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# Surgical Ablation of Atrial Fibrillation: is Electrical Isolation of the Pulmonary Veins a Must?

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**Abstract**

**Ablation of atrial fibrillation (AF) is a well-established treatment option for patients with symptomatic AF refractory to antiarrhythmic drugs. The cornerstone of catheter ablation is electrical isolation of the pulmonary veins, since the pulmonary veins are the most common location for triggers of AF. Electrical reconnection of the pulmonary veins is associated with arrhythmia recurrence and therefore diminishes long-term success of catheter ablation of AF. Therefore, durable pulmonary vein isolation remains a condition sine qua non for catheter ablation of AF. The Cox-Maze procedure is considered an effective surgical cure of AF, however it has never been widely adopted due to its procedural complexity. Since the development of minimal invasive techniques for surgical AF treatment, surgical ablation of AF has regained interest. Most of the minimal invasive surgical AF ablations performed around the globe include pulmonary vein isolation as a part of the procedure. In this review, we explore the necessity of electrical isolation of the pulmonary veins in surgical AF ablation.**

## Historical Perspective

Although the exact pathophysiology of atrial fibrillation (AF) remains unknown, different mechanisms driving the arrhythmia have been proposed. Generally it is accepted that AF requires both a trigger and a substrate capable of perpetuating AF. Mechanisms driving AF can be classified as 'hierarchical' or 'anarchical'.[1] In a hierarchical organization a single source, ranging form local automaticity or triggered activity to local reentrant circuits, drives AF. Contrary to hierarchical AF, anarchical AF indicates that multiple non-localized sources, like reentry circuits or multiple wavelets, act anarchically to drive. Also interactions of several of these mechanisms could be responsible for the initiation and perpetuation of AF.

The multiple wavelet hypothesis, introduced by Moe and coworkers, is a classic example of anarchical AF.[2] In this conceptual model, AF is sustained by the co-existence of multiple wavelets meandering over both atria, given that the atria are big enough (atrial mass) and the refractory period short enough.[2,3] Early 1980s, the only interventional treatment for AF was ablation of the atrio-ventricular node and implantation of a ventricular pacemaker.[4] The Cox-Maze procedure was the first curative attempt in AF treatment and was performed for the first time on 25 September 1987 at the Barnes Hospital in St. Louis, USA by James Cox.[5] The operation consisted of an extensive cut-and-sew incision set in both atria with the goal of blocking macro-reentrant conduction and (re)directing propagation from the sino-atrial node throughout both atria. The concept of this procedure was based on epicardial mapping in patients with paroxysmal AF who were undergoing surgical correction of the Wolff-Parkinson-White syndrome.[6] In this study, Cox et al. demonstrated that, during human AF, mainly multiple wave fronts and macro-reentrant circuits occur.[6] The numerous atrial transections were designed in such way that macro-reentrant circuits no longer could prevail. It is remarkable that, although this surgical procedure was designed long before any knowledge of the arrhythmogenicity of the pulmonary veins (PVs) existed, it did include electrical isolation of the PVs and the posterior left atrial wall (box lesion) as a part of the surgical procedure.[5] As such, success of the Cox-Maze procedure cannot solely be attributed to the prevention of multiple waves to co-exist, but might also be partly due to abolished AF triggers.

The initiation of paroxysms of AF by repetitive discharges originating in the PVs is a typical example of a hierarchical type of AF. In 1998, Haïssaguerre et al. demonstrated that 90% of the triggers responsible for the onset paroxysmal AF were located in and around the orifices of the PVs and that these foci responded well to catheter based radio-frequency (RF) ablation therapy.[7] Later, it was shown that the ectopic activity presumably was a consequence of micro-reentry promoted by the presence of heterogeneity in refractoriness and anisotropic conduction at the atrial junction

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with the PVs and within the PVs.[8,9] These findings have important implications: as frequent discharges of a few focal sources can lead to progressive pathologic changes in the atrial substrate,[10] thereby entraining AF,[11] and ablation of these foci suppresses the trigger and reduces the potential degeneration of the atrial substrate,[7] the underlying mechanism driving human paroxysmal AF seems to be that of multiple foci adjacent to or in the PVs.[12] Since this pioneering work of Haïssaguerre et al.,[7] PV isolation has been regarded as the cornerstone for the treatment of paroxysmal AF and even of persistent AF. However, the underlying mechanism of persistent AF maintenance is not fully understood and might be due to

