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A minimal or maximal ablation strategy to achieve pulmonary vein isolation for paroxysmal atrial fibrillation: a prospective multi-centre randomized controlled trial (the Minimax study)

Alex J.A. McLellan[1,2,3,4], Liang-Han Ling[1,2,3,4,†], Sonia Azzopardi[1,2], Geraldine A. Lee[1,2], Geoffrey Lee[1,2,3,4], Saurabh Kumar[1,2,3,4], Michael C.G. Wong[1,2,3,4], Tomos E. Walters[1,2,3,4], Justin M. Lee[3,4], Khang-Li Looi[10], Karen Halloran[3,4], Martin K. Stiles[8], Nigel A. Lever[9], Simon P. Fynn[10], Patrick M. Heck[10], Prashanthan Sanders[7], Joseph B. Morton[3,4,5], Jonathan M. Kalman[3,4,5], and Peter M. Kistler[1,2,3,4,5,6*]

[1]Alfred Heart Centre, Alfred Hospital, Melbourne, VIC, Australia; [2]Baker IDI Heart and Diabetes Institute, 75 Commercial Road, Melbourne, VIC 3004, Australia; [3]Department of Cardiology, Royal Melbourne Hospital, Parkville, VIC, Australia; [4]Department of Medicine, University of Melbourne, Parkville, VIC, Australia; [5]Melbourne Private Hospital, Parkville, VIC, Australia; [6]Avenue Private Hospital, Windsor, VIC, Australia; [7]Centre for Heart Rhythm Disorders, University of Adelaide and Royal Adelaide Hospital, Adelaide, SA, Australia; [8]Waikato Hospital, Hamilton, New Zealand; [9]Auckland City Hospital, Auckland, New Zealand; and [10]Papworth Hospital, Cambridge, UK

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Aims Pulmonary vein isolation (PVI) is the cornerstone of catheter ablation of atrial fibrillation (AF). The intervenous ridge (IVR) may be incorporated into ablation strategies to achieve PVI; however, randomized trials are lacking. We performed a randomized multi-centre international study to compare the outcomes of (i) circumferential antral PVI (CPVI) alone (*minimal*) vs. (ii) CPVI with IVR ablation to achieve individual PVI (*maximal*).

Methods and results Two hundred and thirty-four patients with paroxysmal AF underwent CPVI and were randomized to a minimal or maximal ablation strategy. The primary outcome of recurrent atrial arrhythmia was assessed with 7-day Holter monitoring at 6 and 12 months. PVI was achieved in all patients. Radiofrequency ablation time was longer in the maximal group (46.6 $\pm$ 14.6 vs. 41.5 $\pm$ 13.1 min; $P < 0.01$), with no significant differences in procedural or fluoroscopy times. At mean follow-up of 17 $\pm$ 8 months, there was no difference in freedom from AF after a single procedure between a minimal (70%) and maximal ablation strategy (62%; $P = 0.25$). In the minimal group, ablation was required on the IVR to achieve electrical isolation in 44%, and was associated with a significant reduction in freedom from AF (57%) compared with the minimal group without IVR ablation (80%; $P < 0.01$).

Conclusion There was no statistically significant difference in freedom from AF between a minimal and maximal ablation strategy. Despite attempts to achieve PVI with antral ablation, IVR ablation is commonly required. Patients in whom antral isolation can be achieved without IVR ablation have higher long-term freedom from AF (the Minimax study; ACTRN12610000863033).

Keywords Atrial fibrillation • Pulmonary vein isolation • Ablation • Intervenous ridge • Reconnection

Introduction

Catheter ablation may be curative for patients with atrial fibrillation, the most prevalent sustained arrhythmia in the community.[1] Since the landmark observation recognizing the role of the pulmonary veins (PVs) as the predominant site of triggers responsible for atrial fibrillation (AF),[2] catheter ablation has evolved as an important treatment.[1] Catheter ablation is more effective than anti-arrhythmic drug

* Corresponding author. Tel: +61 3 8532111, Fax: +61 3 85321111, Email: peter.kistler@bakeridi.edu.au
† Co-first author.

therapy, although hampered by arrhythmia recurrence.[3] A worldwide registry of 182 centres reported a success rate of 75% after a mean of 1.3 procedures in patients with paroxysmal AF undergoing catheter ablation.[4]

Despite advances in catheter ablation technology, imaging and operator experience PV reconnection remains the 'achilles heel' of PV isolation (PVI). The PVs are reconnected in the majority of patients who undergo repeat procedures for recurrent symptomatic paroxysmal AF.[5]

We hypothesized that linear ablation along the intervenous ridge (IVR) to achieve individual PV isolation as part of antral vein isolation may improve single procedure success in patients with paroxysmal AF. Put simply one site of recovery along the ablation line reconnects one PV rather than potentially two veins. Individual PV isolation may not be performed routinely due to the technical challenges of catheter contact on the IVR and concerns regarding increased ablation and procedure time and the potential risks of PV stenosis.

The aim was to perform a randomized multi-centre international study to compare the outcomes of two commonly used strategies for catheter ablation for PVI in patients with paroxysmal atrial fibrillation.

Methods

Study population

We recruited 234 patients with highly symptomatic paroxysmal atrial fibrillation refractory to medical management to undergo circumferential PVI randomized to a minimal or maximal ablation strategy between January 2010 and August 2013. The study protocol was approved by the Human Research Ethics Committee at each of the participating hospitals and associated research institutions in Australia, New Zealand, and the UK (Clinical trial registration: ACTRN12610000863033).

Paroxysmal AF was defined according to consensus guidelines.[1] Exclusion criteria included non-paroxysmal forms of AF, previous PVI, age <18, and incapacity to provide informed consent. Patients with a long left common PV (>15 mm from common orifice to bifurcation[6]) were excluded due to an inappropriateness of branch isolation if randomized to maximal ablation group. Baseline characteristics and failed anti-arrhythmic drugs were recorded. A pre-procedural transthoracic echocardiogram was routinely performed.

