

The Effect of Atrial Fibrillation Ablation Techniques on P Wave Duration and P Wave Dispersion



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Background

A reduction in surface electrocardiogram (ECG) P wave duration and dispersion is associated with improved outcomes in atrial fibrillation ablation. We investigated the effects of different ablation strategies on P wave duration and dispersion, hypothesising that extensive left atrial (LA) ablation with left atrial posterior wall isolation would give a greater reduction in P wave duration than more limited ablation techniques.

Methods

A retrospective analysis of ECGs from patients who have undergone atrial fibrillation (AF) ablation was performed and pre-procedural sinus rhythm ECGs were compared with the post procedure ECGs. Maximal P wave duration was measured in leads I or II, minimum P wave duration in any lead and values were calculated for P wave duration and dispersion. Left atrial dimensions and medications at the time of ECG were documented. Ablation strategies compared were; pulmonary vein isolation (PVI) for paroxysmal atrial fibrillation (PAF) and the persistent AF (PsAF) ablation strategies of pulmonary vein isolation plus additional linear lesions (Lines), left atrial posterior wall isolation via catheter (PWI) and left atrial posterior wall isolation via staged surgical and catheter ablation (Hybrid).

Results

Sixty-nine patients' ECGs were analysed: 19 PVI, 21 Lines, 14 PWI, 15 Hybrid. Little correlation was seen between pre-procedure left atrial size and P wave duration ($r = 0.24$) but LA size and P wave duration was larger in PsAF patients. A significant difference was seen in P wave reduction driven by Hybrid AF ablation ($p < 0.005$) and Lines (<0.02). There was no difference amongst P wave dispersion between groups but the largest reduction was seen in the Hybrid ablation group.

Conclusions

P wave duration increased with duration of continuous atrial fibrillation. Hybrid AF ablation significantly reduced P wave duration and dispersion compared to other ablation strategies including posterior wall isolation via catheter despite this being the same lesion set.

Keywords

Atrial fibrillation • Catheter ablation • Surgical ablation • P wave dispersion

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Introduction

Atrial fibrillation (AF) is the commonest atrial arrhythmia, affecting 7% of the general population. Prolonged P wave duration on a standard surface electrocardiogram (ECG) has been associated with the development of atrial fibrillation [1–3] and AF recurrence following catheter or hybrid ablation. Conversely a reduction of P wave duration has been associated with favourable outcomes following ablation of atrial fibrillation [4–6].

P wave dispersion is the difference between the longest and shortest P wave duration on a surface ECG [7–9] and prolongation is associated with atrial fibrillation development in coronary artery disease and post cardiothoracic surgery [10,11] as well as a number of other clinical situations [9]. Reductions in P wave dispersion are associated with favourable outcomes following AF ablation [12].

The causes of P wave prolongation are complex but intra atrial conduction delay or block due to structural, neurohormonal or autonomic mechanisms have been implicated [9] while shortening of the P wave duration and P wave dispersion following AF ablation has been proposed to be due to structural atrial changes [13].

International guidelines recommend ablation for drug refractory AF and a wide range of approaches exist [14]. Improved outcomes are associated with P wave shortening for both paroxysmal and persistent AF in a variety of lesion sets [4,15,16]. Pulmonary vein isolation (PVI) is the established lesion set for paroxysmal AF but the optimal ablation strategy for persistent atrial fibrillation ablation is undefined [17]. The Substrate and Trigger Ablation for Reduction of Atrial Fibrillation Trial Part II (STAR AF II) trial showed that the addition of linear ablation or the targeting of complex fractionated atrial electrograms provided no increased survival from AF than PVI alone [18]. An alternative approach is the “box lesion pattern”, involving complete isolation of the pulmonary veins and posterior wall of the left atrium, done via catheter or surgical ablation which has shown promise in the treatment of persistent atrial fibrillation although randomised data is lacking [19–22].

Aims

In this retrospective study we compare P wave duration on the surface ECG pre and post ablation in paroxysmal atrial fibrillation patients following pulmonary vein isolation and persistent atrial fibrillation patients who have undergone either catheter ablation or a combined surgical and hybrid ablation. We investigated the effect of different AF ablation approaches and lesion sets on the surface P wave on a standard 12 lead ECG. We hypothesise that more extensive ablation will result in greater change in P wave duration and dispersion. It would then follow that left atrial posterior wall isolation would be associated with the greatest shortening of P wave duration and P wave dispersion due to greater atrial structural and substrate modulation than more limited lesion sets.

