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Contact force and catheter stability are predictive metrics of successful pulmonary vein isolation with high-power short duration ablation in atrial fibrillation.

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ABSTRACT

Introduction- Preliminary data suggest that high power short duration (HPSD) ablation for pulmonary vein isolation (PVI) are safe. Limited data are available on its effectiveness. Aim was to evaluate HPSD ablation in AF ablation using a novel Qdot Micro catheter.

Methods and Results- Prospective multi-centre study evaluating safety and efficacy of PVI with HPSD ablation. First pass isolation (FPI) and sustained PVI was assessed. If FPI was not achieved additional ablation index (AI)-guided ablation with 45W was performed and metrics predictive of this were determined. Sixty-five patients and 260 veins were treated. Procedural and LA dwell time was 93.9±30.4 and 60.5±23.1 minutes respectively. FPI was achieved in 47 (72.3%) patients and 231 veins (88.8%) with an ablation duration of 4.6±1.0 minutes. Twenty-nine veins required additional AI-guided ablation to achieve initial PVI with 24 anatomical sites ablated with the right posterior carina being the most common site (37.5%). A contact force of ≥8g (AUC 0.81; p<0.001) and catheter position variation of ≤1.2mm (AUC 0.79; p<0.001) with HPSD were strongly predictive of not requiring additional AI-guided ablation. Out of the 260 veins, only 5 (1.9%) veins showed acute reconnection. HPSD ablation was associated with shorter procedure times (93.9min vs.159.4min; p<0.001), ablation times (6.1min vs. 27.7min; p<0.001) and lower rates of PV reconnection (9.2% vs. 30.8%; p=0.004) compared to moderate power cohort.

Conclusions- HPSD ablation is an effective ablation modality which results in effective PVI whilst maintaining a safety profile. Its superiority needs to be evaluated in randomised controlled trials.

Key Words- Radiofrequency ablation, Atrial fibrillation, Pulmonary vein isolation, Novel technology.

INTRODUCTION

Pulmonary vein isolation (PVI) remains the cornerstone of catheter ablation for atrial fibrillation (AF). PVI is superior to medical therapy for the treatment of symptomatic paroxysmal AF (PAF) [1, 2] and non-inferior to other ablation strategies in persistent AF [3]. There have been recent publications optimising PVI for AF using contact force sensing catheters and weighted formulae to quantify ablation delivery [1-2]. Using a protocolized ablation strategy dubbed the CLOSE protocol with moderate power (typically 40-45W) and ablation index (AI), high rates of first pass PVI have been demonstrated at 82-98%, with good clinical outcomes [4, 5].

Industry has responded by evolving ablation catheters with external temperature sensing, to allow monitoring of the tissue surface and alter catheter irrigation accordingly for added safety within this power range (Q-MODE, Biosense Webster). They have also developed a facility to deliver high power short duration (HPSD) lesions (90W for 4 seconds). Reported potential advantages of HPSD ablation include less tissue oedema and collateral tissue damage, reduction in procedural time and superior ablation lesion formation [6-9]. In animal models, HPSD ablation has shown improved lesion to lesion uniformity, linear contiguity, and lesion transmurality with a similar safety profile to conventional ablation [6]. Lesions after ablation at 90W are a slightly different shape to those at 40-50W, being shallower and wider. However, in

a human study, HPSD was shown to be a safe ablation modality [7, 8], though there are still limited data on its clinical utility and effectiveness.

This multi-centre study aimed to evaluate HPSD point-by-point radiofrequency (RF) ablation using the novel Qdot Micro ablation catheter (Biosense Webster, Diamond Bar, MA, USA) to achieve PVI using a standardised protocol in patients undergoing ablation for AF. It was hypothesized that HPSD ablation would result in high rates of first pass PVI which would be sustained despite a waiting period and adenosine. If first pass PVI was not achieved with HPSD ablation, or if PV reconnection occurred subsequently, then additional ablation was performed with moderate power (45W) guided by AI. We sought to determine whether certain anatomical sites were resistant to HPSD lesions to potentially inform a hybrid approach using different powers/modalities when ablating at different anatomical locations. Procedural and outcome data with regards to freedom from AF/atrial tachycardia (AT) and safety profile were also compared to a prospectively gathered cohort undergoing PVI utilizing the same protocol but with moderate power (30-40W) guided by AI.

METHODS-

Study design-

This was a prospective, multi-centre study across four UK centres that included consecutive patients undergoing a first catheter ablation procedure for AF. Patients were enrolled consecutively between 2021-2022. All patients underwent HPSD RF point-by-point ablation using Qdot Micro catheter (Biosense Webster, Diamond Bar, MA, USA) to achieve initial PVI. Baseline characteristics, procedural metrics, outcome data and safety outcomes were recorded.

All patients provided written informed consent before the procedure. The study complied with the Declaration of Helsinki and was registered and endorsed by the Barts Health NHS Trust Clinical Effectiveness Unit (registration ID: 12840). Prospective approval for the use of the

HPSD with the Qdot Micro catheter was obtained from the Barts Heart Centre New Technologies Committee.

Procedure protocol-

Patients underwent their procedure under conscious sedation or general anaesthetic depending on patient/operator preference. All procedures were performed with un-interrupted anticoagulation therapy and intravenous heparin administration to achieve an activated clotting time (ACT) of >300s throughout the procedure. Transseptal punctures were either performed through an SL1 sheath (Abbott, IL, US) with either a BRK or BRK1 71cm and Safe-sept transseptal guidewire (Heart Medical Europe BV, NL). An ablation catheter was passed through an Agilis steerable sheath (Abbott, IL, US) or a Visigo steerable sheath (Biosense Webster, Diamond Bar, MA, USA) either through the initial transeptal puncture, or with an additional transeptal puncture performed for the Agilis or Visigo sheath. CARTO 3D mapping system (Biosense Webster, Diamond Bar, MA, USA) was utilized for all the procedures. Left atrium (LA) geometry was created with either a Lasso or PentaRay (Biosense Webster, Diamond Bar, MA, USA) multipolar catheter.