(1) cellular proarrhythmic mechanisms, like automaticity or triggers;

(2) spiral wave reentry or rotors;

(3) multiple wavelet reentry where the fibrillation process is actually driven by waves and no localized sources of AF exist; or

(4) a combination of all, different in each patient.[1] This might explain the pour outcomes reported in (single procedure) PV isolation for persistent AF.[13] After recognition of the PVs as a dominant source of triggers initiating AF, more foci were found at other locations in right and left atria. Amongst them were the ligament of Marshall,[14] the proximal superior vena cava[15] and the left atrial appendage.[16]

Based on the success of compartmentalization in open surgical ablation, addition of left atrial linear lesions to PV isolation were introduced in catheter ablation of AF.[17] For example the mitral isthmus line, a linear line from the lateral mitral annulus to the left inferior PV, was added by Jaïs et al. based on anatomical studies suggesting that preferential propagation is closely correlated to muscle fiber orientation along the posterior LA and circumferentially around the mitral annulus.[18, 19] Another example of substrate modification was the introduction of a linear lesion connecting both superior PVs, the so-called 'roof line' ablation.[20]

In 2004, Nademanee et al. proposed a different substrate-based approach for the treatment of AF. They identified and ablated areas with bipolar complex fractionated electrograms (CFAE),[21] based on the earlier described finding by Konings et al. that unipolar CFAE are found in regions of conduction slowing and conduction block.[22] The authors suggested that ablation of CFAE-sites alter or eliminate random reentry paths preventing fibrillation wavelets to reenter the ablated areas.[21] Although PV isolation was not performed, PVs were identified as key areas where CFAEs were located.[21]

A new method for analyzing AF propagation was introduced by Narayan et al. in 2012. The authors unmasked sustained electrical rotors and/or repetitive focal activation in 97% of mapped human AF (combination of paroxysmal and persistent AF) by using a 64-pole basket catheter and a novel algorithm that produces a video of the computed activation process.[23] These localized sources were low in number, stable in position, mostly located in the left atrium and they controlled surrounding fibrillatory conduction.[24] Catheter ablation at the center of these localized sources terminated or consistently slowed persistent or paroxysmal AF in 86% of patients prior to PV isolation.[24] Of notice, in a recent extension of that report, more rotors and less focal sources were reported compared to earlier reports,[23, 24] which the authors attributed to 'improved software', among other things.[25] This might reflect a high dependence on a special software algorithm enabling the detection of rotors driving human AF.

Even more recently, Haissaguerre et al. used electrograms generated by body surface mapping and biatrial geometry relative from a computed tomography (CT) scan to reconstruct the propagation pattern of fibrillating atria in a noninvasive way.[26] Signal-analysis processing combining filtering, wavelet transform, and phase mapping was used to identify drivers (focal or reentrant activity) in 103 patients with persistent AF.[27] Contrary to Narayan et al.,[23, 24] the authors reported more driver locations, substantial meandering, and periodic occurrence of unstable reentries requiring statistical density maps to identify them.[27] Also here, RF ablation at the driver location resulted in acute AF termination in 75% of persistent AF and 15% of long-lasting AF patients.[27] In this strategy, ipsilateral PV isolation was only performed if drivers were found in the PVs or if the endpoint was not reached.

As discussed before, surgical ablation of AF started with the Cox-Maze III operation, a surgical procedure through median sternotomy on cardio-pulmonary bypass (CPB) in which compartmentalization was created by cutting and sewing in order to interrupt and eliminate macro re-entrant circuits.[5] Later, the Cox-Maze III procedure was changed to the Cox-Maze IV procedure: based on the findings of Haïssaguerre[7] the pulmonary veins were isolated bilaterally, most incision sets were replaced by bipolar RF ablation and cryosurgery was applied at the valve annuli.[4, 28] The Cox-Maze IV can be performed either through a median sternotomy or through a right mini-thoracotomy.[28] Although the right atrial ablations can be performed on the beating heart, CPB is still required for the left atrial lesion set.[28] Several changes to the Cox-Maze procedure have been developed, mainly based on the application of other (and now obsolete) energy sources like microwave, laser, and high-frequency ultrasound.[4] Nitta et al. developed the radial incision procedure, an alternative approach to preserve a more physiologic atrial transport function.[29] This procedure consisted of atrial incisions radiating from the sinus node to allow a more physiologic atrial activation sequence and to preserve blood supply to most atrial segments.[30]

