scar was collected using a Pentaray, and used to assess for late signal elimination. A sided by side comparison of the pre and post ablation Ripple Map is presented. Reduced ripple bar activity within scar post ablation can be appreciated.

Supplemental Video 4b: RM Diastolic Pathway

The Ripple Map of the VT circuit is presented. The diastolic pathway is highlighted as white design lines. The map is played at full speed with bars shown for only those signals above 0.1mV. Breakout of activation within this channel can be appreciated. The map is adjusted to show bars for signals above 0.03mV. In doing so, low amplitude mid diastolic signals within the channel are seen which eventually lead to pre-systolic signals near the isthmus exit.