All patients had PVI performed by wide area circumferential ablation (WACA) using point-by-point RF ablation applied with a QDOT Micro catheter through a steerable sheath. Lesions were delivered using a standardised protocol which was essentially a modification of the CLOSE protocol [10]. Lesions were placed 5-10 mm outside the veno-atrial junction, aiming for isolation as ipsilateral PV pairs. The anterior border of the left PVs was ablated either directly onto the appendage ridge or failing that on the venous side of the appendage ridge, but not on the appendage side of the ridge. An inter-lesion distance of ≤6mm was utilized. In practice this was achieved by using the "distance measurement tool" on Carto which is not respiratory gated and therefore changes continually. Operators aimed to ablated with a distance of 4-6 mm from

the centre of the last lesion. A stable catheter position with contact force of 5-40 g was sought prior to commencing ablation.

Following completion of the WACA lines, PVs were assessed individually for isolation by confirming entrance and exit block with pacing from the PVs. First pass PVI was defined as PVI on completion of the WACA lines. If PVs did not isolate with HPSD, additional AI-guided ablation with a power of 45W were utilized to achieve PVI. AI targets were 350 posteriorly and 450 everywhere else on the WACA line.

To evaluate for sustained PVI, all PVs were individually assessed for reconnection following a 20-minute waiting period after initial PVI was achieved. If the vein remained isolated, isolation was assessed with IV administration of adenosine 12-24mg (as required to achieve atrioventricular block). If the vein showed reconnection after the waiting period or following adenosine, further AI-ablation with moderate power (45W) was performed to achieve re-isolation. Reconnection with either the waiting period or adenosine was recorded as failure to achieve sustained isolation. The waiting period and administration of adenosine were not repeated after repeat RF ablation to achieve PVI.

For those with documented typical right atrial flutter, a cavo-tricuspid isthmus (CTI) line was also ablated. Other ablation was only performed for ATs that occurred during the case and was performed after completion of PVI. Ablation of CTI lines and ATs were performed using AI-guided ablation with 45W.

Follow-up-

The focus of this study was acute PVI. Nevertheless, patients were followed up to determine any late complications and to describe the short-term follow-up data. AF/AT recurrence was defined as documented atrial arrhythmia lasting ≥30 seconds off antiarrhythmic drugs as per guidelines [11]. Given the short-term nature of the follow-up a blanking period was not observed.

Endpoints

The co-primary endpoints were (1) the rate of achieving first pass PVI using HPSD ablation and (2) the rate of achieving sustained PVI following a waiting period and adenosine using HPSD ablation alone. Anatomical sites requiring additional AI-guided ablation and HPSD lesion parameters at sites where HPSD ablation was insufficient were also analysed.

Other secondary endpoints included comparison of safety procedural parameters such as procedural duration, fluoroscopy time and RF ablation time and outcome with regards to freedom from AF/AT with a moderate power cohort. The moderate power cohort consisted of consecutive patients that prospectively underwent ablation for PAF and persistent AF over a 1-year period prior to the introduction of HPSD. These patients underwent PVI utilizing a similar amended CLOSE protocol but with AI-guided ablation (350 posteriorly and 450 elsewhere) and moderate power (30W posteriorly and 40W elsewhere) utilizing a STSF ablation catheter (Biosense Webster, Diamond Bar, MA, USA). Patients in the moderate power cohort underwent the same protocol with regards to the waiting period and IV adenosine administration to assess for PV reconnection. The same mapping catheters and transeptal sheaths were used in the moderate power cohort.

Evaluation of sites where AI-guided ablation was required-

The LPV and RPV ostia were segmented into 11 anatomical sites (Supplemental Figure 1A-B). Anatomical sites where additional AI-guided ablation was required to achieve initial PVI were determined. The contact force for the individual HPSD ablation lesions was determined. The xyz coordinates for the ablation catheter were obtained through CARTO at the start and end of the HPSD ablation lesion. The coordinates were used to determine the position of the catheter on the LA geometry. The change in catheter position was calculated as a surrogate for catheter stability for each HPSD lesion. Impedance drop and interlesion distance was also determined

for each HPSD lesion. These metrics were compared between HPSD lesions where additional AI-guided ablation was not required to those HPSD lesions where additional AI-guided ablation was required.

Statistical analysis-

All statistical analyses were performed using SPSS (IBM SPSS Statistics, Version 25 IBM Corp, NY, USA). Continuous variables are displayed as mean ± standard deviation (SD) or median (IQR). Categorical variables are presented as a number and percentage. Fisher's exact test was used for the comparison of nominal variables. The Student's t-test, or its non-parametric equivalent Mann-Whitney was used for comparison of continuous variables. ANOVA was performed to compare first pass PVI rates with HPSD ablation in accordance with vein type. Multivariate analysis was performed to identify specific metrics that were predictive of a successful first pass PVI of PV pairs with HPSD ablation using binary logistic regression. Receiver Operating Characteristic (ROC) analysis was performed to determine the association between the continuous variables studied and the outcome of first pass PVI with HPSD ablation. Area under the curve (AUC) was determined and optimal cut-off, sensitivity and specificity were determined manually from ROC plots. A p-value of <0.05 was deemed significant.

RESULTS-

Sixty-five patients were included in this study (mean age 61.3±12.8 years and 53 male (81.5%)). Of these, 42 (64.6%) underwent ablation for PAF and 23 (35.4%) for persistent AF. Baseline characteristics are described in Table 1. The average procedure duration was 93.9±30.4 minutes (which included the 20-minute waiting period) with an average LA dwell time of 60.5±23.1 minutes. Procedural metrics are described in Table 2.

Figure 1 demonstrates the consort flow diagram for the study. There was no documentation of coagulation or char at the catheter tip in any of the patients.

i) Initial PVI-

In the 65 patients, a total of 260 veins underwent point-by-point HPSD RF ablation to achieve initial PVI. The average RF ablation duration to achieve initial PVI of all the veins on a per patient basis was 6.1±3.3 minutes (HPSD and additional AI-guided ablation) and 4.6±1.0 minutes (HPSD ablation only).

On a per patient basis first pass PVI of both PV pairs with HPSD only was achieved in 47 (72.3%) patients (Representative Figure 2A-B). In the remaining 18 (27.7%) patients additional AI-guided 45W RF ablation was required to achieve initial PVI. The first pass PVI rates were no different in those patients undergoing the catheter ablation under general anaesthetic vs. conscious sedation (12/16, 75.0% vs. 35/49, 71.4%; p=1.00).

