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Multipolar mapping with the high density grid catheter compared with conventional point by point mapping to guide catheter ablation for focal arrhythmias

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ABSTRACT

Background: Multipolar catheters provide high density mapping which may reduce procedural duration and improve success of catheter ablation (CA) for focal arrhythmias. The high density grid (HDG) catheter is a 16 electrode mapping catheter with bipole recordings at orthogonal splines. The aim of this study is to compare the

clinical and procedural features from a cohort who underwent CA for focal arrhythmias using multipolar mapping (MPM) with an age and case matched cohort using point by point (PbyP) mapping.

Methods: Consecutive patients undergoing CA for focal arrhythmias between October 2018 and January 2020 guided by MPM were compared with PbyP mapping with the ablation catheter over a similar period. Demographics, procedural features and outcomes were compared.

Results: 54 patients (27 in MPM vs 27 in PbyP mapping) underwent CA for 68 focal arrhythmias (26 atrial and 42 ventricular). In the MPM group the electrogram at the successful site was significantly earlier (39 +/- 11 ms) than in the PbyP group (33 +/- 7 ms; p =0.02). In the MPM group the mapping time (35 +/- 24 mins vs 53 +/- 31 mins in PbyP; p= 0.03) and procedural duration (126 +/- 42 mins vs 153 +/- 39 mins in PbyP, p = 0.02) were significantly shorter. There was no significant difference in radiofrequency and fluoroscopy times, acute procedural success, and arrhythmia recurrence.

Conclusion: Multipolar mapping with the HDG catheter for focal tachycardias identified earlier activation times and was associated with shorter mapping and procedure duration with equivalent success to PbyP mapping.

Key words: Multipolar mapping, point by point mapping, HD grid, focal, atrial tachycardia, ventricular tachycardia

INTRODUCTION

Catheter ablation (CA) is well established in the management of patients with symptomatic focal arrhythmias. Mapping has evolved from point by point (PbyP) mapping with a single catheter with a large dedicated bipole to multipolar catheters with smaller electrodes and closer interelectrode spacing[1]. These catheters offer the potential advantages of more rapid electrogram collection with higher density and improved resolution with focus on the area of interest. Additionally, pace mapping can be performed from multiple sites without further catheter manipulation at lower pacing outputs[1]. The success of catheter ablation for focal arrhythmias is often limited by variable inducibility or foci originating from multiple sites. In particular focal atrial tachycardias originating from the pulmonary veins[2] or appendages[3] are not typically inducible with programmed extra-stimuli and the success of ablation is often reliant on maximising mapping with limited ectopy.

The Advisor™ HD Grid catheter is a novel multi-electrode mapping catheter arranged in a 4 X 4 grid configuration which allows for orthogonal bipole recordings along and across its splines. Whilst its use had been reported in mapping scar related VT or complex atrial arrhythmias[4-6], the utility of the HDG catheter to guide ablation for focal arrhythmias has not been well described. The aim of the present study was to compare the procedural and clinical outcomes of mapping and ablation of focal arrhythmias using multipolar mapping (MPM) with the HDG catheter with a matched cohort using conventional PbyP mapping.

METHODS

Study design

This was a multicentre, observational, case-control study comparing the outcomes between multipolar mapping (MPM) using the HDG catheter (Abbott Medical, Abbott Park, IL, USA) and PbyP mapping in patients with focal atrial and ventricular arrhythmias between October 2018 and January 2020. Consecutive patients were identified across 5 centres in Melbourne and Adelaide, Australia. An age and case-matched control cohort utilizing PbyP mapping for focal arrhythmias was identified over a similar time period. The same operators were responsible for all cases and the use of PbyP or MPM was at operator discretion. Patients with atrial fibrillation or known structural heart disease were excluded aside from atrial tachycardia following prior pulmonary vein isolation (PVI). Clinical characteristics, echocardiographic parameters and procedural details for all patients were obtained from medical records. Written informed consent was obtained in all cases as part of routine clinical care. Analysis of this data was approved by the hospital ethics committee of the institutions.

