Automatic identification of VT substrate in the era of ultra-high-density mapping: Do Humans or Machines emerge victorious?

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Abbreviations:

CA catheter ablation

DP double potentials

FP fractionated potentials

LAVAs local abnormal ventricular activities

LP late potentials

LV left ventricular

RV right ventricular

SHD structural heart disease

VT ventricular tachycardia

The legendary story of John Henry is the classic human vs machine tale set in 1800s in West Virginia, USA. John Henry worked on the railroad construction for the Westward expansion of America, He was of

legendary size and strength, over 6 feet tall and able to drive a rail spike with a single swing of his twenty-pound hammer. As legend goes, John Henry's prowess was measured in a race against the newly developed steam-powered rock drilling machine. The race was set to see whether human or machine made the most progress in drilling. On that day, John Henry emerged victorious over the machine only to die in victory with hammer in hand. This epic story, although not quite the same, carries some parallels to the contemporary challenges that face ventricular tachycardia (VT) ablation in the setting of structural heart disease (SHD)-a disease which poses one of the greatest challenges in electrophysiology, where the comparison is now made between automatic vs manual annotation during substrate mapping.

SHD-related VT is predominantly re-entrant in mechanism, in or around ischemic or non-ischemic scar. Catheter ablation (CA) is a class I recommendation for the drug-refractory treatment.[1]Identification of VT isthmii is critical for the efficacy of CA. Historically, activation mapping, followed by entrainment and termination of VT with ablation has allowed identification of VT isthmii and formed the basis for SHD related VT ablation.[2]However, unreliable inducibility, conversion of VT to another, non-sustainability of VT to permit activation/entrainment mapping and the hemodynamic instability during VT, meant that alternative mapping strategies were desirable. This formed the basis for the evolution of substrate mapping. Substrate mapping allows identification of putative VT isthmii by using surrogate markers in stable sinus or paced rhythm representing slow, discontinuous conduction in and around scar. Substrate mapping has improved the feasibility of VT ablation by avoiding the deleterious consequences of prolonged episodes of sustained VT to permit activation/entrainment mapping.[3]

One such surrogate marker, termed local abnormal ventricular activities (LAVAs)[4], represent regions of delayed conduction and are defined as sharp, high-frequency ventricular potentials, which are distinct from the far-field electrogram and often display fractionated, double or multiple components, separated by low-amplitude signals or an isoelectric interval.[4] Typically, these signals have been annotated and tagged on the electroanatomic map manually, because automated algorithms are generally limited in their ability to differentiate the delayed multiple component signals within the scar from the initial far-field component of the electrogram. Advances in multi-electrode mapping catheters and electroanatomic mapping systems now allow rapid collection of a large volume of intra-cardiac electrograms, which poses a significant challenge to this real-time manual electrogram annotation. The Lumipoint algorithm (Boston Scientific, Marlborough, MA) can annotate signals throughout the entire mapping window, as opposed to a peak signal and is therefore able to identify LAVAs rapidly.[5] It is plausible to suggest that the automated annotation of LAVAs may improve procedural efficiency and potentially, the consistency of point annotation and rapid delineation of VT isthmii.

In this study, Nakatani et al.[6] describe 100 patients with SHD ([ischemic n=75, non-ischemic n=25]) related VT undergoing electroanatomic mapping and CA, using the ultra-high-density Rhythmia system (Boston Scientific). The study aimed to determine if the Lumipoint algorithm is accurate in detecting LAVAs. The automatic identification of LAVAs was performed retrospectively using the algorithm features to detect late potentials (LP), fragmented potentials (FP) and double potentials (DP), this was directly compared to the real-time manual electrogram annotation of LAVAs and sites of ablation, performed during each procedure. Mapping was performed using the Intellamap Orion^{TM} catheter (Boston Scientific) in the left ventricle (83%), right ventricle (8%) and epicardium (9%). The average number of points collected per map were 9976 ± 7477 over 31 ± 11 minutes. Overall, the 3 Lumipoint features complemented each other and correctly identified LAVAs equally or better than manual annotation in 79% of patients (64% equally, 15% better). Conversely there were 18% of patients in whom LAVAs were missed by Lumipoint but identified by manual annotation. These discrepancies were predominantly due to Lumipoint detecting very low amplitude LAVAs better than manual annotation but missing fragmented signals with few activation components (the FP feature was set to recognise a minimum of 7 activation components). The impact of wavefront direction (sinus rhythm [n=34], right ventricular [RV] pacing [n=63] or left ventricular [LV] pacing [n=3]) and scar location on the accuracy of the 3 algorithm features (LP, FP, DP), was then assessed by manually checking each automatically highlighted area to determine a percentage of LAVAs within each region. This demonstrated that automatic FP annotation accurately detected LAVAs irrespective of scar location or wavefront direction

(Figure). Automatic LP annotation accurately identified LAVAs in sinus rhythm, but during RV pacing it less accurately detected LAVAs in the LV septum, apex, and epicardium, compared to in the LV lateral wall (Figure). Automatic annotation of DP was unaffected by wavefront direction but was less accurate at identifying LAVAs in the RV and epicardium (Figure). Hence it seems that overall, Lumipoint is better at detecting LAVAs during sinus rhythm in areas of LV scar. With regards to the correlation between LAVAs and VT isthmii, 19 patients underwent activation/entrainment mapping and VT isthmus identification during their procedure. Of these, LAVAs were identified in the VT isthmus in all 19/19 (100%) patients by automatic annotation, and in 17/19 (89%) patients by manual annotation. The identification of LP corresponded to the VT isthmus in 18/19 (95%), FP in 6/19 (32%) and DP in 5/19 (26%) of these cases.