Study design

This was a prospective single blind randomized controlled trial. Patients were block randomized (block size, $n = 8$) using computer random allocation 1 : 1 to a minimal or maximal ablation strategy, with patients blinded to group allocation (electrophysiologists were necessarily aware of group allocation). Assessment of 7-day Holter monitoring for recurrent AF was performed blinded to treatment allocation.

Catheter ablation

Catheter ablation involved antral circumferential PVI as described previously.[7] All anti-arrhythmic medications except amiodarone were stopped five half-lives before the procedure (amiodarone was ceased 2 weeks before the procedure), and peri-procedural anti-coagulation strategy was at the discretion of the treating electrophysiologist.

The procedures were performed either under general anaesthetic or under conscious sedation as determined by the operator. All patients underwent transoesophageal echocardiography to rule out intra-cardiac thrombus. A decapolar catheter was positioned in the coronary sinus and a quadripolar catheter was positioned in the His bundle position via femoral venous access. Two 8 or 8.5 F long sheaths (SL1, St. Jude Medical, St. Paul, MN, USA) were introduced into the left atrium with trans-septal puncture performed with a BRK-1 needle (St. Jude Medical) under fluoroscopy and TEE guidance at the operator's discretion. A Lasso circular mapping catheter (Biosense Webster, Diamond Bar, CA, USA) or a Reflexion spiral catheter (St. Jude Medical) was introduced through the SL1 sheath into the left atrium for electrical mapping of the PVs. An irrigated ablation catheter (4 mm, unidirectional or bidirectional, NaviStar® or EZ Steer® Thermocool®, or Thermocool SmartTouch® (target contact-force >10 g), Biosense Webster or Safire™ BLU™, St. Jude Medical) was introduced through the SL1 sheath into the left atrium for ablation (maximum power 30–35 W reduced to 25 W on the posterior wall). Upon completion of the trans-septal puncture, patients received intravenous heparin to maintain an activated clotting time of >350 s.

Left atrial geometry was created using a three-dimensional electroanatomic mapping system (CARTO-CARTO 3, Biosense-Webster or NavX, St. Jude Medical) and fused with pre-procedural CT or MRI. Pre-procedural cardiac anatomy from CT or MRI was used to determine the dimensions of intervenous and left-PV-left atrial appendage ridges, as described previously.[8] Selection of mapping system and irrigated ablation catheters was at the discretion of the operator.

Catheter ablation was delivered at the PV antrum proximal to the PV–LA junction at 30 W reduced to 25 W on the posterior wall and IVR until electrical isolation was achieved. Pulmonary vein isolation (defined by PV entrance and exit block) was confirmed 30 min after initial isolation including two challenges with intravenous adenosine 18 mg to assess for acute reconnection. If transient or persistent reconnection was present further mapping and ablation was applied to re-establish PV isolation and IV adenosine repeated until no reconnection was evident. The point of electrical isolation for each PV was recorded, as were sites of acute reconnection. Procedural duration, ablation times, radiation dose and fluoroscopy times were recorded. Patients remained in hospital for 48 h post-procedure with resumption or continuation of anti-coagulation from 6 h post-procedure.

Maximal vs. minimal ablation strategy

Minimal ablation (en bloc electrical isolation of PVs as a pair)

This strategy involves wide encirclement of the PVs in ipsilateral pairs with the endpoint of electrical isolation of all 4 PVs (see *Figure 1*). Ablation on the IVR was permissible only after the encircling ablation is complete and sequential repositioning of the circular mapping catheter in each vein confirms the site of breakthrough at the IVR (*Figure 2*).

Maximal ablation (electrical isolation of individual PVs)

This strategy involves antral electrical isolation of the superior vein with linear ablation across the IVR at 25 W until electrical isolation is achieved before ablation is deployed to encircle the inferior vein. This approach ensured electrical isolation of individual veins from each other.

Follow-up

After an initial 3-month blanking period, arrhythmia recurrence was defined as documented atrial arrhythmia (AF or atrial tachycardia) lasting >30 s. Post-procedure patients were followed up in clinic at 1, 3, 6, and 12 months with ongoing review 6 monthly. Patients underwent a 7-day Holter monitor at 6 monthly intervals, with event monitoring performed for patients with recurrent symptoms in the intervening periods. Repeat cardiac computed tomography scan was performed routinely in the first 40 patients at 3 months post-ablation for the presence of PV