The last decades, new technologies enabled the creation of transmural lesions using minimal invasive surgery (MIS) for treatment of stand-alone AF.[31] Most widely used are the RF bipolar clamp devices that allow PV isolation by applying RF energy between the two jaws of the clamp. In addition, creation of a 'box'-lesion and left atrial appendage (LAA) removal or exclusion, usually with ganglionic plexi ablation, is performed via video-assisted MIS.[31-34] The advantage of these MIS approaches, next to the fact that they are truly minimal invasive, is that they can be performed on the beating heart (off-pump).[31-34] The difference, however, between these techniques and the Cox-Maze III lesion set is that the epicardial off-pump techniques lack the possibility of a mitral isthmus line as this lesion cannot be created solely from the epicardium.[35, 36] Therefore, Edgerton et al. developed the 'Dallas lesion set', an epicardial minimal invasive approach in which the mitral isthmus line is replaced by a connecting lesion -using unipolar RF energy- from the left fibrous trigone at the anterior mitral valve annulus across the anterior dome of the atrium to the 'roof' line.[35]

Although much more efficient as unipolar, even bipolar RF energy cannot guarantee transmural lesions.[37] To overcome this shortcoming and to tackle the problem of the mitral isthmus line, a combination of a transvenous endocardial and thoracoscopic epicardial approach in a single procedure, the so-called 'hybrid AF ablation', has been successfully put forward as an alternative.[38] Almost all of the surgical ablation procedures for the treatment of concomitant and stand-alone AF include PV isolation using RF or cryo-energy.

## Is Pulmonary Vein Isolation Mandatory In Catheter Ablation Of AF?

In the initial report on PV trigger ablation for the treatment of paroxysms of AF, Haïssaguerre et al. reported 80% acute success and 62% freedom of AF in a follow-up period of 8±6 months after ablation.[7] Since then PV isolation is considered to be the cornerstone of catheter-based ablation of AF.[12] Initial PV isolation consisted of electrical isolation of the PV myocardium close to the PV ostia, but identification of triggers in the PV antrum and recognition of PV stenosis resulted in a shift towards wider antral PV isolation techniques (e.g. wide area circumferential ablation or WACA).[39-41]

It has been demonstrated that PV isolation is more effective in maintaining sinus rhythm compared to medical therapy.[42] However, catheter-based PV isolation has been reported to be successful in patients with paroxysmal AF, although repeat PV isolation procedures are needed, but far less successful in patients with persistent or longstanding persistent AF.[43-48] Teunissen et al. recently reported on the five-year freedom of atrial tachyarrhythmia after PV isolation.[47] PV isolation restored and maintained long-term sinus rhythm in 48.6% for paroxysmal AF, but only 33.1% in persistent AF and 23.5% in longstanding persistent AF.[47] When allowing multiple re-isolations, freedom of AF increased to 67.8% for paroxysmal AF, but remained disappointing for persistent AF (46.2%) and longstanding persistent AF (38.2%).[47]

The consensus that complete electrical isolation of PVs is a necessity stems from the finding that AF recurrences after PV isolation for paroxysmal AF are almost always associated with electrical PV reconnection based on conduction gaps.[49] The need for durable PV isolation is clearly demonstrated by the results of the Gap-AF–AFNET 1 trial.[50] In this study, 233 patients were randomized to complete and intentional incomplete PV isolation.[50] After 3 months, rhythm follow-up showed that patients with incomplete PV isolation had far more AF recurrences then patients with complete PV isolation (62,2% vs 79.2%).[50] More surprising was the finding that at invasive reevaluation at 3 months the rate of electrical PV reconnection in patients with acute complete PV isolation was up to 70%.[50] This illustrates that initial acute PV isolation using catheter-based RF ablation techniques does not per se translates into a durable PV isolation. What about the second most frequently used catheter-based ablation technology, cryo-energy? Kuck et al recently compared cryoballoon ablation to RF ablation in a large randomized multicenter trial, the 'fire and ice trial' and demonstrated non-inferiority of cryo-ablation to RF ablation.[51] In a report on redo procedures for recurrent AF in 29 out of 131 patients who initially underwent a successful cryoballoon PV isolation, PV reconnection was again found to be the underlying mechanism (PV reconduction in 2.45 + 0.7 veins in each patient).[52] Some techniques have been evaluated to reduce the amount of PV reconnection. Recently, a large randomized trial demonstrated that in patients with dormant PV conduction additional adenosine-guided ablation resulted in a higher freedom of AF compared to no additional ablation (69.4% vs 42.3%).[53] In patients without dormant PV conduction, AF freedom was only 55.7%, suggesting that adenosine is unable to identify all veins that might reconnect.[53] Theoretically, waiting longer after PV isolation could help to reveal early PV reconnection. Bänsch et al. demonstrated that although this resulted in the detection of more gaps, ablation of these gaps did not result in higher freedom of AF in follow-up.[54] Furthermore, demonstration of bidirectional block has been suggested to improve results of PV isolation.[55] Electroporation is a promising technique but still needs to be evaluated in clinical practice.[56]

