Enhanced Ventricular Tachycardia substrate resolution with a novel Omnipolar High Density mapping catheter: the Omnimapping study

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ABSTRACT

Background

Defining diastolic slow conduction channels within the borderzone (BZ) of scar dependent re-entrant ventricular tachycardia (VT) is key for effective mapping and ablation strategies. Understanding wavefront propagation is driving advances in high density (HD) mapping. The newly developed Advisor™ HD Grid Mapping Catheter (HD GRID) has equidistant spacing of 16, 1mm electrodes in a 4X4 3mm interspaced arrangement allowing bipolar recordings along and uniquely across the splines (orthogonal vector) to facilitate substrate mapping in a WAVE Configuration (WAVE). The purpose of this study was to determine the relative importance of the WAVE Configuration compared to the STANDARD Linear-Only Bipolar Configuration (STANDARD) in defining VT substrate.

Methods

Thirteen patients underwent VT ablation at our institution. In all cases a substrate map was constructed with the HD GRID in the WAVE configuration (conWAVE) to guide ablation strategy. At the end of the procedure the voltage map was remapped in the STANDARD configuration (conSTANDARD) using the turbo-map function. Detailed post-hoc analysis of the WAVE and STANDARD maps were performed blinded to the configuration. Quantification of total scar area, BZ and dense scar area with assessment of conduction channels (CC) was performed.

Results

The substrate maps conSTANDARD vs conWAVE showed statistically significant differences in the total scar area (geometric mean 48, [95 % confidence intervals 32-72] cm^2 vs 43, [27-67] cm^2; p=0.013), dense scar area (26, [13-50] cm^2 vs 20, [9-42] cm^2;

p=0.001) and number of CC (3.0, [1.9-4.5] vs 4.0, [2.4-6.8]; p=0.010). conWAVE collected more points than the conSTANDARD settings (p<0.001), however used fewer points in map construction (p<0.001).

Conclusions

The multipolar Advisor™ HD Grid Mapping Catheter in conWAVE provides more efficient point acquisition and greater VT substrate definition of the borderzone particularly at the low voltage range compared to conSTANDARD. This greater resolution within the low voltage range facilitated CC definition and quantification within scar, essential in guiding ablation strategy.

INTRODUCTION

Mapping strategies have evolved from entrainment and pacing manoeuvres during Ventricular Tachycardia (VT), towards contemporary approaches applied on the basis of substrate mapping during sinus or paced rhythm.[1–3] Initially developed for hemodynamically unstable VT and recurrent VT with multiple morphologies, substrate mapping has been endorsed as the method of choice to guide ablation.[4] Indeed with the advantage of avoiding potential complications related to the repeated induction of VT, substrate ablation has consistently shown efficacy in achieving both intra-procedural success and long-term freedom from arrhythmias.[5] The cornerstone of substrate mapping and ablation strategy is the accurate delineation of scar architecture and identification of slow conduction channels and abnormal electrical electrograms (EGMs), which provide the potential for arrhythmogenicity. Indeed defining diastolic slow conduction channels within the borderzone and low voltage regions of scar dependent re-entrant VT is important for effective substrate mapping and ablation strategies.[6–8]

To facilitate substrate mapping, catheters with multiple electrodes have been introduced capable of creating high-density maps increasing the near-field and reducing far-field signals thereby allowing a better definition of the substrate.[9] Multipolar catheters enhance not only map density but can also provide wave-front directional assessment.[9] Bipolar catheter EGMs are dependent on electrode orientation respective to wave-front propagation. The complex electroanatomical remodeling of human myocardial scar[10,11] results in wave-front depolarisation in rapidly changing directions; consequently the amplitude of EGMs recording can change accordingly to the vector line of assessment. As a result, bipolar catheters reliant on single vector orientation may not identify low voltage EGMs propagating orthogonal to the catheter orientation therefore omitting important myocardial arrhythmic substrate.

The newly developed Advisor™ HD Grid Mapping Catheter (HD GRID) is a multipolar catheter with multiple electrodes equally interspaced along each spline and arranged in a grid configuration (16, 1mm electrodes in a 4X4 3mm arrangement).[12] This allows simultaneous bipolar recordings along and uniquely across different orthogonal vectors when the mapping software is set in the bi-directional WAVE configuration (conWAVE) while in the standard bipolar configuration (conSTANDARD) maintains fixed linear spline bipole recordings. Considering the multi-directionality recording of conWAVE and selective signal utilisation software features, we hypothesized that conWAVE would provide a more accurate definition of the scar area, border zone and conduction channels compared to conSTANDARD. The purpose of this study was to determine the relative importance of conWAVE compared to the conSTANDARD linear-only bipolar configuration in defining VT substrate in a cohort of VT ablation patients.