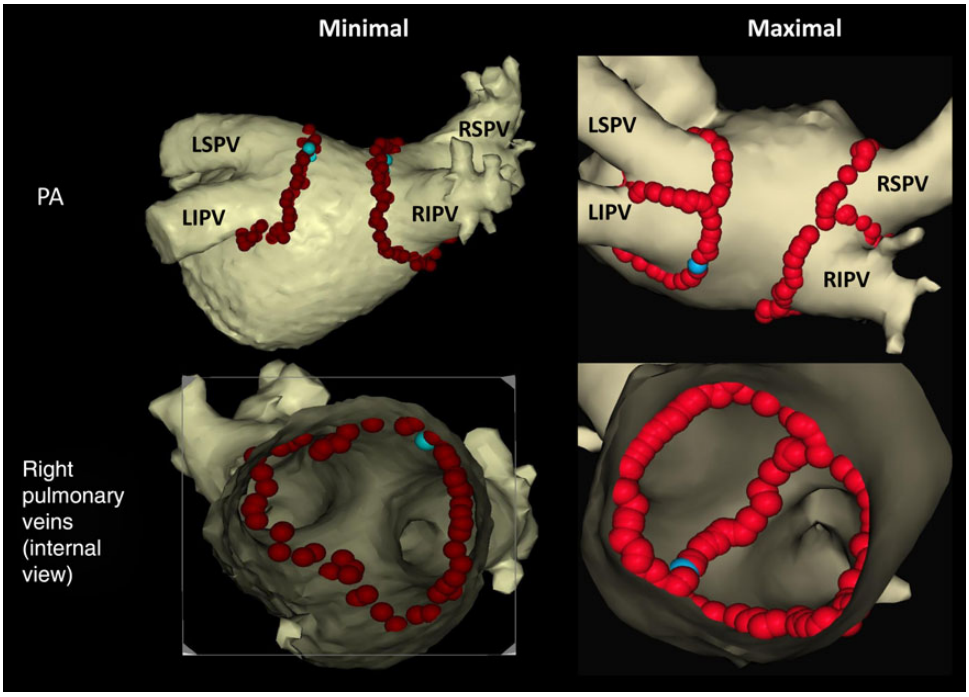

Figure 1 Comparison of minimal and maximal ablation strategy on postero-anterior and internal view of the pulmonary veins. Red dots represent ablation points, blue dots represent isolation points. LSPV, left superior pulmonary vein; LIPV, left inferior pulmonary vein; RSPV, right superior pulmonary vein; RIPV, right inferior pulmonary vein.

stenosis. Patients undergoing redo procedures routinely had pulmonary venography for assessment of PV stenosis.

Statistics

All statistical analysis was performed using SPSS software version 21.0 (SPSS, Chicago, IL, USA) as an intention to treat analysis. A power analysis was performed based on a 20% improvement (60–80%) in 12-month procedural success as clinically relevant, such that a sample of size of 200 patients (100 per arm without drop-out) would be needed using a two-sided *P*-value of 0.05, and power of 0.80. Continuous variables are expressed as a mean ± SD with comparisons between groups performed with either an unpaired Student's *t*-test, or where a normal distribution could not be assumed the Mann–Whitney *U*-test. Categorical variables are expressed as numbers and percentages, and were compared with a χ^2 test. Impact of a minimal vs. maximal ablation strategy on freedom from AF was assessed using Kaplan–Meier analysis after single procedure off anti-arrhythmic medications. Multiple procedure freedom from AF at completion of the trial (incorporating patients with freedom from AF after redo procedures) was assessed at the end of the trial as proportions compared with χ^2 analysis. A two-sided *P*–value of <0.05 was considered statistically significant.

Results

Baseline patient characteristics

Two hundred and thirty-four patients (mean age 59 ± 10 years, male 66%, hypertension 38%, mean AF duration 58 ± 54 months, range 6–360 months) were enrolled and randomized 1 : 1 to a minimal or maximal ablation strategy (see Supplementary material online, *Figure S1*: CONSORT diagram). The groups were well matched for baseline co-morbidities, previous anti-arrhythmic medications, symptomatic status on questionnaire, and echocardiographic parameters (*Table 1*).

Procedural characteristics

Pulmonary vein isolation was achieved in every patient. Total ablation times were significantly longer in the maximal ablation group (46.6 ± 14.6 vs. 41.5 ± 13.1 min in the minimal group; $P < 0.01$). Fluoroscopy time, procedural time, radiation dose, or use of contact-force sensing catheter did not differ significantly between minimal and maximal ablation groups. There was no significant difference in acute PV reconnection between patients in the minimal (49 patients, 43%) and maximal groups (44 patients, 38%; $P = 0.44$) (*Table 2*).

Ablation on the IVR was performed in all 117 patients in the maximal group vs. 51 patients (44%) in the minimal group who required IVR ablation to achieve PVI ($P < 0.001$).

Follow-up and redo procedures: intention to treat

Minimal vs. maximal

On an intention to treat analysis, there was no difference in freedom from AF after single procedure off anti-arrhythmic medication between the minimal and maximal ablation groups at a mean follow-up of 17 ± 8 months (70 vs. 62%, respectively; $P = 0.25$) (*Figure 3*). There was no difference in the mechanism of arrhythmia recurrence (AF, atrial tachycardia, or both) between the two groups. There was no difference in quality of life at follow-up between the two groups.