Mapping and procedural details

Catheter ablation was performed under conscious sedation, with general anaesthesia utilised where clinically indicated. Anti-arrhythmic drug (AAD) therapy was withheld for 5 doses prior to the ablation procedure. Catheter ablation for focal arrhythmias has been previously described[7]. In brief, a standard steerable decapolar was positioned within the coronary sinus (CS) and a quadripolar catheter at the His position. Attempts at arrhythmia induction were made including programmed extra-stimulation and burst pacing. If this was unsuccessful or when ectopy or tachycardia was not

occurring spontaneously, isoproterenol was infused at rates of 2-20mcg/min. Anatomic localisation of the responsible focus involved careful analysis of an unencumbered P wave or QRS. Mapping to locate site of earliest endocardial activation relative to surface P-wave onset was then performed using either a 3.5mm tip mapping/ablation catheter or multipolar mapping catheter. For atrial arrhythmias a fiducial point on a stable intracardiac electrode, usually the CS catheter, relative to P-wave onset was defined to perform point mapping. For ventricular arrhythmias the reference was the QRS onset. Automated collection of local activation time (LAT) points was utilised, annotated to the first rapid deflection from the baseline bipolar electrogram. All points were manually reviewed offline to ensure correction annotation for electrogram analysis. Focal mechanism was confirmed if mapping showing centrifugal activation from central source. Activation mapping and entrainment were used for sustained tachycardia to confirm a focal mechanism. Following mapping and ablation a waiting period of up to 30 minutes, along with a repeat of induction manoeuvres, were used to look for recurrence of arrhythmia

Multipolar mapping (MPM)

The Advisor^{TM} HDG catheter used in the study cohort is a steerable, irrigated 16 electrode catheter consisting of 4 splines oriented parallel to each other. The 1 mm sized electrodes are arranged in a 4X4 grid configuration with equal (3 mm) edge-to-edge inter-electrode spacing, including on adjacent splines. The equi-spaced grid design allows for bipolar electrogram (EGM) creation along the splines and at orthogonal directions. During mapping flexion of the splines as visualized on three dimensional (3D) mapping and / or fluoroscopy was used to confirm sufficient contact with the endocardium[8]. 3D mapping was performed using the Ensite^{TM} Precision/

Velocity™ electroanatomic mapping system (EAM) (Abbott Medical), with interior projection setting set at 7 mm and bipolar signal filtering at 30-500 Hz. The Ensite™ EAM incorporates the HD Wave solution and Best Duplicate Algorithm (BDA) to select the EGM with the largest amplitude at orthogonal bipoles[4, 8] within a 1mm zone. All ablations in the HDG cohort were performed using the irrigated, contact force sensing TactiCath™ SE catheter, with a contact force between 10g and 25g. Power settings utilized were as per operator discretion, typically 25-40 W for atrial ablation and 30-40 W for ventricular ablation.

Point by point (PbyP) mapping cohort

The PbyP cohort was obtained from the hospitals' databases over the same time period and were matched by age, case type (atrial or ventricular arrhythmia)), and location (left or right sided). All cases involved the use of the Ensite™ (Abbott Medical) or CARTO™ (Biosense Webster, Diamond Bar, California) 3D mapping systems and an irrigated contact force sensing ablation catheter.

Electrogram analysis

Electrograms at sites of earliest activation were individually reviewed off line to ensure correct annotation to unencumbered P wave onset for atrial arrhythmias, and QRS onset for ventricular arrhythmias. The electrogram morphology was reported at the site of earliest EGM, in particular the presence of fractionation (defined as ≥ 3 deflection over >50 ms interval)[9], as well as unipolar QS morphology (defined as a rapid descending Q wave from the isoelectric baseline without visible initial R wave on the unipolar EGM)[10]. Once mapping was completed with the MPM catheter the ablator was advanced to the earliest location annotated on the 3D map and further refined with activation timings from the map.

Procedural success was defined as non-inducibility of any atrial or ventricular arrhythmia post ablation with the prior manoeuvres which had been responsible for inducibility.

Follow-up and rhythm confirmation

All patients included in the study were prospectively followed up after their last ablation procedure through clinic visits and/or telehealth consultation. Data regarding AAD continuation, and arrhythmia recurrence were collected based on medical records. Follow-up rhythm was confirmed via electrocardiograms during clinic visits, pre-existing cardiovascular implantable electronic devices (CIED), and 24-hour Holter monitors. Arrhythmia recurrence was defined as ectopy/ tachycardia documented on 12 lead ECG during clinical follow up; or symptomatic ectopy/ tachycardia captured on cardiac monitoring devices. Two clinicians and a research nurse, independent of the ablation procedures, collated and reviewed the data for completeness.