Material and Methods

This was a retrospective study of patients undergoing atrial fibrillation ablation at Derriford Hospital, Plymouth from 2012 to 2016. Four different ablation approaches were compared and we aimed for 20 patients in each group listed below (Figure 1).

1) Pulmonary vein isolation (PVI)

This is our standard lesion set for patients with symptomatic paroxysmal atrial fibrillation. Cases in this study were performed by two different operators via radio-frequency ablation with contact-force catheters using either the CARTO (Biosense-Webster, Diamond Bar, CA, USA) or Velocity (St Jude Medical, St. Paul, MN, USA) systems.

2) Pulmonary vein isolation with additional linear ablation, roof and/or mitral isthmus lines but without left atrial posterior wall isolation (Lines)

This lesion set was used for patients with symptomatic persistent atrial fibrillation. In these 21 cases the lesion set was created with radio-frequency ablation using CARTO with contact-force sensing catheters in nine patients and phased array pulmonary vein ablation catheter (PVAC) and tip-versatile ablation catheter (TVAC) catheters (Medtronic, Minneapolis, MN, USA) in 12 cases.

3) Left atrial posterior wall isolation via catheter with PVI + roof and floor lines (PWI)

This lesion pattern was used for later patients with symptomatic persistent atrial fibrillation using either the CARTO or Velocity systems with Smart-touch (Biosense – Webster) or Tactiath (St Jude Medical) catheters and contact force availability.

4) Two-stage non-concomitant hybrid ablation (Hybrid)

This procedure is offered to patients with long-standing persistent atrial fibrillation (continuous AF duration of greater than 1 year). It involves a surgical epicardial stage to isolate the left atrial posterior wall and target ganglionic plexi using the Cobra Fusion device (AtriCure Inc, Minneapolis, MN, US) with a later catheter ablation stage to confirm and re-isolate the left atrial posterior wall if required using the Velocity system.

As this study was a retrospective observational study of anonymised ECGs, formal ethical approval was considered to be unnecessary and was not sought.

Patients were identified from local registries of ablation procedures from two different operators. Hospital notes were then searched for 12-lead ECGs in sinus rhythm prior to the ablation procedure and ECGs taken immediately after the procedure. Where multiple ECGs were available, those closest to the ablation procedure were used. If the patient was in atrial fibrillation at the time of ablation the most recent ECG in sinus rhythm prior to the ablation was used. Details of left atrial dimensions and antiarrhythmic medication were documented at the time of the ablation procedures and recorded from the notes.

Measurement of maximal P wave duration on the ECGs was taken from the limb leads II or I using calipers and a rate ruler. All the ECGs used had been recorded at standard ECG