Out of the 260 veins treated, first pass PVI was achieved with HPSD ablation alone in 231 (88.8%) veins. On a per vein basis, first pass PVI was achieved with 59/65 (90.8%) left upper pulmonary veins (LUPVs), 63/65 (96.9%) left lower pulmonary veins (LLPVs), 53/65 (81.5%) right upper pulmonary veins (RUPVs) and 56/65 (86.2%) right lower pulmonary veins (RLPVs). There was a significant difference in first pass PVI rates between the vein types (p=0.01). First pass PVI rates were significantly higher with the LPVs compared to the RPVs (122/130, 93.8% LPVs vs. 109/130, 83.8% RPVs; p=0.02). Initial PVI was achieved in all patients.

ii) Analysis of factors associated with failure to achieve initial PVI with HPSD ablation

A total of 24 anatomical sites required additional AI-guided ablation to achieve initial PVI. Out of these anatomical sites, 6 anatomical sites were the same sites that resulted in isolation of both PVs and 2 anatomical sites were targeted to achieve isolation of one of the RUPVs. The

most common anatomical site where additional AI-guided ablation was required was right posterior carina (9/24, 37.5%). Anatomical sites where additional AI-guided ablation was required to achieve initial PVI are demonstrated in Figure 3A-B.

The average contact force for all the HPSD lesions was 14.5±5.6g. The average variation in catheter position at the start and end of the HPSD ablation lesion was 1.4±0.9mm. The average interlesion distance was 4.5±1.8mm. The average impedance drop was 15.8±4.2Ω. The contact force and catheter stability were shown to be significantly different for the HPSD lesions that did not require additional AI-guided ablation vs. those that did require additional AI-guided ablation (Table 3). The right posterior carina which was the most common anatomical site that required additional AI-guided ablation demonstrated a lower catheter stability with greater catheter position variation compared to all other anatomical sites with or without additional AI-guided ablation (1.8±0.8mm vs. 1.3±0.9mm; p<0.001). The variation in catheter position was no different in those patients undergoing the catheter ablation under general anaesthetic vs. conscious sedation (1.3±1.0mm vs.1.4±0.8mm; p=0.75).

In the multivariate analysis, contact force (odds ratio 1.32, 95% CI 1.24-1.43; p=0.003) and catheter stability (odds ratio 0.88, 95% CI 0.81-0.95; p=0.002) was shown to be independent predictors of first pass PVI of PV pairs with HPSD ablation (Table 4).

Contact force of ≥8g was shown to have a good discriminative capacity for achieving first pass PVI of PV pairs with HPSD ablation alone (Table 5).

Catheter stability i.e., catheter position variation of ≤1.2mm was shown was shown have a good discriminative capacity for achieving first pass PVI of PV pairs with HPSD ablation alone (Table 5).

In the moderate power cohort independent predictors of first pass PVI of PV pairs was interlesion distance (odds ratio 1.31, 95%CI 1.21-1.42; p<0.001) and impedance drop (OR

1.54, 95%CI 1.35-1.60; p<0.001). The optimal cut off for interlesion distance was <5mm and the optimal cut off for impedance drop was ≥3Ω.

iii)Sustained PVI

Out of the 260 veins, 5 (1.9%) veins showed acute reconnection after the waiting period. An additional 3 (1.2%) veins showed acute reconnection following IV administration of adenosine. Therefore, a total of 8 (3.1%) veins were reconnected. On a per vein basis 4 (6.1%) RUPVs, 2 (3.1%) RLPVs and 2 (3.1%) LUPVs demonstrated PV reconnection. PV reconnection was more common in the RPVs than LPVs (6/8, 75.0% RPVs vs. 2/8, 25% LPVs). On a per patient basis, acute PV reconnection was seen in 6 out of the 65 patients (9.2%).

AI-guided ablation at 45W was performed to achieve sustained PVI. The anatomical sites of AI-guided ablation included posterior carina for the 2 RLPVs, anterior and posterior carina for 3 of the RUPVs, superior for one of the RUPVs and anterior superior for the 2 LUPVs. Thereby reconnection was seen at posterior carina (n=5), anterior carina (n=1), superior (n=1) and anterior superior (n=2). An average ablation duration of 2.2±1.8 minutes was required to achieve sustained PVI. PV reconnection was more commonly seen with PVs that did not achieve first pass PVI with HPSD and required additional AI-guided ablation compared to PVs that achieved first pass PVI with HPSD ablation (7/29 (24.1%) vs. 1/231 (0.4%); p<0.001).

iv) Follow-up

All patients reached at least three months follow-up, and none had any late procedural complications. During an average follow-up 11.8±2.7 months, 56 (86.2%) patients remained free from AF/AT off anti-arrhythmic drugs. Out of the 9 (13.8%) patients that had AF/AT recurrence during follow-up, 7 had AF recurrence and 2 had AT recurrence. Out of the 9 (13.8%) patients that had AF/AT recurrence during follow-up, 2 (25.0%) had PAF prior to their procedure and 7 (77.8%) had persistent AF. Freedom from AF/AT during follow-up in

the PAF patients was 95.2% and in the persistent AF patients was 69.6%. There was a significant difference in AF/AT recurrence during follow-up in patients with paroxysmal AF versus persistent AF (2/42, 4.8% vs 7/23, 30.4%; p=0.007).

v) Comparison between HPSD cohort and moderate power cohort-

When comparing the HPSD and moderate power cohort there was no significant difference in baseline characteristics (Table 6) besides the patients in the HPSD cohort being more frequently on direct oral anticoagulants compared to the patients in the moderate power cohort (n=62, 95.4% vs. n=51; 78.5%; p=0.008). When comparing procedural metrics (Table 7), the procedural duration (93.9±30.3 minutes vs. 159.4±38.5 minutes; p<0.001),LA dwell time (60.5±23.1 minutes vs. 125.3±42.3 minutes; p<0.001), fluoroscopy times (2.8±2.6 minutes vs. 7.2±5.1 minutes; p<0.001),DAP dose (56.2±80.2 $cGycm^2$ vs. 125.8±129.6 $cGycm^2$; p=0.004) and time taken to isolate the PVs was significantly shorter in the HPSD cohort compared to the moderate power cohort.