Statistical analysis

Categorical variables are expressed as proportion/percentage and compared using the χ^2 test. Parametric continuous variables were compared using the Student *t* test whilst non parametric variables were compared using the Mann Whitney U test. Data normality was assessed using the Kolmogorov- Smirnov test. $P < 0.05$ was considered statistically significant. Study analyses were performed using IBM SPSS Statistics 26 software.

RESULTS

Baseline characteristics

The study population included 54 patients (27 in the MPM and 27 in the PbyP groups). The total number of focal tachycardias mapped and targeted intra-procedurally was 35 in the MPM (11 atrial, 24 ventricular) and 33 in the PbyP (15 atrial, 18 ventricular) groups. Baseline characteristics are presented in **Table 1**. There were no significant differences between the groups in relation to underlying comorbidities, concurrent medications, and echocardiographic details. **Figure 1** illustrates representative cases of multipolar mapping and ablation. There was no significant difference in the cases performed with MPM versus PbyP between operators (p= 0.17).

Procedural characteristics

The mapping time was significantly shorter in the MPM group (35 +/- 24 mins vs 53 +/- 31 mins in the PbyP group; p= 0.03, see **Figure 2a**). Entrainment was used to guide mapping when tachycardia was sustained in 11 cases (31%) in the MPM and 12 cases (33%) in the PbyP groups. The procedure duration was significantly shorter in the MPM group (126 +/- 42 mins vs 153 +/- 39 mins in PbyP group, p = 0.02, see **Figure 2b)**. There was no significant difference in the radiofrequency (RF) ablation or fluoroscopy times between groups. Comparison between the MPM and PbyP groups stratified according to chamber of origin are presented in **Table 2**. For ventricular arrhythmias in the MPM group, procedure duration (128 +/- 35 mins vs 157 +/- 43 mins in PbyP group, p= 0.04) was significantly shorter.

Electrogram characteristics

The electrogram at the successful site was significantly earlier in the MPM group (39 +/- 11 ms vs 33 +/- 7 ms in the PbyP group, p =0.02; see **Figure 2c).** There was no significant difference in the presence of fractionation or a unipolar QS morphology at the site of earliest activation between the groups (**Table 3**).

Within the MPM group, the earliest activation time detected by the MPM catheter was compared with the earliest time detected by the subsequent use of the ablation catheter, within the same case. The earliest activation time was 39 +/- 10 ms on the MPM catheter vs 35 +/- 13 ms on the ablation catheter (p = 0.23).

In the MPM group, EGMs from orthogonal bipoles on the HDG catheter were available for review in 27 focal tachycardias to compare activation times recorded *along* (for example A1-B1) as opposed to *across* (for example A1-A2) adjacent bipoles. The earliest activation time was recorded from bipoles across splines in 11 (41%) and from bipoles along splines in 10 (37%). There was no difference in activation time between orthogonal bipole orientations in the remainder (n= 6) (**Figure 3)** The mean activation time recorded from the earliest bipole *along* the spline (40 +/- 15 ms) was not significantly different to *across* the spline (39 +/- 14 ms, p =0.8).

Clinical outcomes

Acute success was achieved in 85.2% in the MPM group compared with 81.4% in PbyP group (p=0.60). In the MPM group, acute success was not achieved due to multifocal changing activity (n= 3) and ectopy recurrence (n=1). In the PbyP group, this was due to multifocal site (n=2), ectopy recurrence (n=3). There was no intra or

post procedural complication. At a mean follow up of 9.4 ± 4.6 months recurrent arrhythmia in patients with acute success was present in 2 patients (1 AT, 1 VT) in the PbyP group compared with 2 patients (2 VT) in the MPM group (p = 0.97)

DISCUSSION

In the present study we compared the use of multipolar mapping (MPM) with the HDG catheter to conventional point by point (PbyP) mapping for ablation of focal arrhythmias in the absence of structural heart disease. Multipolar mapping was associated with:

1) a significantly earlier electrogram at the site of successful ablation;
2) a significant reduction in mapping and procedural duration;
3) no significant difference in acute procedural or long term success of catheter ablation.