METHODS

Patient population

Patients who underwent consecutive catheter ablation for VT from March 2018 to December 2018 at the University Hospital Coventry & Warwickshire with substrate mapping using the HD GRID were included in the study. All adult patients (≥ 18 years) were listed having been discussed at an arrhythmia multidisciplinary team meeting. For structural heart VT, indications included symptomatic VT despite medical therapy, three or more episodes of VT within 24 hours, at least 3 episodes of VT requiring anti-tachycardia pacing or at least one defibrillator shock. All patients provided written consent prior to the procedure. Approval for the study was provided by our Local Audit and Research Department. The study applied the principles of the declaration of Helsinki.

Substrate mapping protocol

All ablation procedures were performed under conscious sedation with selective procedures under general anaesthesia where procedural risk was deemed high. Imaging was performed in all patients prior to the procedure to rule out the presence of intra-cardiac thrombus. All patients were administered intravenous unfractionated heparin to maintain an activated clotting time of ≥250 s prior to left ventricle (LV) access. Endocardial access to the LV was obtained via trans-septal access and retrograde aortic approach in all patients. Epicardial access was obtained in selected cases using the standard subxyphoid approach described elsewhere prior to systemic anticoagulation.[13]

Electro-anatomical substrate and activation mapping was performed using the Ensite NAVX/Velocity/Precision (Abbott Medical, Inc., Minneapolis, MN) system. The HD GRID, which has equidistant spacing of 16, 1mm electrodes in a 4X4 3mm interspaced arrangement, was used for mapping in sinus or paced rhythm. Substrate mapping performed in conWAVE was used to guide ablation strategy. Dense scar regions were defined as areas with bipolar electrogram voltage ≤0.5 mV and scar border zone areas as those with a low bipolar voltage between 0.5 and 1.5 mV. Conduction channels were defined as conducting corridors of voltage differences detected by scanning at different voltage thresholds inside the scar area (0.2 mV–0.3 mV–0.4 mV–0.5 mV bipolar voltage) of the low-voltage tissue (< 1.5mV bipolar voltage) with at least 1 late activation signal electrogram inside this corridor. Ablation strategy was a substrate guided approach targeting early late decrementing potentials and conduction channels. If VT was hemodynamically stable then activation mapping was additionally used to guide ablation. Acute success was defined as termination of clinical VT with failure to induce clinical VT or VT with a longer tachycardia cycle length with 3 extra-stimuli from 2 sites.

Data analysis

Post-procedure off-line analysis using the turbo-mapping function was carried out to construct a substrate map based on the Standard configuration (conSTANDARD). A quantitiative assessment of the substrate maps was performed in patients with structural heart VT by a physician blinded to the procedure and configuration used. Total scar area (TSA), borderzone area (BZA), dense scar area (DSA) and number of conduction channels were determined in each chamber using the Ensite Precision™ measurement tools for perimeter tracking and area calculation. The area of electroanatomical scar and low voltage area was provided in absolute value (cm^2). The primary end-point of the study was to determine whether conWAVE altered VT substrate definition compared to conSTANDARD in relation to total, dense scar and borderzone areas. Secondary end-point were: the total number of points collected and total number of points used to construct maps were collected for each patient; the proportion of points used (as a percentage) of the total points collected in map construction was determined.

Statistical analysis

Continuous variables were tested for normality using the Kolmogorov Smirnov test. Normally distributed data was expressed as mean±standard deviation. Non-normally distributed data was logarithmically transformed and expressed as geometric mean and 95 % confidence intervals (CI). Categorical variables were expressed as frequency (percentage). Group differences were tested using paired t test. P value<0.05 defined statistical significance. Statistical analysis was performed using SPSS Version 22 (IBM, New York, USA).

RESULTS

Thirteen patients (70±11 years, 9 male) underwent VT ablation and were included in the study; of which 10 had structural heart disease (7 ischemic cardiomyopathy, 2 dilated cardiomyopathy, 1 ARVD) and 3 had normal heart outflow tract tachycardia. Mean ejection fraction was 39±13 %. All patients were taking betablockers and 69 % Amiodarone. This was the first ablation procedure for all patients aside from one patient with ischemic cardiomyopathy who had a prior failed ablation. Endocardial mapping was performed in all patients aside from one patient with ARVD where epicardial mapping was performed. The mean fluoroscopy and procedural times were 34±12 mins and 325±126 mins respectively. In all patients the procedure was acutely successful with no complications. In total, 15 substrate maps were performed in 13 patients. In 2 patients both right and left ventricles were mapped.

