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RESEARCH LETTER

Optimization of decrementing evoked potential mapping for functional substrate identification in ischaemic ventricular tachycardia ablation

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Ventricular tachycardia (VT) ablation approaches based on high-density mapping, which enable the rapid acquisition of thousands of mapping points in order to delineate slow conduction zones, have been widely adopted.[1] The identification of functionally relevant substrates has been advanced by the identification of potentials participating in the initiation and/or maintenance of scar-dependent VT. During right ventricular apical (RVA) pacing with an extra-stimulus (S2), these potentials display delayed conduction (decremental) behaviour (DeEP).[2] This methodology has been shown to be more specific in identifying the critical isthmus of re-entrant VT.[3] An important factor accounting for decrement is conduction velocity (CV) restitution.[2] With a short-coupled S2, CV will decrease, and further delay occurs in the near-field signal with respect to the far-field signal, creating DeEPs. Conventionally, the S2 has been delivered at ventricular effective refractory period (VERP) + 20 ms to elicit decrement.[3–5] However data are lacking on justifying the delivery of the S2 at VERP + 20 ms, which may result in areas defined as DeEP due to intrinsic CV restitution properties, thus creating larger-than-required ablation target areas. We hypothesized that DeEPs are better identified with longer S2 coupling intervals. The second hypothesis was to consider the definition of a DeEP as the range of decrement beyond 10 ms has not been previously explored and to identify the best combination of these parameters.

Patients with post-myocardial infarction VT were prospectively recruited at the University Hospital Coventry. To minimize bias/errors in the sensitivity/specificity analyses, patients with one clinical VT were included. Cardiac mapping was performed with the HD Grid catheter (Abbott, Des Plaines, IL, USA). Voltage maps in sinus rhythm and DeEP maps were collected sequentially. Following a two-beat drive train of 600 ms, DeEP mapping was performed using three S2 coupling intervals: (i) 400 ms (DeEP-400); (ii) clinical VT cycle length (DeEP-VTCL); and (iii) VERP + 20 ms (DeEP-VERP). The VT exit sites were identified based on VT activation maps. Ablation was delivered at manually tagged DeEP-400 sites. Post-ablation, standard VT inducibility testing was performed.[3–5] The endpoint was the non-inducibility of all monomorphic VT, and post-procedure implantable cardioverter defibrillator data were collected for 6 months.

Omnipolar EGMs were exported for bespoke offline analysis using EnPlot (v3.4, J Winter) to create DeEP maps based on differences in S1 and S2 EGM duration. The figure shows example substrate and VT activation maps with the corresponding offline-generated DeEP maps (purple area). The DeEP maps were constructed with decrement thresholds ranging from 10 to 50 ms in 10 ms increments for the three S2 coupling intervals. Percentage DeEP map areas were calculated as a proportion of the total mapped area. The VT exit site was used for comparison with the DeEP maps. To derive DeEP map diagnostic accuracy measures (sensitivity and specificity), points located ≤5 mm from the VT exit site were considered to co-localize the VT exit site.

Baseline characteristics are listed (*Table 1*). A total of 195 DeEP maps were analysed from 13 patients. There was a significant and sequential decrease in the S2 coupling intervals (DeEP-400, 400 ms vs. DeEP-VTCL, 353 ± 48 ms vs. DeEP-VERP, 300 ± 20 ms) ($P < 0.0001$). No clinical or non-clinical VT was inducible post-ablation.

DeEP maps analysed using the 10 ms decrement threshold demonstrated no difference in measured DeEP areas between the groups; however, DeEP-400 performed better than DeEP-VERP at colocalizing the VT exit site (sensitivity 92.3 vs. 76.9%; specificity 67.8 vs. 59.2%). The definition of DeEP was altered from the standard >10 ms to multiple thresholds of >10 to >50 ms in 10 ms increments. For all three DeEP maps, sensitivity decreased, while specificity increased for larger thresholds (*Figure 1*). The optimal threshold where the sensitivity and specificity curves crossed was >20 ms. The receiver operating characteristic curve area under curve was 0.88, 0.83, and 0.77 for DeEP-400, DeEP-VTCL, and DeEP-VERP, respectively. The DeEP maps were re-analysed using the >20 ms decrement threshold. The absolute DeEP and percentage DeEP areas were smaller in the DeEP-400 maps (20.6 ± 10.0 cm^2, 17.0 ± 7.0%) than in the DeEP-VERP maps (34.7 ±

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Table 1 Baseline and procedural characteristics

Age at ablation, years	70 ± 12
Male sex, *n* (%)	13 (100)
Ethnic background	
Caucasian, *n* (%)	12. (85)
South Asian, *n* (%)	2 (15)
Past medical history	
AF/flutter, *n* (%)	5 (38)
Hypertension, *n* (%)	4 (31)
Diabetes, *n* (%)	5 (38)
COPD, *n* (%)	0 (0)
Cerebrovascular disease, *n* (%)	1 (8)
CABG, *n* (%)	1 (8)
CKD, *n* (%)	7 (54)
ICD, *n*	1
S-ICD, *n*	1
CRT-D, *n*	11
Pre-ablation ATP, *n*	57
Pre-ablation shocks, *n*	55
Mean LVEF, %	30 ± 12
NYHA classification	
I, *n* (%)	1 (8)
II, *n* (%)	7 (54)
III, *n* (%)	5 (38)
IV, *n* (%)	0 (0)
VT cycle length (mean), ms	353 ± 48
VERP + 20 ms (mean), ms	300 ± 20
Amiodarone, *n* (%)	10 (77)
B-blocker, *n* (%)	13 (100)
Mexiletine, *n* (%)	1 (8)
Mean procedure time, min	218 ± 38
Mean fluoroscopy time, min	30 ± 9
Mean number of RF lesions, *n*	50 ± 22
Mean RF time, min	23 ± 13
Mean substrate map points used, *n*	2468 ± 707
Clinical VT induced, *n* (%)	13 (100)
Late potentials identified, *n* (%)	13 (100)
Decrementing evoked potentials mapped, *n* (%)	13 (100)
VT exit isthmus identification, *n* (%)	13 (100)