MPM represents a significant technological advancement in localising and targeting complex cardiac arrhythmias and are routinely used in catheter ablation for atrial fibrillation and VT in the presence of structural heart disease. More recently the importance of non-pulmonary vein triggers has been recognised in improving the success of catheter ablation for atrial fibrillation[(11)]. Often just a single beat is available before the onset of atrial fibrillation with multipolar mapping fundamental to the accurate targeting of the responsible trigger[(12)]. The role of multipolar catheters in focal arrhythmias in the absence of a diseased substrate is less well established. A number of catheter designs with considerable variation in size, spacing and number of electrodes have become available[(13-15)] and continue to evolve. Potential advantages of multipolar catheters include higher mapping resolution with less signal averaging and

cancellation effects from larger electrodes. Our findings confirm the effect of high resolution mapping with MPM identifying a significantly earlier electrogram at the successful site compared with the 3.5mm bipole of the ablation catheter. Josephson and colleagues demonstrated similar bipolar voltages in normal atria but significantly larger bipolar voltages in regions of low voltage using the PentaRay™ multipolar mapping catheter compared with conventional point mapping[1]. The atrial regions of low voltage were significantly smaller and the ability to pace within these zones was enhanced with a MPM catheter, attributable to greater mapping resolution with smaller more closely spaced electrodes. In contrast for ventricular tachycardia in structural heart disease, MPM has been shown to produce larger regions of low voltage but better delineation of conducting isthmuses and discrimination of late potentials [16-18]. The smaller region of low voltage seen with PbyP mapping in the ventricle may in part be explained by a more pronounced effect of far-field over-sensing from the adjacent ventricular myocardium with higher normal amplitudes compared with the thinner atrium [16]. Contact force, wavefront direction and the angle of the electrode tissue interface also impact on voltage amplitude and may vary between PbyP mapping and MPM and between chambers. Overall MPM catheters appear to improve the characterization of diseased substrate and arrhythmia mechanism, although the impact on outcome has yet to be subject to randomised trials[13].

Multipolar vs point by point mapping: prior studies

Prior clinical studies have demonstrated the role of MPM catheters for the treatment of atrial and ventricular arrhythmias in the presence of structural heart disease[19-22]. However, few studies have compared multipolar with conventional PbyP mapping.

Bun et al reported a significant reduction in mapping and ablation times with MPM using the PentaRay^{TM} for macro (69%) and focal AT following AF ablation. Arrhythmia recurrence was significantly less in the MPM group however the historical PbyP control group had all undergone ablation in a time period earlier than the MPM[23] and there were significantly difference in the incidence of focal tachycardias between the groups. In a case series of 24 adults undergoing catheter ablation for complex AT in the presence of congenital heart disease, MPM with the HD grid catheter was associated with an increase in acute procedural success compared to a historical cohort undergoing ablation without MPM[24]. Several studies have demonstrated shorter mapping times and procedure duration for catheter ablation for VT in the presence of structural heart disease assisted by MPM compared to historical controls undergoing PbyP mapping[18, 25]. However, a reduction in arrhythmia recurrence has not been demonstrated. In the present study over a comparative time period MPM for focal arrhythmias was associated with a significant reduction in mapping time and procedure duration.

Orthogonal bipole recordings in HDG catheter

Clinical studies have demonstrated the usefulness of the HD grid catheter in patients undergoing catheter ablation for atrial fibrillation and ventricular arrhythmias in structural heart disease[4-6, 8, 24]. A novel feature of the HDG catheter is an ability to create bipolar electrograms at orthogonal directions to account for the direction of wavefront propagation[4]. Previous studies have shown that the electrode orientation in relation to wavefront activation is in part responsible for the bipolar electrogram[21, 26]. If wavefront propagation is orthogonal to the orientation of the bipole it may be subject to a cancellation effect[27]. The effect of directionality on bipolar electrogram

amplitude has been previously demonstrated [28, 29]. In our study there were differences in the timing of the earliest electrogram between orthogonally opposed bipoles presumably related to the orientation to the propagation wavefront. The ability to incorporate activation timing according to mapping along or across splines did not impact procedural outcomes although the sample size was insufficient to determine this.