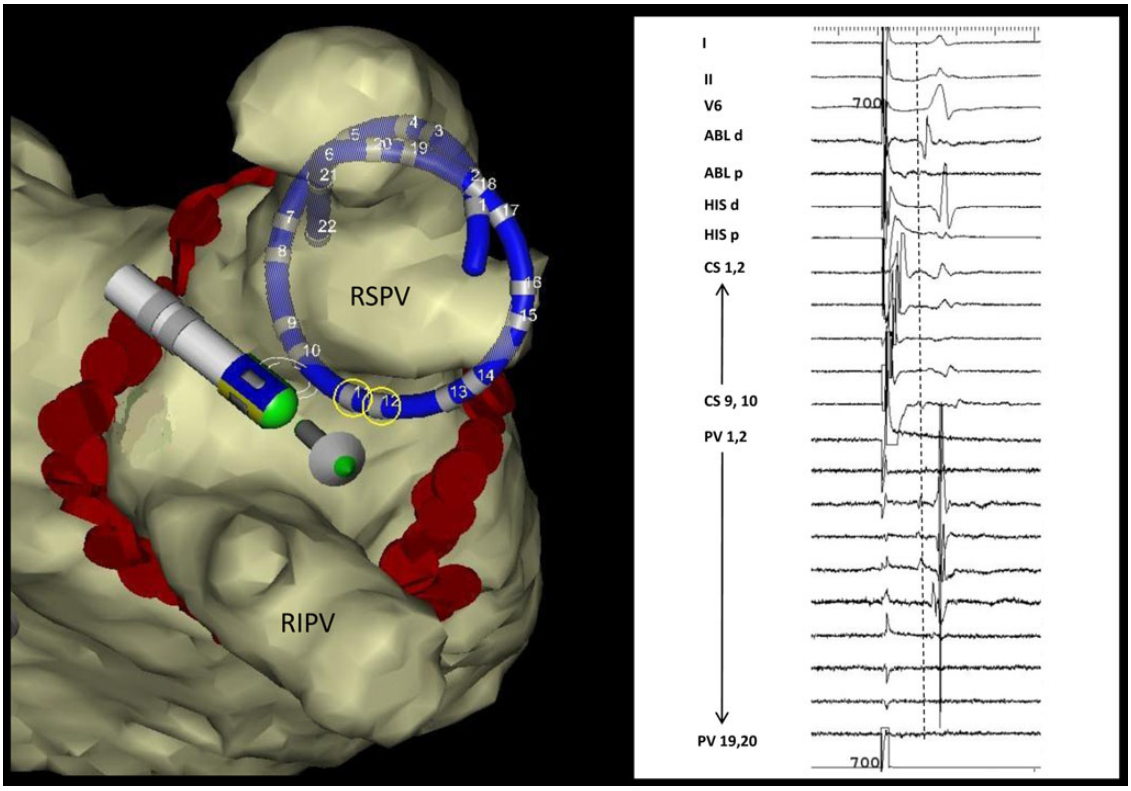

Figure 2 Representative figure of a minimal patient requiring ablation on the intervenous ridge. Despite a complete antral circumferential ring, the right superior pulmonary vein remains connected (PV 1–2 → PV 19–20) with earliest activation at PV11–12 (adjacent to the intervenous ridge); the ablator signal is earlier still (ABLd) and isolation was achieved at this site.

Redo procedures were performed in 20 patients (17%) in the minimal group and 28 patients (24%) in the maximal group ($P = 0.20$). At redo procedure, 43 patients (90%) had PV reconnection of at least one PV, and there was no difference in the site of reconnection at the IVR (maximal group 43% vs. minimal group 55%, $P = 0.34$). On pulmonary venography at redo procedure, there was no patient with evidence of PV stenosis related to the index procedure. After multiple procedures, there remained no significant difference in freedom from AF between the minimal (80%) and maximal (80%) groups ($P = 0.87$) (*Table 3*).

Sub-group analysis

Minimal vs. minimal requiring intervenous ridge ablation

In the minimal group, 51 of 117 patients (44%) required ablation on the IVR to achieve electrical isolation. There were no significant differences in baseline characteristics between patients who did and did not require IVR ablation within the minimal ablation group (*Table 4*). The radiofrequency ablation time was significantly longer in the minimal group who required IVR ablation compared with minimal group patients who did not require IVR ablation (47.4 ± 14.4 vs. 37.0 ± 9.9 min; $P < 0.001$), and was associated with longer procedure time in the group requiring IVR ablation (182.5 ± 38.6 vs. 157.2 ± 38.1 min; $P = 0.001$). There were no significant differences in fluoroscopy time or radiation dose between groups. Acute PV reconnection occurred in 28% of the minimal group who did not require IVR ablation and in 62% of the minimal group who required IVR ablation to achieve isolation ($P < 0.001$), with the IVR being the site of acute reconnection significantly more frequently in patients requiring IVR ablation to achieve initial isolation (68% vs. 25% in patients without IVR ablation, $P < 0.01$).

The dimensions of the left IVR length were significantly larger in minimal group patients who required ablation on the IVR to achieve electrical isolation vs. minimal patients not requiring IVR ablation (length 16.5 ± 4.3 vs. 13.6 ± 2.8 mm, $P < 0.01$; and area 1.3 ± 0.5 vs. 1.0 ± 0.7 mm, $P = 0.04$). However, there were no significant differences for the right IVR, left PV-left atrial appendage ridge, or presence of a short left common PV (see Supplementary material online, *Table S1*).

Follow-up and redo procedures: sub-group analysis

Minimal without intervenous ridge ablation vs. minimal requiring intervenous ridge ablation

Within the minimal group, there was a significant increase in freedom from AF in patients who did *not* require IVR ablation to achieve electrical isolation (80%) compared with those who did require IVR ablation (57%; $P < 0.01$) (*Figure 4*). There was no significant difference in mechanism of arrhythmia recurrence between these

Table 1 Baseline patient characteristics

	Minimal (n = 117)	Maximal (n = 117)	P-value
Age (years)	59.0 ± 8.8	59.1 ± 10.5	0.93
Sex: male	75 (64)	79 (68)	0.58
AF duration (months)	52.2 ± 55.7	64.5 ± 52.3	0.09
Hypertension	44 (38)	45 (38)	0.81
LVH	6 (5)	9 (8)	0.41
Ischaemic heart disease	13 (11)	9 (8)	0.39
Heart failure	1 (1)	4 (4)	0.17
Diabetes	6 (5)	3 (3)	0.31
Lone AF	66 (56)	63 (55)	0.80
Anti-arrhythmic drugs			
Sotalol	62 (53)	70 (60)	0.29
Flecainide	84 (72)	79 (68)	0.48
Amiodarone	34 (29)	31 (27)	0.66
Number of failed AAD	1.5 ± 0.7	1.6 ± 0.7	0.60
Quality of life			
CCS-SAF	3.0 ± 0.6	3.1 ± 0.5	0.62
SF-36, physical component summary	43.5 ± 11.0	44.2 ± 10.9	0.76
SF-36, mental component summary	48.0 ± 10.0	49.4 ± 10.2	0.36
Echocardiography			
LA area (cm^2)	24.5 ± 5.7	23.5 ± 4.9	0.16
LVEF (%)	59.2 ± 7.0	59.8 ± 6.5	0.52

All values are mean ± SD or number (%).
AF, atrial fibrillation; LVH, left ventricular hypertrophy; AAD, anti-arrhythmic drug; CCS-SAF, Canadian Cardiovascular Society Severity of Atrial Fibrillation scale; SF-36, Short Form-36 health survey; LA, left atrial; LVEF, left ventricular ejection fraction.