When comparing the two co-primary endpoints to the moderate power cohort, there was no significant difference in the number of patients in whom first pass PVI was achieved for both left and right PV pairs when comparing the HPSD and moderate power cohorts (47/65, 72.3% vs. n=42, 64.6%; p=0.45). This was also applicable on a per vein basis (Table 7). However, the rate of acute PV reconnection per patient was significantly higher in the moderate power cohort than the HPSD cohort (n=20, 30.8% vs. n=6, 9.2%; p=0.004). This was also applicable on a per vein basis (Table 7). On a per vein basis, the PV reconnection rate was significantly higher in the moderate power cohort compared to the HPSD cohort (39/260, 15.0% vs. 8/260, 3.1%; p<0.001). For both cohorts the RPVs were more commonly the veins that demonstrated reconnection (6/8, 75% HPSD vs. 26/39, 66.7% moderate power; p=1.00). However, the anatomical sites of reconnection were different. In the moderate power cohort, 42 anatomical sites were ablated to achieve sustained PVI (n=16, 38.1% superior RPVs, n=2, 4.8% posterior

carina RPVs, n=9, 21.4% inferior RPVs, n=8, 19.0% superior LPVs, n=7, 16.7% inferior LPVs). Whilst PV reconnection was more at the posterior carina of the RPVs in the HPSD cohort (5/9 sites, 55.6%) PV reconnection was more common in the superior of the RPVs in the moderate power cohort (16/42 sites, 38.1%).

Freedom from AF/AT during a compatible follow-up (11.8±2.7 months HPSD cohort vs. 11.3±3.2 months moderate power cohort; p=0.89) was also comparable between the two cohorts (56/65, 86.2% HPSD cohort vs. 54/65, 83.1% moderate power cohort; p=0.81).

DISCUSSION

This multi-centre prospective study evaluated effectiveness and safety of HPSD in achieving PVI in patients undergoing catheter ablation for PAF and persistent AF. This is the first multi-centre study that has evaluated the effectiveness of HPSD with regards to achieving first pass PVI and sustained PVI following a waiting period and IV administration of adenosine. This is also the first study that has identified specific ablation metrics that are predictive of achieving first pass PVI with HPSD. The main findings were:

1. High rate of first pass PVI was achieved with HPSD (>70%). Only a small proportion of veins required additional AI-guided ablation to achieve initial PVI (11.2%).

2. Specific anatomical sites were more common to require additional AI-guided ablation to achieve initial PVI with the most common site being the right posterior carina.

3. Specific metrics were predictive of achieving effective lesion set with HPSD to achieve first pass PVI and not requiring additional AI-guided ablation including a contact force of ≥8g and high catheter stability with a catheter position variation of ≤1.2mm. These metrics were different to those that were predictive of first pass PVI in the moderate power cohort.

4. Anatomical sites of PV reconnection were different in the HPSD cohort compared to the moderate power cohort with the posterior carina of the RPVs being the most common site in

the HPSD cohort whilst in the moderate power cohort the superior of the RPVs was the most common site.

5. Procedure times, fluoroscopy times, RF ablation times and rates of acute PV reconnection were lower with HPSD ablation than with AI-guided ablation at moderate power.

i) Initial PVI in HPSD cohort

In this study, a majority of patients achieved first pass PVI of both PV pairs with HPSD RF point-by point ablation. Only a small proportion of veins required additional moderate power AI-guided ablation to achieve PVI. On a per vein basis there was a significant difference in the first pass PVI rates with the LPVs having a higher rate of first PVI compared to the RPVs. This therefore suggests that when utilising HPSD additional care is required when isolating the RPVs. Further to this, certain anatomical sites were more frequently associated with requiring AI-guided ablation particularly the right posterior carina further emphasising that additional care is required when HPSD ablation is performed at these sites. It may be prudent to add additional lesions at these sites on or inside the WACA line, or to consider a hybrid approach with AI-guided lesions at moderate power. It is unclear why the posterior carina at the right pulmonary veins was the most likely area to require further ablation to isolate the PVs or the most likely site of reconnection. The tissue is not as thick as areas such as the roof or appendage ridge, so lesion depth is unlikely to be the problem. Key factors predicting first pass PVI on multivariate analysis were catheter contact force and catheter stability. This area typically has poor catheter stability which may be a particular problem for HPSD lesions.

The findings of first pass PVI achieved in this study is significantly greater than that reported in a previous study utilizing HPSD [7]. In this study, 90W 4 seconds ablation was consistently used anteriorly and posteriorly whilst in the other study that evaluated HPSD the ablation duration was limited to 90W 3 seconds posteriorly [7]. The first pass PVI in the previous study was only 18% on a per patient basis and 54% on a PV pair basis which is lower than what was

demonstrated in this study [7]. It is possible that the shorter ablation duration utilized posteriorly in this study accounts for the difference in the first pass PVI rates seen when compared to the findings in this study. Another study also evaluating HPSD ablation with Qdot-Micro catheter also reported lower rates of first pass PVI compared to the findings obtained in this study (49% vs. 72.3%) [9]. It remains unclear why the first pass PVI rates were that different between these two studies. As shown in this study, contact force and catheter stability were predictive of an optimal ablation lesion. It is therefore possible that the differences in first pass PVI between these two studies is accounted for by differences in these metrics. A steerable sheath was used routinely in this cohort but may not have been in other studies.

ii) Sustained PVI in HPSD cohort

In this study, a majority of PVs demonstrated sustained PVI (96.9%). The veins that did demonstrate reconnection were more frequently the PVs that required additional AI-guided ablation to achieve initial PVI. These findings are thereby suggestive that achieving an effective lesion set with HPSD during the initial PVI ensures greater likelihood of sustained PVI. The rates of PV reconnection were higher in other studies (32% and 21%) perhaps relating to the lower rate of first pass PVI with HPSD [7, 9]. This emphasises that first pass PVI with HPSD provides optimal lesion sets that prevents acute PV reconnection and ensures sustained PVI. It is unclear why this should be the case as this is lower than has been reported in most studies using other ablation modalities. It may be due to rapid lesion formation and indeed WACA completion which may negate any problems that oedema may cause with RF ablation delivery.

iii) Procedural metrics associated with the need for additional AI-guided ablation-

In this study, we have shown that achieving certain ablation metrics are more likely to ensure effective lesion sets with HPSD that results in not requiring additional AI-guided ablation. Achieving a contact force of ≥8g and catheter stability of ≤1.2mm was strongly predictive of

not requiring additional AI guided ablation to achieve initial PVI. Due to the shorter duration of ablation with HPSD it is critical that contact force and catheter stability remains optimal during the 4-second ablation to ensure an optimal lesion set is delivered. Position and contact therefore ought to be carefully optimised prior to ablation as the operator will not have sufficient time to correct or optimise these during ablation (which may sometimes be feasible with longer AI-guided lesions).