Clinical implications

The study was underpowered to determine if the earlier activation times recorded with MPM translate to improved outcomes compared with PbyP mapping. However the ability to record a wider area of the myocardium simultaneously from multiple bipoles and to accommodate wavefront directionality may be clinically meaningful with focal arrhythmias as mapping can be limited. Inducibility may be challenging, the origins multifocal and a single ectopic may result in atrial fibrillation when attempting to map non PV triggers. The later activation times with PbyP mapping may reflect an inability to identify the exact same local site identified by MPM although this effect is likely not large given a relatively small absolute difference in timings effect.

Study Limitations

There are several limitations with this study. This was a non- randomised study although the control population was undertaken over a similar time period, which was a distinct difference to earlier studies. The use of a MPM catheter was at the operators' discretion and may reflect a difference in arrhythmia complexity. Additionally, the 3D mapping system utilized varied in the PbyP group but not the MPM group.

CONCLUSION

Multipolar mapping with the HD grid catheter for focal arrhythmia identified earlier activation times and shorter mapping and procedure duration when compared with point by point mapping over a similar time period. There was no significant difference in acute success and medium term outcomes. Randomised studies are required to determine whether multipolar mapping improves outcomes for ablation of focal arrhythmias.

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FIGURES

Figure 1: Multipolar mapping using the HDG catheter in focal AT and VT ablation

Figure 1A (modified AP view): Activation mapping showing focal AT localised to mitral annulus with earliest EGM on D3-D4 (arrow) with significant fractionation

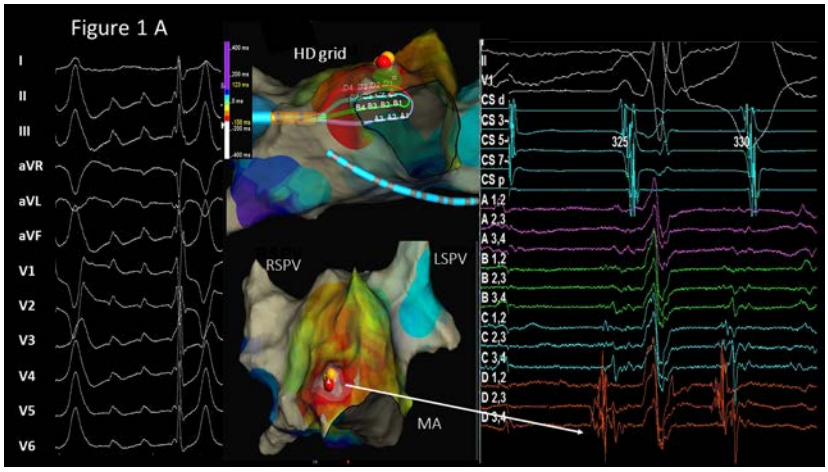


Figure 1B (modified LAO view): Focal VT at mid anterior right ventricle with earliest EGM on D3-D4 (arrow)

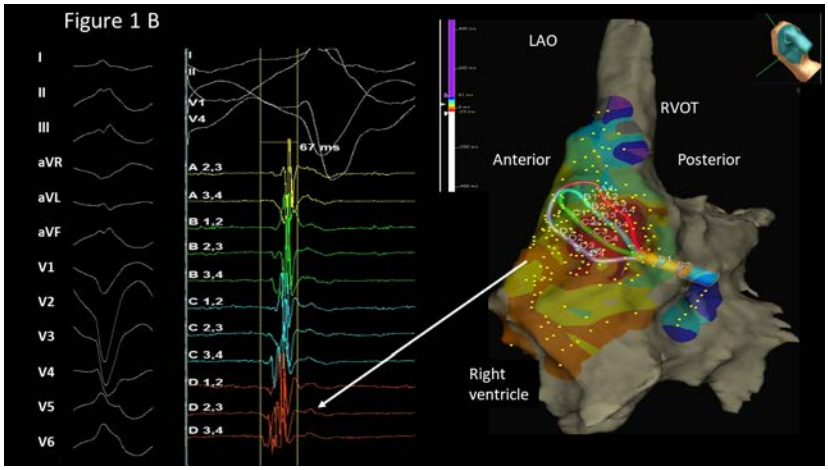


Figure 1C (modified LAO view): Focal VT at LV posteromedial papillary muscle with earliest EGM on D2-D3 (arrow). Unipolar QS EGM on D3 electrode (box)