Table 2 Procedural characteristics

	Minimal (n = 117)	Maximal (n = 117)	P-value
Sinus rhythm pre-procedure	103 (88)	99 (85)	0.45
Procedure time (min)	167.9 ± 40.2	170.0 ± 34.2	0.45
Fluoroscopy time (min)	23.2 ± 6.7	24.6 ± 8.1	0.28
Radiation dose (mGy × cm^2)	39 069 ± 21 880	39 183 ± 28 679	0.39
Contact-force catheter	36 (31)	29 (25)	0.31
Total RF time (min)	41.5 ± 13.1	46.6 ± 14.6	<0.01
Right PV RF time (min)	21.0 ± 7.4	24.0 ± 8.2	<0.01
Left PV RF time (min)	19.5 ± 7.9	21.8 ± 10.1	0.04
PV isolation	117 (100)	117 (100)	1.0
PV Potentials	63 (57)	53 (48)	0.18
Isolation on ridge (left)	37 (33)	53 (48)	0.02
Isolation on ridge (right)	23 (21)	43 (39)	<0.01
Isolation on ridge (either)	51 (44)	74 (67)	<0.01
Acute reconnection	49 (43)	44 (38)	0.44
Acute reconnection on IVR	25 (51)	20 (45)	0.61
Intra-procedural DCR	15 (13)	17 (15)	0.74
Complications	5 (4)	2 (2)	0.24

All values are mean ± SD or number (%).
RF, radiofrequency ablation; PV, pulmonary vein; IVR, intervenous ridge; DCR, direct current cardioversion.

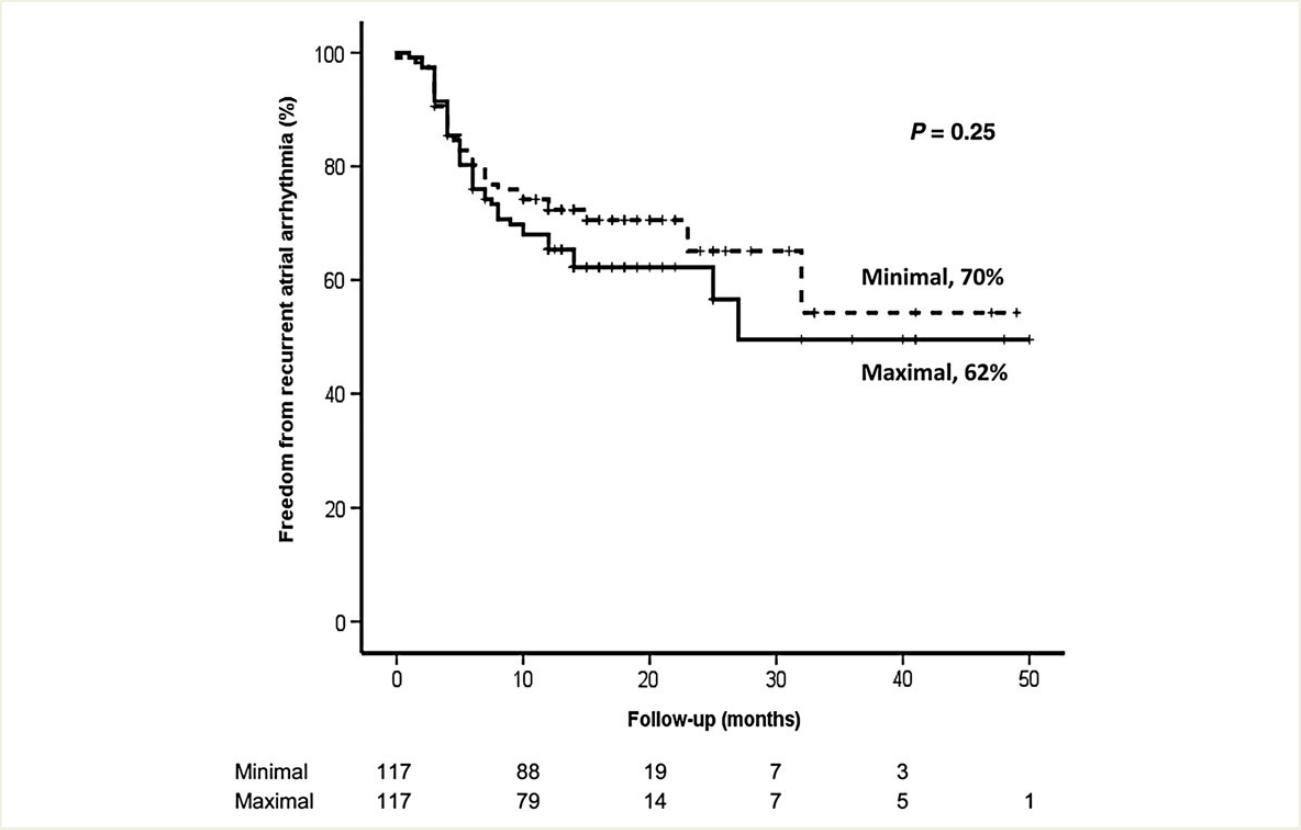

Figure 3 Single procedural success off anti-arrhythmic medications: intention to treat analysis.