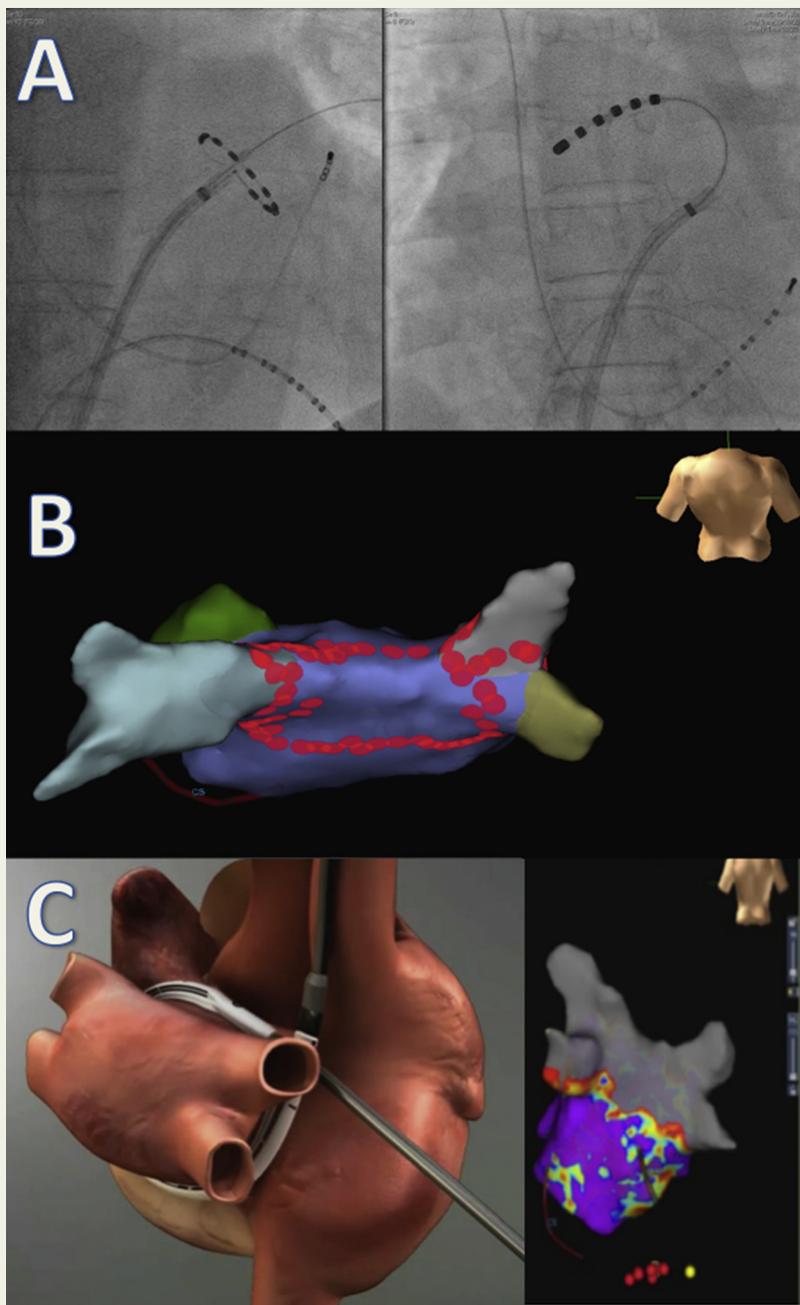


Figure 1 Creation of the lesion sets in the study. *Panel A* shows the PVAC catheter on the left and TVAC catheter on the right. This was used in 12/21 cases to isolate the pulmonary veins and perform linear ablation. *Panel B* shows the final lesion set following left atrial posterior wall isolation via catheter ablation using the Velocity system. *Panel C* demonstrates the two-stage hybrid ablation process whereby on the left the left atrial posterior wall is isolated first by epicardial ablation using the Cobra Fusion device. Patients then return for electroanatomical mapping and further ablation to complete isolation if required. The image on the right shows an isolated left atrial posterior wall. Abbreviations: TVAC, tip-versatile ablation catheter; PVAC, pulmonary vein ablation catheter.

settings of 25 mm/s and 10 mm/mV. One investigator (GF) identified and selected the ECGs as well as making the initial measurements of maximal P wave duration. The ECGs were then anonymised and randomised before being re-measured by three further investigators (DP, ED, SK) blinded to the initial results, ablation approach and timing of the ECG. At this stage an additional measurement of the minimal P wave

duration in any lead was calculated in the anonymised ECGs and a measurement of P wave dispersion was made by subtracting the largest P wave in the limb leads (I or II) from the shortest P wave duration in any lead. This resulted in four measurements of maximal P wave duration and three measurements of P wave dispersion for each ECG. The change in P wave duration and P wave dispersion pre and post ablation

was calculated for each procedure and a mean value calculated for each procedure.

The P wave duration, P wave reduction post ablation and the P wave dispersion measurements were compared for each ablation approach.

Statistical Analysis

Values given are mean (+/– standard deviation) unless stated otherwise. Change in P wave was compared between pre ablation and on the first ECG post procedure for each group with the Kruskal Wallis test used to analyse variance between groups and a using Wilcoxon Signed Rank Test used to compare interventions as the data was not normally distributed (Shapiro-Wilk test on change in P wave duration $p = 0.07$). Correlations between P wave change and left atrial AP diameter were examined using the Spearman correlation. Statistical analysis was performed using the R statistical package version 3.2.2 (The R project).

Results

Eighty-five procedures were identified from the registries of the different AF ablation approaches; of these only 69 patients had usable ECGs available from before and after the procedure. This resulted in 19 in the PVI group, 21 in the Lines group, 14 in the PWI and 15 in the Hybrid group. The patients who underwent PVI were all paroxysmal atrial fibrillation patients, whereas those in the Lines, PWI, and Hybrid groups all had persistent atrial fibrillation. All of the Hybrid group had longstanding persistent atrial fibrillation with continuous atrial fibrillation durations or greater than 1 year.