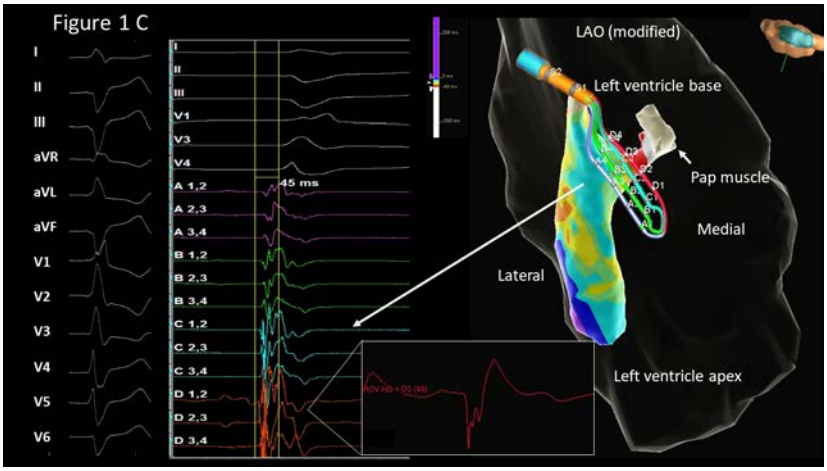


Figure 2: Comparison of procedural findings between MPM and PbyP cohorts

MPM mapping was associated with a) shorter mapping time (p=0.03); b) shorter procedural duration (p=0.02); c) earlier EGM detection (p=0.02) compared to PbyP mapping,

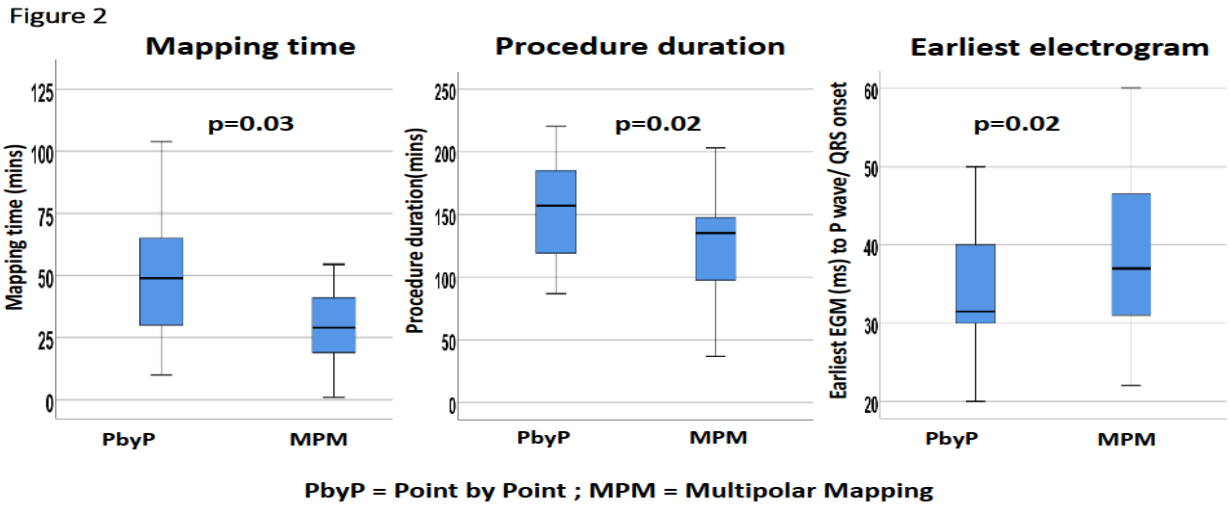
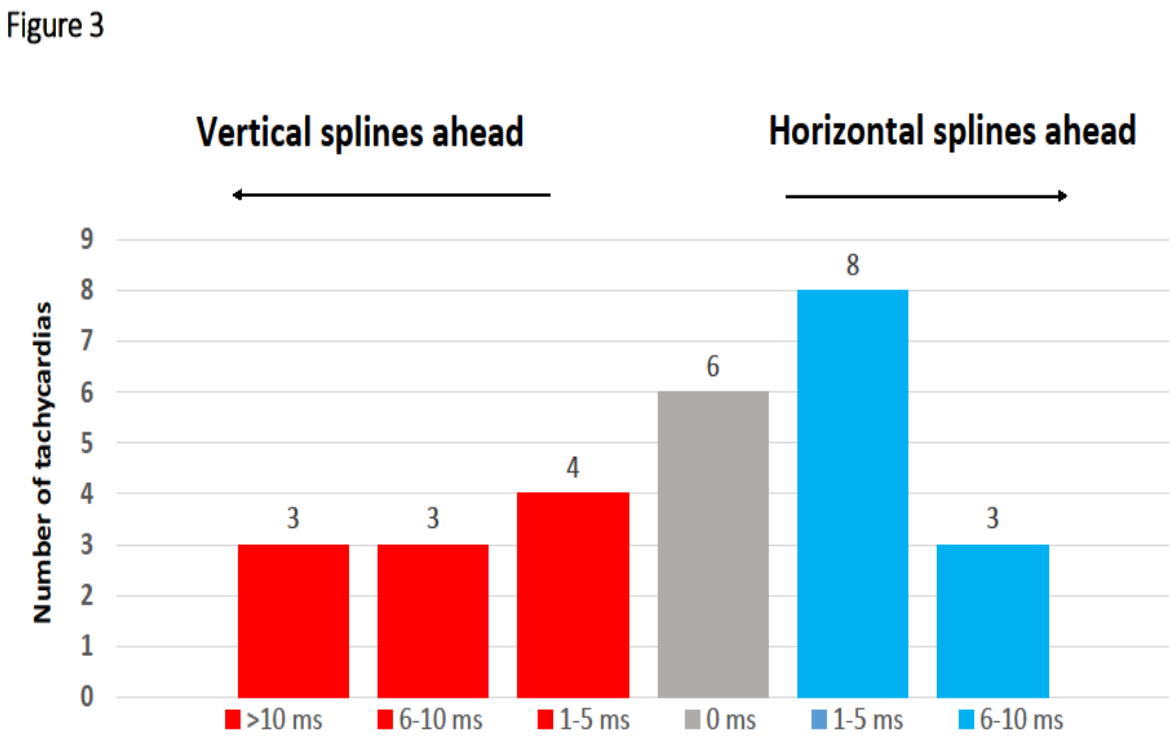