Table 3 Follow-up

	Minimal (n = 117)	Maximal (n = 117)	P-value
Freedom from AF	82 (70)	73 (62)	0.25
Recurrence			0.85
AF	21 (60)	24 (55)	
AT (atrial tachycardia)	7 (20)	11 (25)	
AF+AT	7 (20)	9 (20)	
Redo procedure	20 (17)	28 (24)	0.20
PV reconnection			0.34
IVR	11 (55)	12 (43)	
Not at IVR	6 (30)	14 (50)	
No PV reconnection	3 (15)	2 (7)	
Number of AAD at last follow-up	0.2 ± 0.4	0.2 ± 0.4	0.79
Multiple procedure freedom from AF	94 (80)	93 (80)	0.87
Echocardiography			
LA area (cm^2)	21.4 ± 5.2	21.0 ± 4.2	0.65
LVEF (%)	61.2 ± 6.9	62.0 ± 6.6	0.54
Quality of life			
CCS-AF	0.8 ± 1.2	0.8 ± 1.2	0.69
SF-36, physical component summary	46.7 ± 11.4	46.8 ± 10.3	0.97
SF-36, mental component summary	51.9 ± 10.3	53.8 ± 9.0	0.24

All values are mean ± SD or number and (percentage). For abbreviations refer previous tables.

Table 4 Minimal ablation group

	Minimal ($n = 66$)	Minimal + IVR ($n = 51$)	*P*-value
Patient characteristics			
Age (years)	59.1 ± 9.3	58.9 ± 8.3	0.89
Sex: male	44 (67)	31 (61)	0.51
AF duration (months)	55.3 ± 62.7	48.6 ± 46.6	0.54
Hypertension	28 (42)	16 (31)	0.22
Ischaemic heart disease	8 (12)	5 (10)	0.69
Lone AF	33 (50)	34 (65)	0.11
Number of failed AAD	1.5 ± 0.7	1.6 ± 0.7	0.76
LA area (cm^2)	24.5 ± 5.6	24.6 ± 5.9	0.89
LVEF (%)	60.0 ± 6.9	57.9 ± 7.1	0.15
Procedure characteristics			
Procedure time (min)	157.2 ± 38.1	182.5 ± 38.6	0.001
Fluoroscopy time (min)	22.5 ± 5.5	24.2 ± 8.0	0.20
Radiation dose (mGy × cm^2)	40462 ± 22970	37015 ± 20259	0.43
Total RF time (min)	37.0 ± 9.9	47.4 ± 14.4	<0.001
PV potentials	37 (58)	26 (55)	0.79
Acute reconnection	18 (28)	31 (62)	<0.001
Acute reconnection IVR	4 (25)	18 (68)	<0.01
Follow-up			
Freedom from AF	53 (80)	29 (57)	<0.01
Recurrence: AF	6 (46)	15 (68)	0.38
Recurrence: AT	4 (31)	3 (14)	
Recurrence: AF + AT	3 (23)	4 (18)	
Redo procedure	7 (11)	13 (26)	0.03
Multiple procedure freedom from AF	60 (91)	34 (67)	0.001

All values are mean ± SD or number (%). For abbreviations refer previous tables.

two groups (*Table 4*). Patients in the minimal group who required IVR ablation (13 patients, 26%) were more likely to undergo repeat procedures compared with those not requiring IVR ablation (7 patients, 11%; $P = 0.03$). There was no difference in the proportion of patients with reconnection sites on the IVR at redo procedure (57% in minimal without IVR ablation vs. 54% in the minimal with IVR ablation; $P = 0.99$). After multiple procedures, 91% of minimal patients who did not require IVR ablation at initial procedure were free of recurrent arrhythmia, compared with 67% in patients who did require IVR ablation at initial procedure ($P = 0.001$).

Minimal without intervenous ridge ablation vs. minimal with intervenous ridge ablation vs. maximal

The single procedure success of PVI was significantly better for minimal patients without IVR ablation (80%) compared with maximal patients (62%, $P = 0.02$), with no difference between the maximal patients (62%) and minimal patients with IVR ablation (57%, $P = 0.45$). After multiple procedures minimal patients without IVR ablation had significantly improved freedom from AF compared with maximal patients (91 vs. 80%; $P = 0.045$). There was a non-significant trend for increased multiple procedural success between the maximal group and minimal group with IVR ablation (80 vs. 67%; $P = 0.08$).

Contact-force guided ablation

Sixty-four of 234 patients (28%) had contact-force sensing catheters utilized, with no difference in utilization between the minimal (31%) or maximal groups (25%, $P = 0.31$).

Complications

In the minimal ablation strategy group, there was one pericardial effusion managed conservatively, one retroperitoneal haematoma, and one major groin haematoma. In the maximal ablation strategy, there was one neck haematoma (internal jugular vein access for coronary sinus catheterisation inadvertently rupturing internal thyroid artery which required surgical evacuation) and one major groin haematoma.

There was no evidence of PV stenosis in the first 40 patients who underwent routine cardiac CT at 3 months post-ablation. Due to concerns regarding unnecessary radiation, no further routine CT scanning was performed unless clinically indicated.

Discussion

This multi-centre international randomized controlled study reports the outcome of paroxysmal AF patients undergoing circumferential