The increasing duration of atrial fibrillation was reflected in an increasing left atrial size between groups from PVI to Hybrid and also an increasing initial P wave duration from PVI to Hybrid. There was little correlation between P wave duration and left atrial AP diameter ($r = 0.2475$). No difference was seen in medications between ECG recordings as patients had antiarrhythmic medications continued up until the ablation procedure and were taking these drugs when the post-ablation ECGs were recorded on the day of procedure.

The findings of left atrial AP diameter, P wave change and P wave dispersion can be seen in [Table 1](#).

Intra-Observer Variability

One-hundred-and-twelve measurements of maximal P wave duration were recorded by all four observers. As minimal P wave duration was measured only by the three blinded observers they made a further 154 measurements on the study ECGs. The intraclass coefficient (ICC) statistic for the four observers was 0.58 (95% CI: 0.46–0.67) and when the same lead was used by each observer the reliability improved with an ICC statistic of 0.63 (95% CI: 0.5–0.74).

Correlation between the blinded measurements was excellent. Two-hundred-and-seventy-six measurements of maximal or minimal P wave duration were made by each of the three observers with a calculated ICC statistic of 0.8 (95% CI: 0.72–0.86).

P Wave Duration

A significant difference was seen in the change in mean P wave duration between groups (Kruskal-Wallis rank sum test $p = 0.016$). Hybrid ablation produced the largest reduction in P wave duration, followed by the Lines group, PWI and then PVI. There was a trend towards statistical significance comparing the Hybrid group against Lines ($p = 0.076$) and PWI ($p = 0.06$) but significance was only met compared to PVI alone ($p = 0.005$). The Lines group had the next most significant reduction in P wave duration and this was again statistically significant against the PVI group ($p = 0.04$) but not against PWI ($p = 0.35$) (Figures 2 and 3).

P Wave Dispersion

The Kruskal-Wallis test did not suggest a significant difference between groups ($p = 0.44$) but, again, there was a greater reduction in mean P wave dispersion with complexity of ablation from PVI to Hybrid ablation, which resulted in the largest decrease in P wave dispersion. The Hybrid group was the only approach to achieve a statistically significant difference when compared against the combined other three approaches ($p = 0.02$) (Figure 4).

Discussion

In this study we investigated the association between different ablation strategies and changes in surface ECG P wave duration and P wave dispersion following ablation, hypothesising that more extensive ablation would lead to greater change in P wave duration. These simple measurements have been shown to be easily measured on a standard 12-lead ECG [7] and prolongation of both has previously been shown to be associated with the development of atrial fibrillation [3,1] while reductions of P wave duration and dispersion following catheter ablation confers better outcomes [12,23,24].

This study demonstrates that measurements of P wave duration on standard ECGs can be reliably and reproducibly analysed. There was fair to good correlation between all four observers, which was improved when the same ECG lead was used. Correlation amongst the three observers who made blinded measurements was excellent. Given that standard ECGs were measured with the need to round measurements up or down to the nearest 10 ms it is to be expected that some intra observer variability was seen. For further study it may be that measuring ECGs at 50 mm/s rather than the standard 25 mm/s would improve accuracy and even result in improved correlation.

As in previous studies [5], P wave duration in this study was associated with the duration of atrial fibrillation and

Table 1 Summary of findings.

| Ablation Technique | Number of patients | AF syndrome | Pre procedure Left atrial AP diameter (mm) | Pre procedure maximal P wave duration (ms) | Pre Procedure P wave dispersion (ms) | Mean change in P wave duration | Median Change in P wave duration (IQR) | p value | Mean change in P wave dispersion (ms) | Median Change in P dispersion (IQR) | p value (pdisp) |
|--------------------|--------------------|----------------------------|--|--|--------------------------------------|--------------------------------|--|-----------|---------------------------------------|-------------------------------------|-----------------|
| PVI | 19 | Paroxysmal AF | 36.79 | 114 | 58.5 | 0.66 | 5 (-7.1-14.2) | p = 0.88 | -2.37 | -2.37 (-10-10) | p = 0.67 |
| Lines | 21 | Persistent AF | 42.25 | 123 | 64 | -10.51 | -10.51 (-25-2.5) | p < 0.02 | -7.71 | -10 (-20 - 10) | p = 0.17 |
| PWI | 14 | Persistent AF | 39.64 | 118 | 51 | -7.86 | 0 (-21.7-0) | p = 0.21 | -6.86 | 0 (-33 - -6.9) | p = 0.57 |
| Hybrid | 15 | Longstanding Persistent AF | 46.2 | 133 | 69 | -27.45 | -37.5 (-50 to -3.75) | p < 0.005 | -22.07 | -28.5 (-36.8 - 6.25) | p < 0.05 |

Abbreviations: AF, atrial fibrillation; PVI, pulmonary vein isolation; Lines, additional linear lesions; PWI, posterior wall isolation.