Points Collected

The total number of points collected was significantly greater in conSTANDARD (geometric mean 12 148, [95 % CI 4968-29 696]) compared to conWAVE (19 570 [8147-47 000]; $p<0.001$) (Figure 1). There were significantly more points used in conSTANDARD (1884 [995-3566]) compared to conWAVE (1676 [855-3284]; $p<0.001$). The proportion of points used/points collected was significantly lower using the conWAVE configuration (8.6 [5.6-13.0] %) compared to conSTANDARD (15.5 [10.0-24.0] %; $p<0.001$).

Substrate Analysis of Scar area

Eleven substrate maps from 9 patients were used in the final anaylsis. Four maps were not used due to absence of scar (n=3, outflow tract VT) and technical failure (n=1, ARVD). TSA was significantly larger in conSTANDARD (48 [32-72] cm^2) compared to conWAVE (43 [27-67] cm^2; p=0.013) (Figure 2). DSA was significantly larger in conSTANDARD (26 [13-50] cm^2) compared to conWAVE (20 [9-42] cm^2; p=0.001). BZA was similar when mapped in conSTANDARD (18 [38-75] cm^2) and conWAVE (19 [12-28] cm^2; p=0.756) however the proportion of BZA to TSA was significantly greater in conWAVE (43 [33-58] %) compared with conSTANDARD (38 [28-51] %; p= 0.041). Conversely, the proportion of DSA to TSA was significantly lower in conWAVE (46 [30-70] %) compared to conSTANDARD (54 [38-75] %; p=0.023).

Conduction Channel identification

A greater number of conduction channels were identified using conWAVE (4.0 [2.4-6.8]) compared to conSTANDARD (3.0 [1.9-4.5]; p=0.010). conWAVE showed all the channels identified with conSTANDARD. Analysis of the additional channels identified using conWAVE demonstrated a total of 87 points used to define the channels of which 81 points (93%) were orthogonal vector points. Figure 3 is a representative example of a conduction channel identified with voltage screening and the 4 points which have identified the channel are all orthogonal vector points.

DISCUSSION

Our study has shown that the HD GRID in the WAVE configuration compared to a standard linear multipolar configuration provided greater VT substrate definition and more efficient point acquisition. Major differences were observed in the substrate maps obtained in conWAVE compared to conSTANDARD, as summarised in Figure 3. Total scar sizes and dense scar area were significantly smaller in conWAVE resulting in a much larger proportion of the total scar being represented as borderzone in the WAVE configuration. Accordingly, conWAVE appears to better define the borderzone at the low voltage range where conduction channel definition within scar is evident.

Our study we believe is the first reported in human data of the HD GRID mapping catheter in patients undergoing VT ablation. Previously, Takigawa et al.[14] assessed the effect of bipolar orientation on voltage and distribution of LAVAs in 7 sheep with myocardial infarction using the HD-32 Grid. They demonstrated significant differences in the bipolar voltage and distribution of LAVAs between diagonally orthogonal vectors (north east v south east). These differences were demonstrated despite no change in the orientation of the HD-32 Grid catheter

Conduction Channel Identification

We have shown a 30% increase in number of conduction channels identified with voltage scanning in the low voltage range using conWAVE compared to conSTANDARD. Furthermore, we have shown that the orthogonal vector was critical in defining these additional conduction channels as the points were almost exclusively orthogonal vector points. Identification and elimination of conduction channels as a mapping and ablation strategy has become an established technique.[15] Our study showed that the WAVE configuration facilitates this approach. These findings support the notion that the standard recording from a fixed bipolar electrode may underestimate the amplitude of signals with a wave front propagation not perpendicular to electrode orientation.