This therefore emphasises that the operators should ensure an optimal force and catheter stability is achieved prior to ablation delivery. Catheter stability has previously been shown to be important during moderate power ablation [13]. Whilst impedance drop has been shown to be a predictor of first pass PVI [14] it was not shown to be a predictor of first pass PVI of PV pairs with HPSD. This is the first study that has provided ablation metrics that can be of use during the application of HPSD RF point-by-point ablation during PVI. These are slightly different to ablation at lower or moderate powers, where 5-6 g seems adequate and catheter stability may be slightly more forgiving [4, 15]. Nevertheless, a majority of these cases were performed without general anaesthesia which does not seem to be a requirement for these cases. Further to this, catheter stability and contact force were not independent predictors of first pass PVI in the moderate power cohort where interlesion distance and impedance drop were independent predictors. This highlights that the metrics identified for HPSD are more specific for this type of ablation power and time and should be considered by operators when performing HPSD ablation.

iv) Safety

This study has shown that HPSD is safe with no complications reported acutely and a 30-day follow-up. This is consistent with the findings achieved in other studies [7, 12]. In this study, there was no oesophageal temperature monitoring or post procedural cardiac magnetic resonance imaging however, the findings of previous studies have shown that HPSD was not associated

with a significant rate of oesophageal injury and symptomatic cerebral events [7, 8, 12]. Therefore, the study was performed based on the reassuring findings from these previous studies and to allow evaluation of this technology and ablation modality in accordance with its clinical intention without the need for the additional investigations.

vi) Comparison between HPSD cohort and moderate power cohort-

When comparing PVI utilizing HPSD with moderate power the procedural metrics are significantly different. Procedural and LA dwell times were significantly lower with HPSD compared to the moderate power cohort. Fluoroscopy times and DAP doses were also significantly lower likely due to the shorter procedural time. These findings are consistent with the findings from another study comparing HPSD with conventional power-controlled ablation with a STSF catheter [16]. Total ablation duration and average ablation duration per vein pair was also significantly lower with HPSD compared to moderate power. Therefore, HPSD allows quicker procedures with the need for less radiation and ablation. As a result, the use of this ablation modality has the potential to ensure quicker catheter lab turn around and lower procedural risk to the patient. The quicker procedures and lower ablation duration did not compromise the first pass PVI rates. The first pass PVI rates were compatible on a per patient basis when comparing the HPSD and moderate power cohort. However, HPSD ablation resulted in a significantly higher rate of sustained PVI on a per patient basis basis compared to the moderate power cohort. These findings therefore suggest that the lesion set achieved with HPSD ablation is more durable compared to moderate power AI-guided ablation. Further to this, the anatomical site of PV reconnection was different in the HPSD cohort compared to the moderate power cohort whereby in the HPSD cohort posterior carina of the RPVs were the most common site whilst in the moderate power cohort it was the superior of the RPVs. These differences should be considered when utilizing HPSD ablation. Even though these differences in acute procedural outcomes did not result in a difference in freedom from AF/AT these

findings are promising by demonstrating that effective PVI can be achieved quicker, with the need for less ablation and radiation.

Limitations

This is a small study in terms of evaluating complications and outcomes. Although these data are reassuring, large long-term registries are required to define the rate of infrequent adverse events. The data regarding clinical outcomes should be regarded as pilot data. Large multicentre studies using a standardised approach with long term follow up are required to define outcomes, although theses can test only one strategy at a time, and it is hoped that these data will be useful in defining standardised target led approaches. The comparison with a moderate power cohort was non-randomised. A randomised controlled trial is required to evaluate the superiority of HPSD ablation in PVI.

CONCLUSION

This multicentre study has demonstrated that HPSD RF point-by-point ablation is safe and efficient in achieving PVI in patients with AF. HPSD ablation results in high rates of first pass PVI and sustained PVI. Certain ablation metrics (contact force and catheter stability) were significantly predictive of the need for additional AI-guided ablation to achieve initial PVI. Certain anatomical sites more frequently required additional AI-guided ablation. These ablation metrics and anatomical sites were different when compared to the moderate power cohort. These findings can be utilized to optimise delivery of HPSD RF ablation. HPSD ablation was also associated with significantly lower procedure times, ablation duration and fluoroscopy times compared to a moderate power cohort without compromising on the first pass PVI rates achieved and resulting in a higher rate of sustained PVI. Its superiority needs to be further evaluated in randomised controlled trials.

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DISCLOSURES

Professor Hunter has received travel grants for the purposes of attending conferences from Biosense Webster. Professor Lambiase receives research grants from Medtronic, Abbott and Boston Scientific. Dr Honarbakhsh is a British Heart Foundation Clinical Intermediate Fellow and receives funding from the British Heart Foundation. Professor Hunter and Dr Honarbakhsh are inventors of the STAR Mapping system and Founders of Rhythm AI. Dr Martin has received research grants and consultancy fees from Boston Scientific and speaker and travel grants from Boston Scientific and Medtronic.

DATA AVAILIBILITY STATEMENT

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

Table 1- *Baseline characteristics*

Baseline characteristics	**Cohort n= 65**
Age yrs. mean ± SD	61.3±12.8
Male n (%)	53 (81.5)
Diabetes mellitus n (%)	7 (10.8)
Hypertension n (%)	23 (35.4)
TIA/CVA* n (%)	6 (9.2)
Ischaemic heart disease n (%)	9 (13.8)
Cardiac surgery n (%)	2 (3.1)
Cardiomyopathy n (%)	14 (21.5)
Left ventricular $EF^T \geq 55\%$ n (%)	50 (76.9)
LA size mm, mean ± SD	41.2±4.1
AF type	
Paroxysmal n (%)	42 (64.6)
Persistent n (%)	23 (35.4)