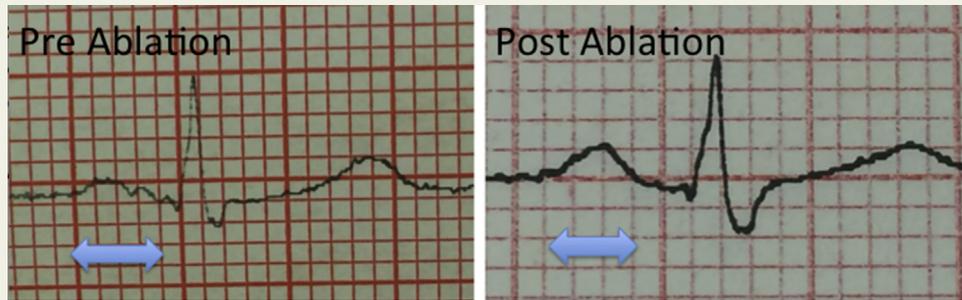


Figure 2 Reduction in P wave duration seen on a surface ECG pre and post AF ablation. (Lead II, 25 mm/s, 10 mm/1 mV). Abbreviations: ECG, electrocardiograph; AF, atrial fibrillation.

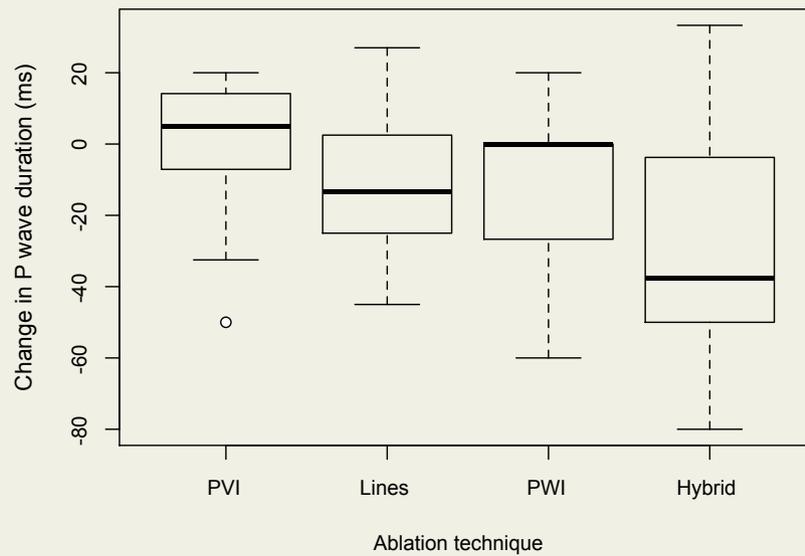


Figure 3 Box plot of change in mean P wave duration following ablation.

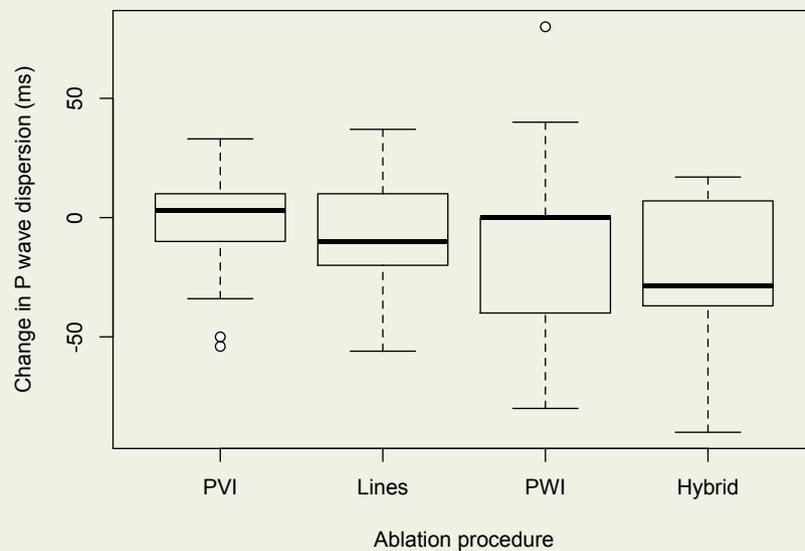


Figure 4 Box plot of change in mean P wave dispersion following ablation.

increased from patients with paroxysmal atrial fibrillation to patients with persistent and longstanding persistent atrial fibrillation. Left atrial size also increased between these groups but no correlation was seen between the left atrial AP diameter and P wave duration suggesting structural changes alone do not account for P wave prolongation.