Brunckhorst et al, assessed in a case series of 11 patients with VT and ischemic cardiomyopathy, the changes in the electrogram amplitude recorded by a fixed bipolar electrode according to the direction of the wave front of activation.[16] The authors obtained a variation in the wave front propagation by pacing sequentially from the atrium and the ventricle and detected a difference in the electrogram amplitude greater than 50% in more than 28% of the sites.[16] Of note the authors reported that such recording difference was less relevant for area of low voltage (<1.5 mV). However, the authors stated that the variation of the wave front propagation in relation to the orientation of fixed bipolar electrode may impact the size and shape of the mapped scar.[16]

More recently, Tung et al.[17] assessed the impact of different wave front propagation on the substrate mapping of 23 patients undergoing VT ablation. Substrate maps were performed in sinus rhythm, and during pacing from the right and left ventricle and biventricular pacing; the signals were recorded in unipolar and bipolar mode. The authors observed a significant difference in the size of the scar area mapped with the change in the wave front activation.[17] Most importantly such difference were more relevant for mixed scar (defined by scar with dense scar <10 cm2) and septal scar. Remarkably, the authors reported a discordant distribution of the critical sites between scar area and vital myocardium with different front of activation.[17]

The HD Grid catheter acquires simultaneous signals across orthogonal planes and provides a more thorough evaluation of electrogram amplitude and direction. We have previously shown that VT exit sites constitute a specialized region of the borderzone in which clusters of cardiomyocytes are bridged via high numbers of stromal cells providing the necessary coupling between dispersed cardiomyocytes resulting in slow conduction.[18] Histological analysis of these exit sites and borderzone conduction channels show that the cellular arrangement is non-linear, in a zig-zag arrangement[10,18] and conWAVE facilitates electrogram directionality assessment thus enhancing the identification of conduction channels. By better defining the borderzone, largely by accurately delineating and reducing the proportion of the dense scar zone, we have shown that the area in which conduction channels are identifiable is made larger. Conventional substrate guided ablation strategies have targeted the interface between healthy myocardium and borderzone where VT exit sites are found; conWAVE does not significantly impact the delineation of this zone.

The complete elimination of all the substrates responsible for VT occurrence is an additional step to reduce VT recurrence[3]; a strategy based on the assumption that the substrate not participating in VTs at the time of ablation could activate and become part of a VT isthmus during follow-up. Substrate mapping during sinus or paced rhythm permits the characterization of scar areas supporting possible reentry circuits of VTs namely conduction channels. Berreuzo et al demonstrated high acute VT noninducibility rates by combining the targeting of conduction channels with a conventional ablation approach.[15] Long-term recurrences of sustained VT episodes were observed in 26% of patients over 2 years and the only independent predictor of any sustained VT episode was incomplete conduction channel elimination. Although we do not currently have long term follow up data, in all our cases acute VT non-inducibility was achieved. The enhanced definition of the borderzones and the identification of a greater number of conduction channels provided by the conWAVE setting may have facilitated this.

Point Acquisition Differences

Our data has shown major differences in point acquisition with conWAVE compared to conSTANDARD. Analysis of the point usage shows that conWAVE is a far more efficient mode in data acquisition for substrate map generation. The greater number of points collected is not surprising as both linear bipolar and orthogonal bipolar vectors are included in conWAVE. However, conWAVE filters to a greater extent using overall less points than conSTANDARD as the conWAVE workflow seeks to utilise best signal quality resulting in less points used for map creation.

Limitations

The main limitation of our study is that this was a non-randomised study of a small population. Furthermore, all procedural maps were constructed in the conWAVE configuration to guide ablation. The ability of the HD Grid system to perform a post-hoc map in the conSTANDARD setting is a strength allowing to control potential confounding factors (e.g. variations in patient anatomy, catheter location and operator). Although the analysis of the substrate maps was performed blind, differences in map geometry may have been seen had initial maps been constructed in the conSTANDARD configuration. This study did not assess the impact of mapping configuration on patient outcomes. Further evidence is needed to confirm whether the differences in mapping observed in this study translate into improved patient outcomes.

Conclusion

The multipolar Advisor™ HD Grid Mapping Catheter using the additional orthogonal vector bipolar electrogram configuration compared to a standard linear multipolar configuration provides more efficient point acquisition and greater VT substrate definition of the borderzone. This greater resolution within the low voltage range facilitates conduction channel definition and quantification within scar which is important in guiding ablation strategy.