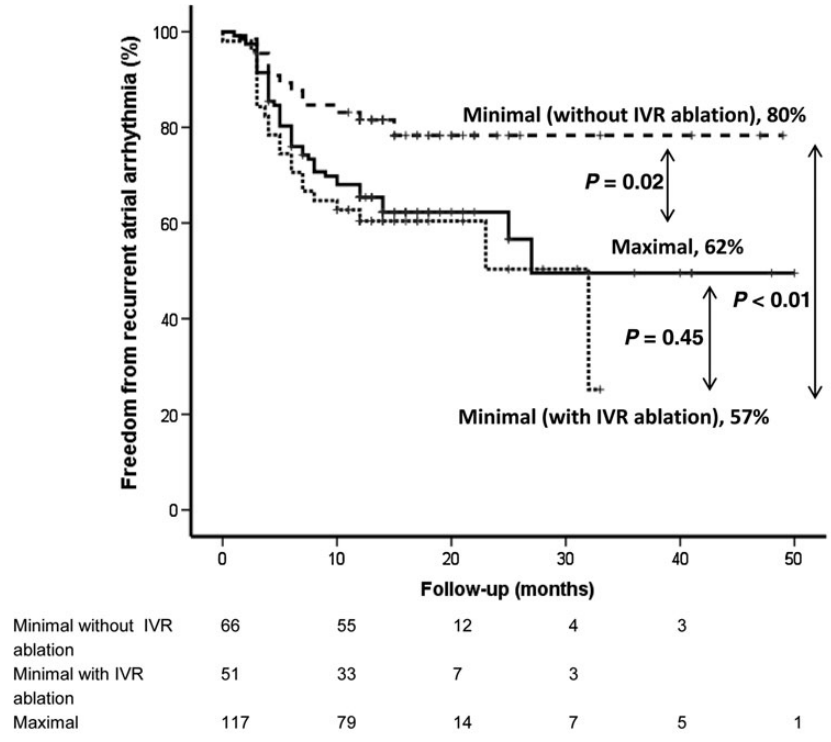

Figure 4 Single procedural success off anti-arrhythmic medications: sub-group analysis.

pulmonary antral ablation randomized to either a minimal or maximal ablation approach to achieve electrical isolation. The major findings are:

(1) On intention to treat analysis, no statistically significant difference in freedom from AF between a minimal and maximal ablation strategy after single or multiple procedures.
(2) In the minimal group, electrical isolation could not be achieved with antral isolation in 44% of patients and was successfully deployed on the IVR to achieve antral PV isolation.
(3) There was a significant improvement in freedom from AF in the minimal group without IVR ablation compared with the maximal group and minimal group who required IVR ablation.
(4) Increased ablation times to achieve electrical isolation with a maximal vs. minimal ablation strategy with no differences in procedure or fluoroscopy times, acute reconnection, or procedural complication between groups.

Pulmonary vein isolation

Since the landmark observation by Haissaguerre and co-workers defining the PVs as harbouring the majority of triggers initiating atrial fibrillation, PVI has become the cornerstone for catheter ablation strategies.[1]

However, the location of ablation lesions deployed to achieve PVI varies between operators. While catheter ablation along the IVR is often incorporated to achieve PVI,[9] there have been no randomized studies comparing routine PVI with and without ablation along the IVR in patients with paroxysmal AF.

In the present report, there was no statistically significant difference in freedom from AF after single or multiple procedures in patients randomized to a minimal or maximal ablation strategy on intention to treat analysis. Importantly, 44% of minimal group patients effectively crossed over to a maximal strategy as IVR ablation was required to achieve electrical isolation, and is in keeping with previous non-randomized studies identifying the difficulty of achieving PVI without IVR ablation.[10,11] We additionally identified the novel finding of reduced freedom from AF in minimal patients requiring IVR ablation. These findings may be explained by patients with unfavourable anatomy such as more complex connections at the IVR or inadequate contact force at the antral ring to achieve acute and enduring PVI with an antral approach.

Pulmonary intervenous ridge

The IVR is frequently incorporated into ablation strategies to achieve PV isolation however the impact of routine IVR ablation on procedural outcomes and complications has not been adequately assessed. A non-randomized study in patients with both paroxysmal and persistent AF identified no difference in freedom from AF in patients with IVR ablation performed to eliminate PV potentials.[9] A small randomized controlled trial (76 patients) reported no difference in freedom from AF in patients randomized to IVR ablation or not; however, significant limitations included a follow-up of <12 months, patients with both paroxysmal and persistent AF, and small patient numbers.[12]

In the minimal ablation strategy group, despite dedicated attempts to achieve electrical isolation on the antral ablation line, 44% of

patients required ablation on the IVR to achieve electrical isolation of at least one PV. Ablation on the IVR to achieve electrical isolation despite an apparently complete ablation ring has been previously reported,[9] and may be explained in part by a myocardial thickness twice that at the superior and inferior venous aspects.[13] Kistler *et al.*[10] reported the need to ablate on the IVR on the right in 51% and on the left in 41% of patients undergoing catheter ablation for AF. During long-term follow-up the IVR was the most common site for PV reconnection.[11] Autopsy studies[6] have demonstrated myocardial strands between ipsilateral PVs traversing the IVR which are often epicardial and may act as a bridge across the circumferential ablation line. The requirement for ablation along the IVR to achieve electrical isolation may be explained by more complex muscular connections. We identified increased dimensions of the left IVR in minimal patients requiring IVR ablation to achieve electrical isolation without significant differences on the right IVR or LAA/left PV ridge.

Contact force

This study utilized contact-force sensing catheters in the minority of patients (28%), and was not powered to assess the impact of contact-force catheters or contact-force parameters on outcomes as these tools were not available during the study design or majority of enrolment phase. Inadequate contact-force on the antral ring may in part explain the requirement for ablation on the IVR in 44% of minimal patients.

Study limitations

While the trial design was randomized, the electrophysiologist was necessarily unblinded to patient allocation which may represent a potential source of bias. As PVI is a necessary endpoint for procedural success, a significant proportion of patients randomized to a minimal ablation strategy required ablation on the IVR to achieve electrical isolation after completion of circumferential antral PVI representing an effective crossover from a minimal-to-maximal strategy. The rates of freedom from AF may be lower than reported due to asymptomatic AF in the periods between 7-day Holter monitoring. Given a trend to an increase in freedom from AF in minimal vs. maximal patients, a sample size of 550 patients would be required to confidently assert equivalence between strategies. Many of the secondary endpoints (such as PV stenosis in patients with repeat CT, anatomical findings, and findings at redo procedures) are underpowered, with the possibility of a type 2 error. The study was underpowered to determine the impact of contact force on clinical outcomes as the technology became available towards the end of study enrolment.

Conclusion

There was no statistically significant difference in freedom from AF between a minimal and maximal ablation strategy to achieve PVI. Despite attempts to achieve PV isolation with antral ablation a significant proportion of patients require ablation on the IVR which is associated with an increase in recurrent AF. Pulmonary vein isolation achieved with antral ablation alone is associated with high long-term freedom from AF.