The authors ought to be congratulated on their important contribution to substrate mapping using high density mapping and a highly sophisticated electroanatomic mapping algorithm that attempts to automate the vast amount of substrate mapping data detected. The study raises several interesting points of discussion. The correct annotation of electrograms collected during substrate mapping is dependent on multiple factors, including the catheter electrode size and spacing, catheter contact with the myocardium, the frequency of the signal/ability of the signal to be seen, location of the mapping catheter and the direction of the intrinsic or paced wavefront. All procedures were performed using the Intellamap Orion^{TM} catheter, which has 64 electrodes, 0.4 mm^2 in size, with 2.5 mm inter-electrode spacing. This large number of small electrodes allows a high sensitivity to near-field signals and the creation of ultra-high-density electroanatomic maps.[7] Noise was filtered using a 0.02 mV cut-off but there was no disclosure regarding the gain used for manual electrogram interpretation during the procedure. This is particularly important because the findings suggest Lumipoint may be able to detect LAVAs better than manual annotation when very low amplitude signals were present. It is possible that these missed low amplitude signals might have been more apparent if an increased gain was used during manual annotation. In contrast, the Lumipoint algorithm might have recognised more FP with few activation components if the algorithm had been set to recognise a lower number of activation components (eg. 5 instead of 7). The scar location and wavefront direction were shown to impact the accuracy in the automatic detection of LAVAs, in keeping with previous work by Tung et al.[8], whereby differing wavefront directions affected electrogram amplitude and scar area. With regards to the detection of LAVAs, automatic annotation relies on the abnormal signal falling within the specified window of interest. However, if an area is activated relatively early compared to this window, as can happen if a closely adjacent site is paced (eg. RV pacing for septal scar), then delayed conduction may appear earlier than the algorithm is programmed to accept and therefore not identified as LAVAs.

The vast number of points collected per map, over a very short time, highlights the considerable challenges faced when attempting to annotate electrograms manually in real-time whilst performing ultra-high-density mapping. The authors did not disclose overall procedure times and it seems likely that manual annotation of electrograms continued after substrate mapping or even at the end of the procedure. In addition, the inclusion of ablated areas as regions of manually annotated LAVAs, potentially affected the validity of the results, as such regions may have been identified through either activation or pace mapping, without the need for manual annotation of LAVAs. Nevertheless, these ablated regions likely represented VT isthmii, and the purpose of this study was primarily to determine the ability of Lumipoint to identify these regions, therefore this approach seems reasonable. It should be noted however, that complete reliance on the automatic annotation of LAVAs is unable to guarantee the localisation of the critical VT isthmus, as the algorithm will only identify regions where delayed/abnormal conduction generates signals that fall within a specified window of interest, potentially in an outer loop of the VT circuit or the scar borderzone. Entrainment mapping is therefore required to determine the site of the critical isthmus.

Previously, Martin et al.[5], performed a similar study on a smaller number of patients. The Lumipoint algorithm was applied retrospectively to the electroanatomic maps of 27 patients who had undergone CA of either ischemic (n=22) or dilated cardiomyopathy (n=5) related VT. VT isthmii were accurately identified in 25/27 patients, as seen by the manually annotated map, entrainment, and response to ablation. The current study by Nakatani et al. builds on this prior work, by including a larger patient population and describes the ability of Lumipoint to identify the various components of LAVAs (LP, DP, and FP) according to the cardiac

rhythm/wavefront direction and site of scar location. Both studies focused predominantly on patients with ischemic cardiomyopathy, where regions of delayed conduction tend to be more common, but the findings do suggest efficacy in detecting these regions in non-ischemic patients, albeit in a small population.

In summary, the study by Nakatani et al.[6] offers an important insight into the potential utilisation of the automatic Lumipoint algorithm, for identifying regions of delayed conduction in the context of SHD related VT. Their findings suggest the retrospective use of Lumipoint can achieve an overall equivalence to the real time manual electrogram annotation of LAVAs. However, its accuracy is affected by wavefront direction and scar location, performing best during sinus rhythm for LV scar annotation. At present it remains likely to be utilised as a supportive tool, with manual annotation still required to check automatically annotated LAVAs. A future prospective, randomised study would further validate these findings. As the legend of John Henry taught us, although machines can automate a large part of work in substrate mapping, human effort and knowledge is critically necessary in working together to achieve cure for one of the most challenging diseases of our era, that is SHD-related VT.

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FIGURE. The automatic annotation of LAVAs depending on the accurate identification of fragmented potentials, late potentials and double potentials. Accurate annotation is depicted by a tick and poor annotation by a minus. Fragmented potentials were accurately annotated regardless of wavefront direction or scar location. Late potentials were accurately annotated during sinus rhythm and in lateral LV scar but this accuracy was reduced during RV pacing and in LV septal, LV apical and epicardial scar. Double potentials were accurately annotated regardless of wavefront direction and in LV scar but this accuracy was reduced in RV and epicardial scar.

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machines-emerge-victorious

*Insufficient data to determine the accuracy of late potential annotation during LV pacing

Abbreviations: LV, left ventricular; RV, right ventricular; SR, sinus rhythm