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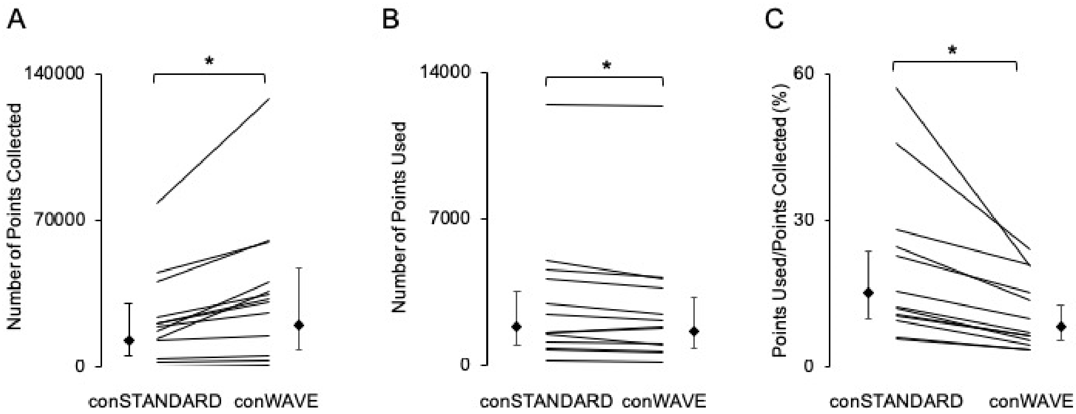
FIGURES

Figure 1. Whisker plots (group data, geometric mean and 95 % confidence intervals) and line graphs (individual data) demonstrating a greater number of points collected (A) but fewer points used (B) with conWAVE compared to conSTANDARD settings resulting in a smaller proportion of points used (C). * P<0.001.

Figure 2. Whisker plots (group data, geometric mean 95 % confidence intervals) and line graphs (individual data) demonstrating (A) TSA, (B) DSA, (C) BZA, (D) BZA/TSA, (E) DSA/TSA and (F) total number of oncduction channels identified with conSTANDARD and conWAVE settings. BZA borderzone area, DSA dense scar area, TSA total scar area. *P<0.05.

Figure 3. The HD Grid catheter simultaneously acquires signals across orthogonal planes which may provide a more proper assessment of electrogram voltage, independent of the directionality of the activation front.

Figure 4. Substrate maps performed in conSTANDARD and conWAVE mode. In the yellow circle an area of viable myocardium is identified in the conWAVE mode, which was detected as dense scar in the conSTANDARD mode. In the white circle a conduction channel can be seen in the conWAVE map which was included in the dense scar in the conSTANDARD mode.



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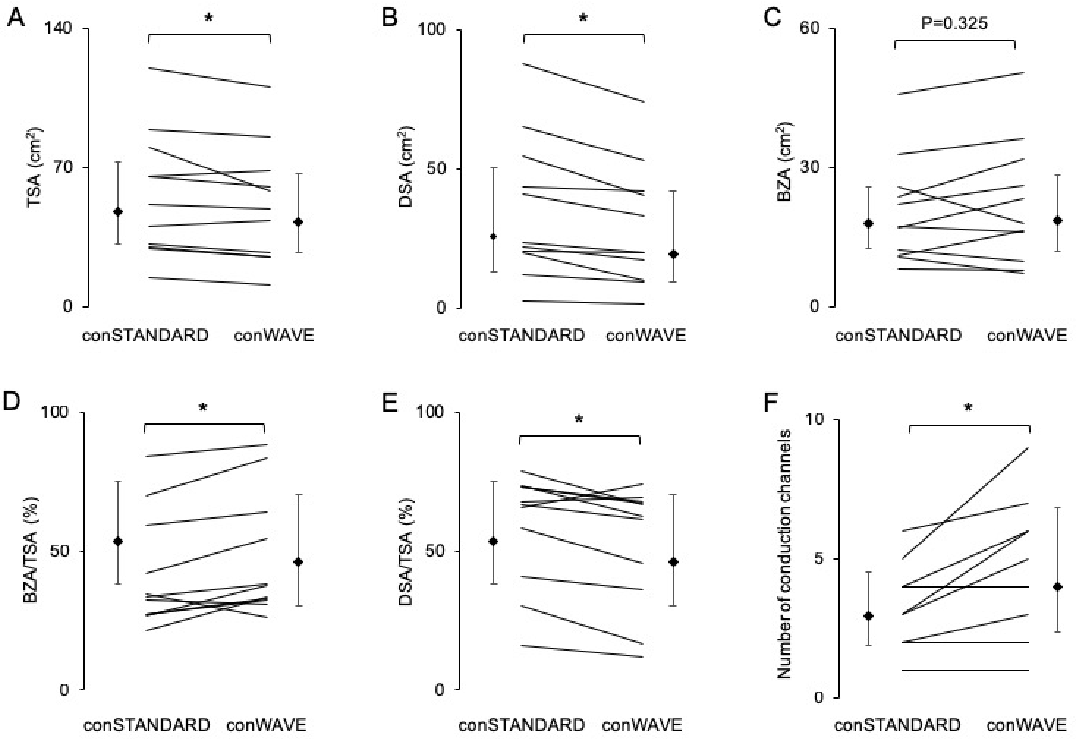