Supplementary material

Supplementary material is available at *European Heart Journal* online.

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Conflict of interest: Dr Sanders reports having served on the advisory board of Biosense-Webster, Medtronic, St. Jude Medical, Sanofi-Aventis and Merck, Sharpe and Dohme. Dr Sanders reports having received lecture and/or consulting fees from Biosense-Webster, Medtronic, St. Jude Medical, Boston Scientific, Merck, Sharpe and Dohme, Biotronik and Sanofi-Aventis. Dr Sanders reports having received research funding from Medtronic, St. Jude Medical, Boston Scientific, Biotronik and Sorin.

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CARDIOVASCULAR FLASHLIGHT

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‘Snooker-Ball’-sized cardiac ateriovenous malformation compressing coronary sinus visualized by 4D cardiac computed tomography

Michael Behnes[1]*, Ibrahim Akin[1], Reinhard Stier[1], Thomas Henzler[2], and Holger Haubenreisser[2]

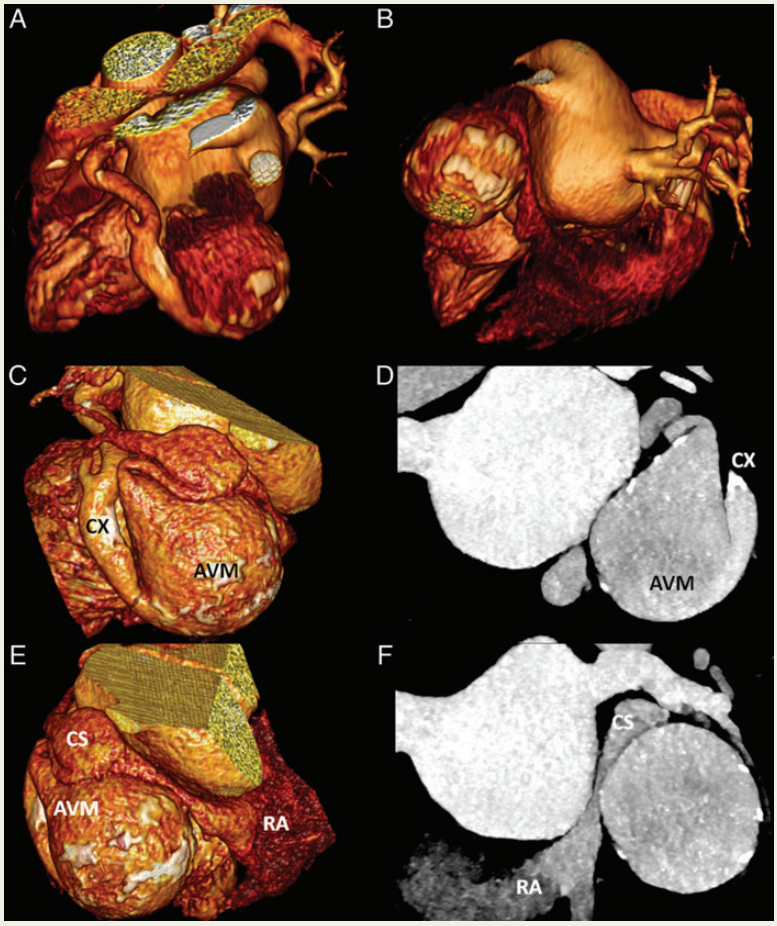
[1]First Department of Medicine, University Medical Center Mannheim and [2]Institute of Clinical Radiology and Nuclear Medicine, University Medical Center Mannheim, Faculty of Medicine Mannheim, Heidelberg University, Theodor-Kutzer-Ufer 1-3, Mannheim D-68167, Germany

* Corresponding author. Tel: +49 621 383 2204; Fax: +49 621 383 3821; Email: michael.behnes@umm.de

A 66-year-old woman was referred to our cardiologic department to clear up an unusual cardiac mass being detected during routine outpatient trans-thoracic echocardiographic examination.

Initial cardiac magnetic resonance imaging (MRI) confirmed a mass located around the left ventricular posterior wall. Contrast enhancement of the structure was simultaneously to the thoracic aortic peak enhancement during dynamic MRI. However, the relationship of the lesion to the cardiac cavities and thoracic vessels remained unclear on MRI (see Supplementary material online, *Video S1*, right panel).

Therefore, a combined cardiac computed tomography (CT) angiography with a 4D CT volume perfusion acquisition was performed in order to define the exact vascular origin of the lesion (see Supplementary material online, *Video S2*). Cardiac 4D CT angiography found a ‘snooker-ball’-sized partly calcified arteriovenous malformation (AVM, maximum diameters, 5–7 cm) with antegrade vascularization from an enlarged circumflex coronary artery (CX, maximum diameter, 1 cm) (*Panels A*, *C*, and *D*). The arterial blood stream was directly drained into the enlarged coronary sinus (CS, maximum diameter, 9 mm). Most notably, the CS was compressed by the AVM to a minimum diameter of 2 mm (*Panels B*, *E*, and *F*). Supplementary material online, *Video S3* demonstrates time-resolved contrast in sequence of the right heart chambers, left atrium and ventricle, finally contrasting the extended AVM and CS (also see *Panels A* and *B*).



Subsequently performed invasive coronary angiography showed no relevant coronary artherosclerosis. A coronary Runthrough guidewire (Terumo Cardiovascular Systems Corporation, USA) was advanced into the CX, passing the formation, finally reaching the CS (see Supplementary material online, *Video S1*, left panel).

This case highlights the usefulness of 4D cardiac CT angiography to reliably detect and differentiate cardiac tumors and vascular malformations.

Supplementary material is available at *European Heart Journal* online.