Continued

AF, atrial fibrillation; ATP, adenosine triphosphate; CABG, coronary artery bypass graft surgery; CKD, chronic kidney disease; CRT, cardiac resynchronization therapy; COPD, Chronic obstructive pulmonary disease; ICD, implantable cardioverter defibrillator; NYHA, New York Heart Association classification; RF, rheumatoid factor; S-ICD, subcutaneous implantable cardioverter defibrillator; VT, ventricular tachycardia.

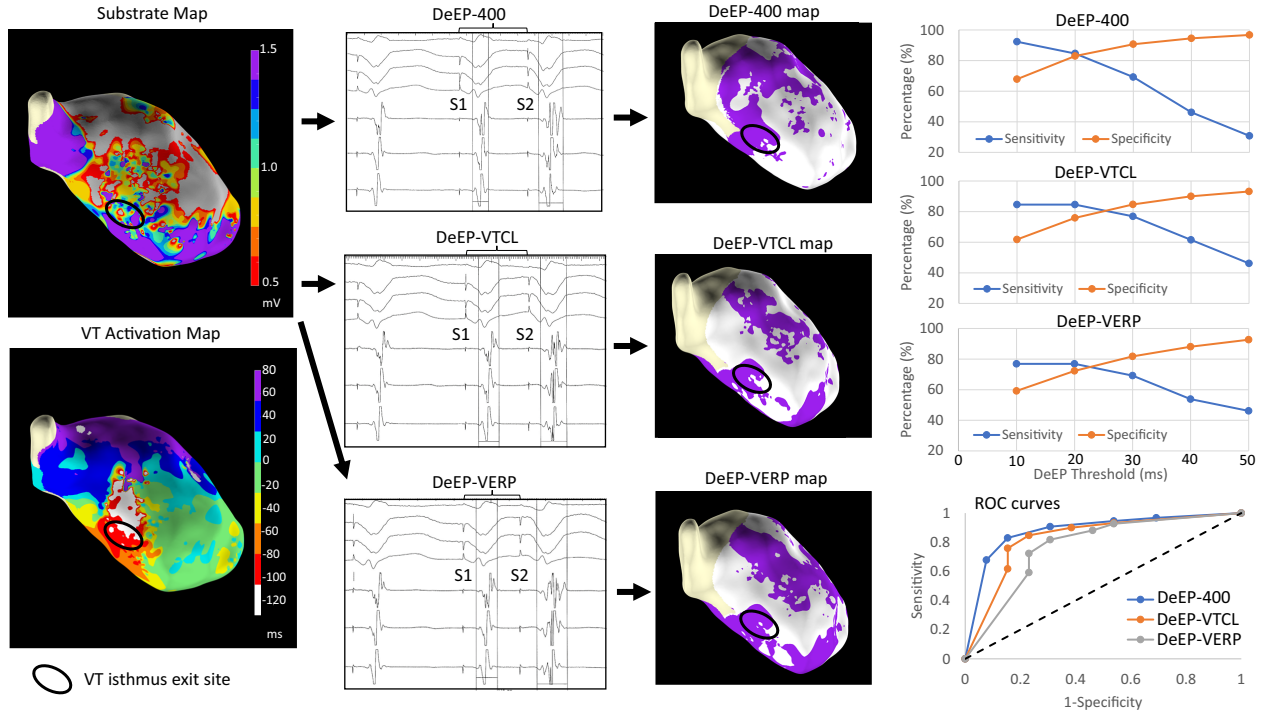

Figure 1 Study Workflow and example offline generated Decrementing Evoked Potential (DeEP) maps with corresponding sensitivity/specificity analyses.

20.9 cm^2, 27.7 ± 12.7%) ($P = 0.016$). Collectively, DeEP-400 with decrement >20 ms provides the greatest diagnostic performance.

In the 6 months pre-ablation, 57 anti-tachycardia pacing episodes and 55 shocks occurred. Six months post-ablation, the mean VT burden reduced from 9 to 0.5 events/patient; mean shock/patient burden decreased from 4.6 to 0 with a 92% freedom from device-detected VT.

The primary study findings are: (i) DeEP signals are best defined by decrement >20 ms; and (ii) DeEP areas are co-localized more accurately to the VT exit site with a 400 ms S2. Delivering the S2 at the conventional VERP + 20 ms using a 10 ms decrement threshold yielded a sensitivity of 76.9% and a specificity of 59.2%. With the S2 at 400 ms using a 20 ms decrement threshold, sensitivity remained high (84.6%) with improved specificity (83.0%), resulting in a 59% reduction in the ablation target area. Previous studies focused DeEP mapping to predefined areas of interest rather than mapping the entire ventricle.[2,3,5,6] This may overestimate the specificity, which improves when DeEP mapping is guided by additional substrate information. This mechanistic study was non-randomized and patients with one clinical VT were included. It is plausible that false-positive DeEPs are sites for future VT exit sites, and further studies in patients with multiple VTs/VT recurrences are ongoing. Automation of DeEP mapping will allow for rapid identification, enabling RCTs to investigate the following: (i) S2 delivery from non-RVA sites; (ii) performance in non-ischaemic substrates; and (iii) combining alternative functional substrate and pace mapping strategies with novel imaging approaches to improve substrate specificity.[7,8]

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Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

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