Figure 3 – Difference in earliest bipole EGM between horizontal (across) splines and vertical (along) splines



Comparison of the single earliest EGM recorded on the horizontal (across) versus vertical (along) splines on the HDG catheter, subcategorised by magnitude of time difference (x axis), with the number of tachycardias in each subcategory shown (y axis). (Grey box= no difference between orthogonal splines; blue box= horizontal splines ahead; red box = vertical splines ahead)

Table 1. Baseline characteristics of MPM and PbyP groups

	MPM (n= 27)	PbyP Cohort (n= 27)	*p value*
Arrhythmia location • Right atrium • Left atrium • Right ventricle • Left ventricle	 6 5 11 5	 6 5 11 5	
Age (years) (mean,SD)	59.0 +/- 10.6	58.7 +/- 12.5	0.92
Male (n,%)	14 (52%)	14 (52%)	1.00
Hypertension (n,%)	7 (26%)	6 (22%)	0.81
IHD (n,%)	3 (11%)	5 (19%)	0.41
Obesity (n,%)	7 (26%)	9 (33%)	0.55
Other arrhythmia (n,%)	9 (33%) • SVT – 1	6 (22%) • SVT - 2	0.30

	• AF – 6 • AFL -2	• AF – 4	
No. of failed AADs (mean, SD)	1.4 +/- 0.9	1.2 +/- 0.6	0.49
LVEF (%) (mean, SD)	55.0 +/- 9.2	50.9 +/- 10.6	0.15
LVEDD (mm) (mean, SD)	50.7 +/- 7.6	53.5 +/- 5.1	0.25
LAVI (ml/m2) (mean, SD)	41.9 +/- 19.5	37.6 +/- 8.6	0.54
RA area (cm2) (mean, SD)	20.5 +/- 6.8	20.5 +/- 5.8	0.98