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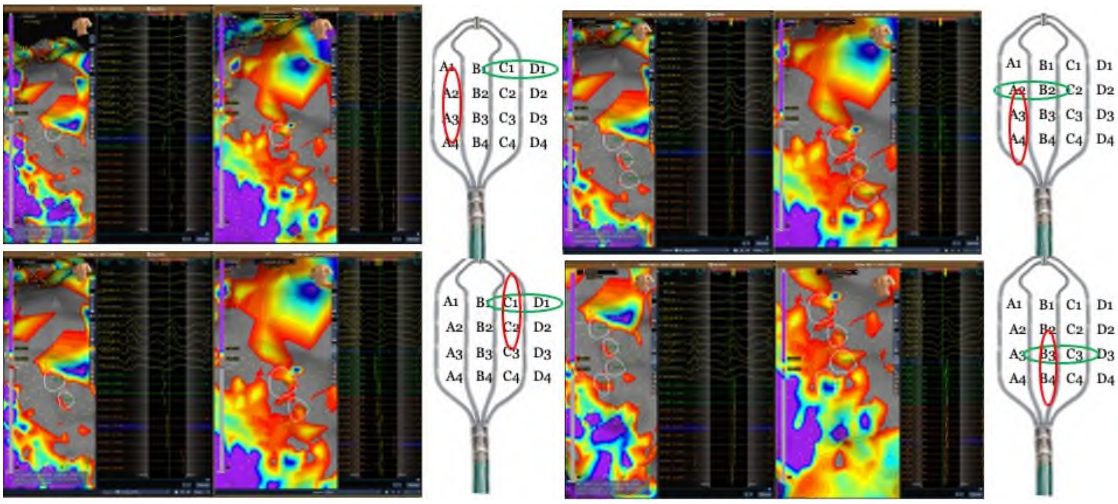

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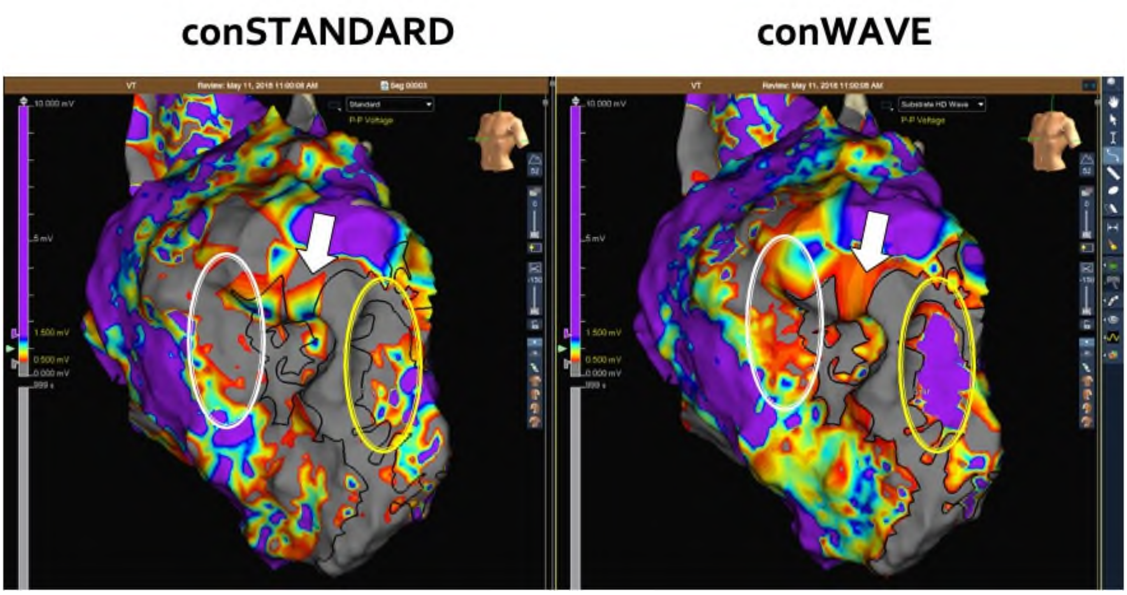

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