Current antiarrhythmic or rate-controlling strategy	
Beta-blockers including Sotalol n (%)	48 (73.8)
Amiodarone n (%)	7 (10.8)
Flecainide n (%)	16 (24.6)
Verapamil n (%)	3 (4.6)
Digoxin n (%)	1 (1.5)
Current anticoagulation strategy	
Warfarin n (%)	3 (4.6)
Direct oral anticoagulants	62 (95.4)
Apixaban n (%)	27 (41.5)
Edoxaban n (%)	7 (10.8)
Rivaroxaban n (%)	28 (43.1)

*TIA/CVA- Transient ischaemic attack/Cerebrovascular attack
TEF- Ejection fraction

Table 2*- Procedural metrics with HPSD ablation on a per patient basis.*

Procedural metrics	**Cohort n=65**
General anaesthetic n (%)	16 (24.6)
Procedural time, min mean ± SD	93.9±30.3
LA dwell time, min mean ± SD	60.5±23.1
Fluoroscopy time, min mean ± SD	2.8±2.6
Dose area product, cGycm^2 mean ± SD	56.2±80.2
Ablation duration for PVI (90W + additional 45W), min mean ± SI	6.1±3.3
LPVs*, min mean ± SD	2.6±1.3
RPVsT, min mean ± SD	3.2±2.4
Ablation duration 90W mean ± SD	4.7±1.0
LPVs, min mean ± SD	2.2±0.6
RPVs, min mean ± SD	2.3±0.7
Time to isolate PVs	
LPVs, min mean ± SD	10.5±5.4
RPVs, min mean ± SD	12.8±6.5
First pass isolation per patient n (%)	47 (72.3)
Additional 45W ablation per patient n (%)	18 (27.7)
Ablation duration 45W in 18 patients, min mean ± SD	4.9±3.3
LPVs, min mean ± SD	2.7±1.4
RPVs, min mean ± SD	4.5±2.7
Additional ablation beyond PVI n (%)	

CTI line n (%)	5 (7.7)
Day case procedure n (%)	49 (75.4)
Complications	0 (0)

	HPSD lesions only	**HPSD lesions that required additional AI-guided ablation**	**p-value**
Contact force g mean ±SD	15.5±4.7	6.2±5.2	<0.001
Catheter stability mm mean ±SD	1.2±0.4	1.8±0.8	<0.001
Interlesion distance mm mean ±SD	4.3±1.4	4.6±1.5	0.78
Impedance drop Ω mean ±SD	13.5±4.8	13.3±4.9	0.78

Table 3- *Differences in parameters between the HPSD lesions that did not require additional AI-guided ablation to achieve initial PVI vs. those HPSD lesions that required additional AI-guided ablation to achieve initial PVI.*

Table 4- *Demonstrates the findings of the multivariate analysis which shows the metrics that were predictors of first pass PVI of PV pairs with HPSD.*

	Univariate analysis		**Multivariate analysis**	
Ablation metrics	**P-value**	**Odds Ratio (95%CI**	**P-value**	**Odds Ratio (95%CI)**
Interlesion distance, mm	0.78	0.99 (0.98-1.00)	-	-
Contact force, g	<0.001	1.20 (1.12-1.28)	0.003	1.32 (1.24-1.43)
Catheter stability (variation in catheter position), mm	<0.001	1.21 (1.13-1.30)	0.002	0.88 (0.81-0.95)
Impedance drop, Ω	0.68	0.95 (0.93-0.98)	-	-
Number of ablation lesions in initial WACA lines (used as a surrogate for WACA size) n	0.81	0.98 (0.97-1.01)	-	-

*LPVs- Left pulmonary veins
TRPVs- Right pulmonary veins

Table 5- *Demonstrates the diagnostic accuracy of the ablation metrics in predicting first pass PVI*

Diagnostic accuracy parameters	**Contact force g**	**Catheter stability (variation in catheter position) mm**
AUC (95%CI, p-value)	0.81 (0.75-0.87, <0.001)	0.79 (0.74-0.85, <0.001)
Optimal cutoff	≥8	≤1.2
Sensitivity (95%CI)	93.8 (83.0-98.7)	76.3 (70.2-83.1)
Specificity (95%CI)	62.8 (42.9-82.6)	78.7 (75.4-83.3)
PPV (95%CI)	86.5 (78.6-91.9)	93.9 (85.3-98.1)
NPV (95%CI)	76.9 (53.0-91.5)	67.7 (49.1-83.2)

Table 6- *Differences in baseline characteristics between HPSD cohort and Moderate power*

Baseline characteristics	**HPSD Cohort n=65**	**Moderate power Coho n= 65**	**p-value**
Age yrs. mean ± SD	61.3±12.8	60.1±11.6	0.32
Male n (%)	53 (81.5)	50 (76.9)	0.67
Diabetes mellitus n (%)	7 (10.8)	6 (9.2)	1.00
Hypertension n (%)	23 (35.4)	22 (33.8)	1.00
TIA/CVA* n (%)	6 (9.2)	4 (6.2)	0.74
Ischaemic heart disease n (%)	9 (13.8)	2 (4.0)	0.16
Cardiac surgery n (%)	2 (3.1)	3 (6.0)	0.24
Cardiomyopathy n (%)	14 (21.5)	2 (4.0)	0.09
Left ventricular $EF^T \geq 55\%$ n (%)	50 (76.9)	48 (73.8)	0.84
LA size mm, mean ± SD	41.2±4.1	38.9±5.5	0.67
AF type			
Paroxysmal n %	42 (64.6)	40 (61.5)	0.43
Persistent n %	23 (35.4)	25 (38.5)	0.43

Current antiarrhythmic or rate-controlling str			
Beta-blockers including Sotalol n %	48 (73.8)	42 (64.6)	0.34
Amiodarone n %	7 (10.8)	5 (7.7)	0.76
Flecainide n %	16 (24.6)	11 (16.9)	0.39
Verapamil n %	3 (4.6)	2 (3.1)	1.00
Digoxin n %	1 (1.5)	4 (6.2)	0.37
Propafenone n %	0 (0)	3 (4.6)	0.24
Current anticoagulation strategy			
Warfarin	3 (4.6)	14 (21.5)	0.008
Direct oral anticoagulants n (%)	62 (95.4)	41 (63.1)	0.008
Apixaban n (%)	27 (41.5)	25 (38.5)	0.86
Edoxaban n (%)	7 (10.8)	1 (1.5)	0.06
Rivaroxaban n (%)	28 (43.1)	24 (36.9)	0.22
Dabigatran n (%)	0 (0)	1 (1.5)	1.00

Cohort.