Abbreviations: AAD = anti-arrhythmic drug; IHD ischaemic heart disease; LAVI = indexed left atrial volume; LVEDD = left ventricular end diastolic diameter; LVEF= left ventricular ejection fraction; MPM= multipolar mapping; PbyP = point by point; RA = right atrial; RV = right ventricle

Table 2. Procedural and EAM features for AT/ VT cohorts

	Atrial arrhythmias			**Ventricular arrhythmias**		
	MPM Cohort (Mean +/- SD)	**PbyP Cohort** (Mean +/- SD)	*p*	**MPM Cohort** (Mean +/- SD)	**PbyP Cohort** (Mean +/- SD)	*p*
No. of tachycardia targeted	1.0 +/-0.0	1.0 +/- 0.8	0.22	1.5 +/- 0.8	1 +/- 0.3	0.13
Earliest electrogram, msecs	41 +/- 11	35 +/- 8	0.16	38 +/- 12	31+/- 7	0.05
Total points collected (number)	1595 +/- 1452	154+/- 133	<0.01	3519 +/- 5230	166 +/- 131	0.01
Total points used (number)	498 +/- 295	129 +/- 109	<0.01	399 +/- 339	137 +/- 117	<0.01
Total mapping time (mins)	23 +/- 14	38+/- 20	0.06	45 +/- 26	63 +/- 33	0.10

Procedural duration (mins)	125 +/- 52	147 +/- 33	0.25	128 +/- 35	157 +/- 43	0.04
Fractionation (n,%)	7 (78)	10 (83)	0.75	14 (70)	14 (77)	0.59
Unipolar QS (n,%)	7 (78)	6 (55)	0.28	17 (85)	15 (83)	0.89
RF lesions (number)	10 +/- 17	9 +/- 7	0.69	14 +/- 14	13 +/- 12	0.34
RF time (mins)	5.2 +/- 2.9	7.9 +/- 6.9	0.25	9.8 +/- 5.4	10.8 +/- 7.6	0.66
Fluoroscopy time (mins)	12.1 +/- 6.9	8.5 +/- 4.8	0.18	13.7 +/- 6.9	12.4 +/- 7.6	0.62

Abbreviations: AT = atrial tachycardia; RF = radiofrequency ablation; LAVI = indexed left atrial volume; LVEDD = left ventricular end diastolic diameter; LVEF= left ventricular ejection fraction; MPM= multipolar mapping; PbyP = point by point; VT = ventricular tachycardia

Table 3. Procedural characteristics and outcomes

	MPM Cohort (Mean +/- SD)	**PbyP Cohort** (Mean +/- SD)	*p*
No. of AT/ VT targeted	1.29 +/- 0.7	1.0 +/- 0.7	0.70
Spontaneous (including ectopy) (n,%)	24 (69%)	27 (81%)	0.26
Induction with PES (n,%)	7 (20%)	5 (15%)	0.56
Earliest electrogram (msecs)	39 +/- 11	33 +/- 7	0.02
Total points collected (number)	3442 +/- 5510	162 +/- 132	<0.01
Total points used (number)	441 +/- 319	134 +/- 111	<0.01
Total mapping time (mins)	35 +/- 24	53 +/- 31	0.03
Procedural duration (mins)	126 +/- 42	153 +/- 39	0.02
Fractionation at earliest EGM (n,%)	21 (72%)	24 (80%)	0.49
Unipolar QS at earliest EGM (n,%)	24 (83%)	21 (72%)	0.35

RF time (mins)	7.9 +/- 5.0	9.7 +/- 7.4	0.31
Fluoroscopy time (mins)	13.0 +/- 6.8	10.9 +/- 6.8	0.25
Acute procedural success (n,%) *	23 (85%)	22 (81%)	0.60
Arrhythmia recurrence on follow up (n,%)	2 (8.7%)	2 (9.1 %)	0.97

Procedural success = non inducibility of atrial / ventricular arrhythmia, including with induction manoeuvres

Abbreviations: AT = atrial tachycardia; RF = radiofrequency ablation; LAVI = indexed left atrial volume; LVEDD = left ventricular end diastolic diameter; LVEF= left ventricular ejection fraction; MPM= multipolar mapping; PES = programed extra –stimulus; PbyP = point by point; VT = ventricular tachycardia