The largest reduction in surface ECG P wave duration following ablation was seen in the Hybrid ablation group but a significant reduction was also demonstrated in the group who underwent pulmonary vein isolation with linear ablation (roof and mitral isthmus ablation). Hybrid ablation alone resulted in a significant reduction in P wave dispersion when compared to the other ablation approaches. This supports the findings from previous studies that reductions in P wave duration and P wave dispersion are seen following AF ablation but the study was not designed to obtain follow-up to provide outcome data in these groups.

The mechanism determining P wave duration is not known but is most likely due to a complex series of factors including structural changes in the atrium, atrial fibrosis, intra-atrial conduction time and autonomic innervation [16,25]. The findings of this study would suggest that more extensive ablation is linked with greater reduction in P wave duration but the confounding factor is that P wave duration increases with duration of atrial fibrillation and longer durations of atrial fibrillation have more complex ablation strategies.

The greatest change in P wave duration and P wave dispersion was seen in the Hybrid group. The left atrial posterior wall isolation lesion set in the Hybrid and PWI groups was identical and the main difference between them is the surgical epicardial ablation and ganglionic plexi excision in the Hybrid group. One claimed advantage of surgical ablation over catheter ablation is that ganglionic plexi can be directly targeted and excised which may result in greater autonomic modulation [26]. In this study P wave duration was longer in the Hybrid group at baseline but greater reductions in P wave duration and P wave dispersion were seen in this group compared to the PWI group.

No measurement of autonomic modulation was made in these cases but autonomic triggers for atrial fibrillation are well described. Studies have shown that targeting ganglionic plexi, which can be mapped endocardially and targeted by catheter ablation can improve outcomes of atrial fibrillation ablation [27–29]. Changes in autonomic innervation have also been shown to effect the P wave on a surface ECG [30] while P wave prolongation has been demonstrated in spinal injury patients with autonomic dysfunction who had a subsequent increased risk of AF [31] and also diabetics with neuropathies [32].

The association between epicardial ablation, ganglionic plexi excision and changes in P wave duration and P wave dispersion warrants further study. If these are surrogate markers of autonomic modulation then it may be that where P wave duration or dispersion is shortened by catheter ablation from any approach it is due to ablation of autonomic triggers rather atrial substrate modulation. This could

provide a novel measurement to assess the degree of autonomic modulation following a catheter or surgical ablation as well as give an indication of the likelihood of AF recurrence. Further research could lead to alternative ablation endpoints or follow-up strategies for patients whose P wave duration remains prolonged.

Limitations of the Study

This is a small, retrospective observational study in which baseline P wave duration varied between groups. Longer pre-ablation P wave duration may allow for greater P wave shortening with ablation and we have not made direct randomised comparison between ablation techniques and the mean post procedure P wave duration is similar across all groups. There is a greater change for P wave dispersion with a lower post procedure value after Hybrid ablation than the other groups but this is again non-randomised data that may be susceptible to unrecognised confounding factors.

The ECG measurement of P waves was limited by the retrospective study design in which only standard ECGs were available. Greater accuracy may be shown by either using ECGs at 50 mm/s speed or automated measurement. It may also have been possible to enlarge the ECGs for measurement. Due to the use of standard ECGs the measurement of P wave duration was always to the nearest 10 ms and automated or computerised measurements may give rise to greater accuracy.

Conclusions

P wave duration and P wave dispersion increased with duration of continuous atrial fibrillation from paroxysmal to long-standing persistent atrial fibrillation. Hybrid AF ablation was associated with the largest reduction in P wave duration post ablation and was the only technique associated with a significant decrease in P wave dispersion. We hypothesise that the greater reduction in P wave dispersion is due to autonomic rather than substrate modulation.

Conflicts of Interest and Disclosures

GH has intellectual property related to catheter design and has received honoraria and speaker fees from AtriCure Inc, St Jude.

DP has received fellowship support from AtriCure Inc.

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