*TIA/CVA- Transient ischaemic attack/Cerebrovascular attack
TEF- Ejection fraction

Table 7- *Procedural, freedom from AF/AT during follow-up and acute ablation outcome differences between HPSD cohort and Moderate power Cohort.*

	HPSD Cohort n=65	**Moderate power Cohort n=65**	**p-value**
Procedural metrics			
General anaesthetic n (%)	16 (24.6)	26 (40.0)	0.09
Procedural duration, min mean ± SD	93.9±30.3	159.4±38.5	<0.001
LA dwell time, min mean ± SD	60.5±23.1	125.3±42.3	<0.001
Fluoroscopy time, min mean ± SD	2.8±2.6	7.2±5.1	<0.001
Dose area product, cGycm^2 mean ± SD	56.2±80.2	125.8±129.6	0.004
Ablation duration, min mean ± SD	6.1±3.3	27.7±9.3	<0.001
LPVs*, min mean ± SD	2.6±1.3	13.6±4.3	<0.001
RPVsT, min mean ± SD	3.2±2.4	15.6±5.6	<0.001
Time taken to isolate PVs mean ± SD	10.5±5.4	30.4±10.5	<0.001
LPVs, min mean ± SD	12.8±6.5	33.3±14.4	<0.001
RPVs, min mean ± SD	4.5±1.8	4.1±1.3	0.68

Interlesion distance mm mean ± SD	1.4±0.9	1.5±0.8	0.74
Catheter stability mm mean ± SD	0 (0)	0 (0)	1.00
Complications, n (%)	56 (86.2)	55 (84.6)	0.51
Freedom from AF/AT n (%)			
Acute ablation outcomes			
First pass initial PVI per patient, n %	47 (72.3)	42 (64.6)	0.45
LPVs first pass initial PVI, n (%)	122 (93.8)**	118 (92.0)**	0.49
RPVs first pass initial PVI, n (%)	109 (83.8)**	100 (76.9)**	0.21
Sustained PVI per patient, n %	59 (90.8)	45 (69.2)	0.004
LPVs sustained PVI, n (%)	128 (98.5)**	117 (90.0)**	0.006
RPVs sustained PVI, n (%)	124 (95.4)**	104 (80.0)**	<0.001

*LPVs- Left pulmonary veins
TRPVs- Right pulmonary veins
**Out of 130 PVs

FIGURE LEGENDS-

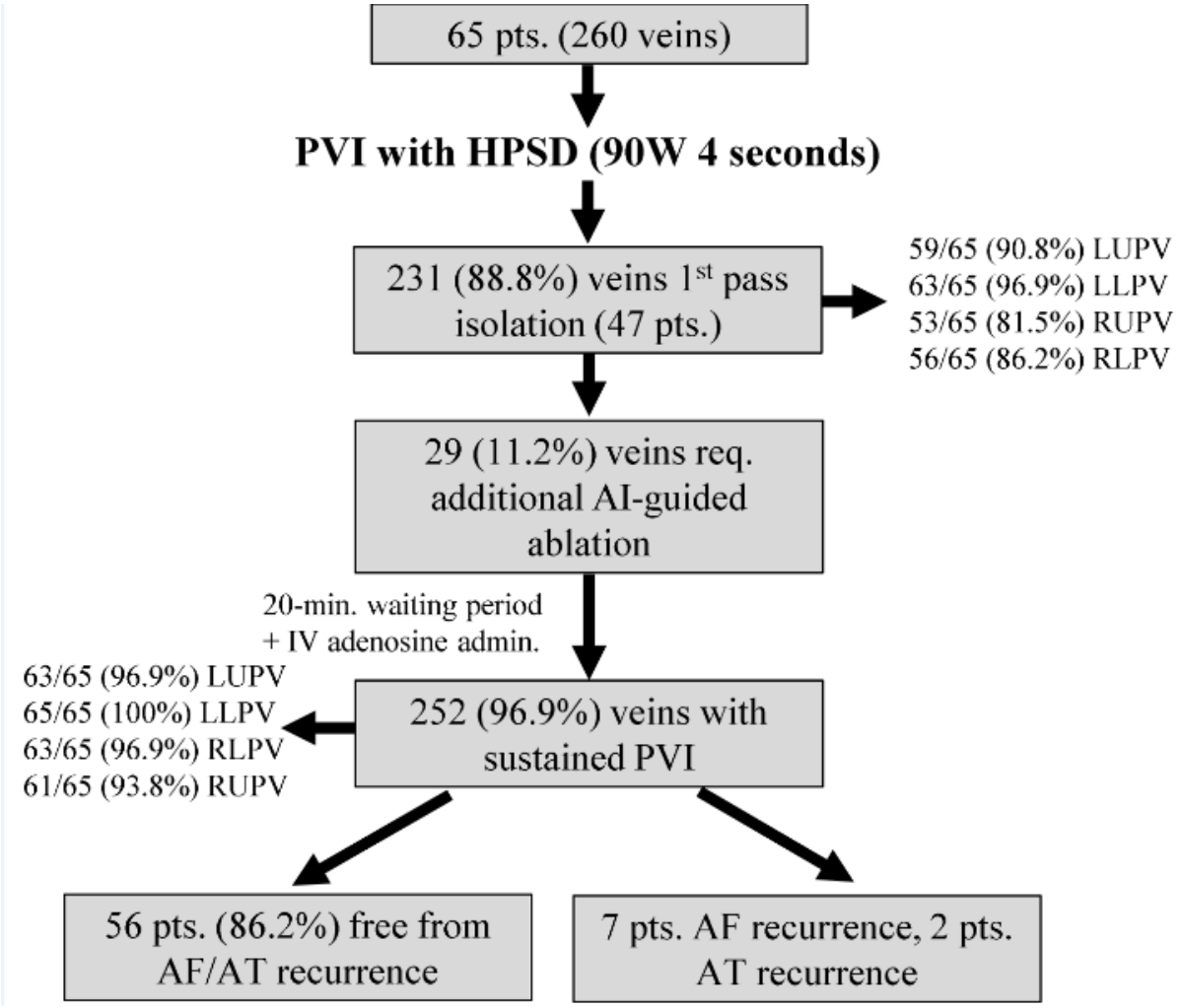

Figure 1- *Demonstrates the consort flow diagram for the study.*

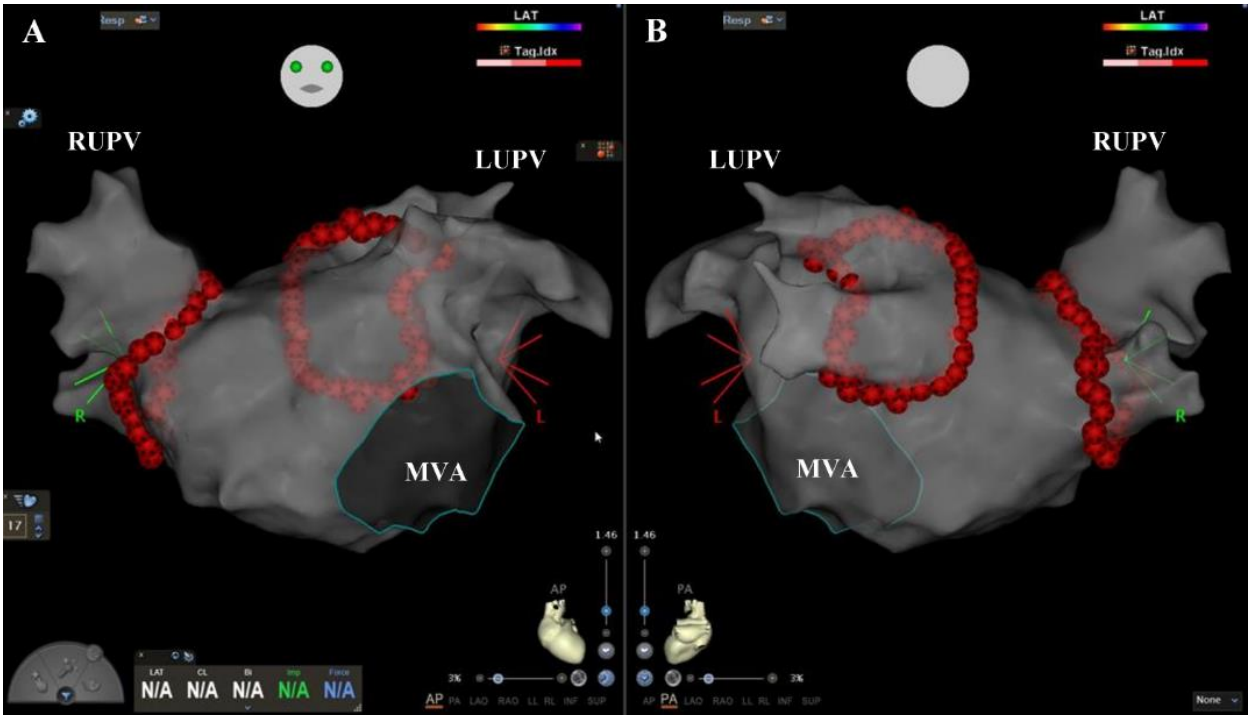

Figure 2A-B- *Demonstrates a CARTO map with bilateral WACAs performed with HPSD ablation in* ***A-*** *Anterior posterior-view* ***B-*** *Posterior-anterior view.*

LUPV- Left upper pulmonary vein

RUPV- Right upper pulmonary vein

MVA- Mitral valve annulus

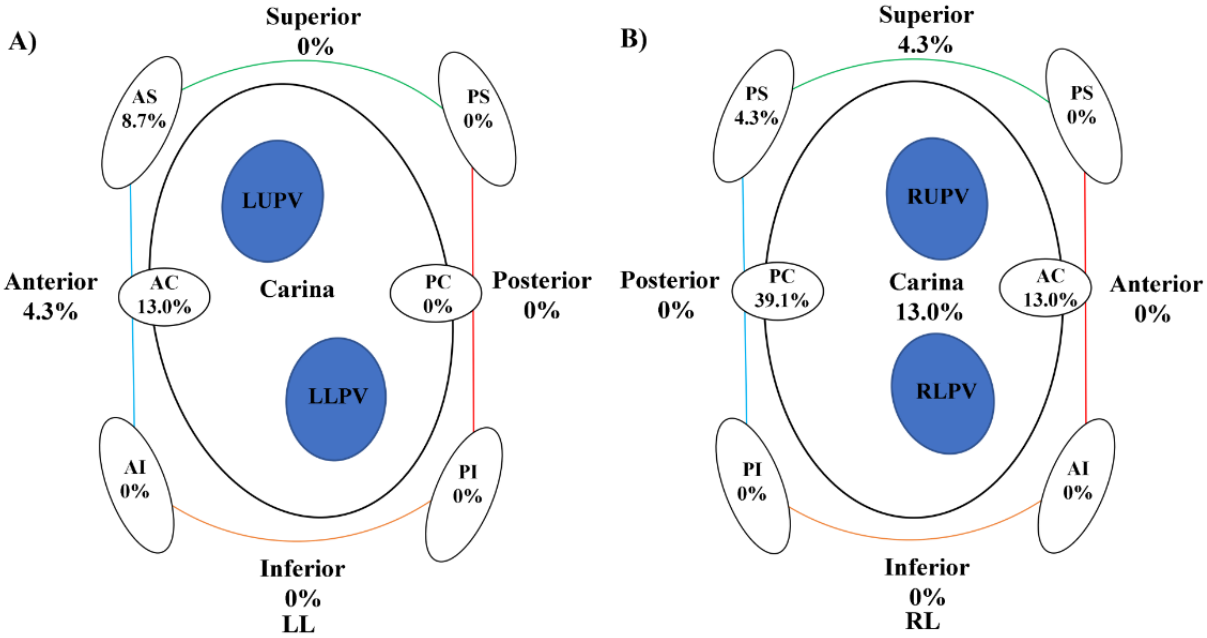

Figure 3A-B- *Demonstrates the anatomical sites requiring additional AI-guided ablation. A total of 23 anatomical sites were targeted.* ***A-*** *Left pulmonary veins in a left lateral (LL) view,* ***B-*** *Right pulmonary veins in a right lateral (RL) view).*

AS- Anterior superior
PS- Posterior superior
AC- Anterior carina
PC- Posterior carina
AI- Anterior inferior
PI- Posterior inferior

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