As discussed before, the short and long term results of PV isolation are less convincing in patients with persistent and longstanding persistent AF.[44-48] As a result, additional substrate modifications, such as linear lesions or ablation of CFAEs, have been proposed for catheter-based ablation of persistent AF.[18, 21, 57] The initial report on CFAE ablation by Nademanee et al. presented very high acute (98%) and 1-year follow-up (91%) freedom of AF rates.[21] In this study, no PV isolation was performed. Does this finding challenge the need for PV isolation? It might, but although PV isolation was not performed, the PVs were identified as key areas for CFAEs.[21] Estner et al. compared CFAE ablation with PV isolation in combination with CFAE ablation in patients with persistent AF.[58] In the CFAE ablation only group, sinus rhythm off AAD was present in 9% after a mean follow-up time of 13 + 10 months, compared to 41% in the CFAE plus PVI ablation group.[58] Moreover, Oral et al. randomized patients with long-lasting persistent AF who did not convert to sinus rhythm after PV isolation to CFAE ablation or no further ablation and failed to demonstrate an add-on value of CFAE ablation to PV isolation.[59] Because of the dynamic nature of CFAEs and the inability of current algorithms to adequately define CFAEs, it remains challenging to identify sites critical for AF termination.[60, 61]

Also addition of linear lesions has been reported with varying success. For example, Gaita et al. randomized patients with paroxysmal or persistent/permanent AF to 2 different ablation schemes: PV isolation and PV isolation plus left linear lesions.[62] The authors reported that addition of linear lesions is more effective in maintaining sinus rhythm off anti-arrhythmic drugs ).[62] In contrast, several recent randomized trials failed to show any benefit of additional substrate modifications techniques over PV isolation alone.[63-65] Of interest is the STAR AF 2 trial, a large randomized trial evaluating currently used substrate modifications techniques.[63] Verma et al. randomized 589 patients with persistent atrial fibrillation to PV isolation alone, PV isolation in combination with CFAE ablation or PV isolation with linear lesions across the left atrial roof and mitral valve isthmus.[63] The authors failed to show any benefit in AF freedom between the 3 techniques, independent of AAD-allowance or repeat procedures.[63]

The poor results of additional substrate modification in patients with non-paroxysmal forms of AF should be interpreted with caution, however, as they might be due to the relative incapacity of catheter-based unipolar RF to create transmural lesions.[66] As such, it would be interesting to (re-)evaluate these 3 techniques in patients were effective PV isolation has been proven by electrophysiological testing at a fixed time point after the initial procedure.

In 2012, Narayan et al. proposed a new ablation technique, focal impulse and rotor modulation (FIRM), based on the hypothesis that localized sources or rotors sustain human AF.[23] When comparing FIRM in addition to PV isolation with PV isolation alone, FIRM-guided cases had higher freedom from AF (82.4% vs. 44.9%).[67] These promising results were confirmed in a 3-year follow up report.[68] However, in these studies FIRM ablation was always performed in combination with PV isolation. Recently, Gianni et al reported that FIRM ablation as a sole therapy, so without PV isolation, in patients with non-paroxysmal AF did not result in AF termination.[69] After a mean follow-up of 5.7 months, single-procedure freedom from atrial arrhythmia was 17% without AADs, 28% allowing AADs.[69]

In conclusion, PV isolation is not only mandatory in catheter ablation of AF; it forms the cornerstone of this therapy. Whether additional substrate modification techniques, in combination with PV isolation or as a sole therapy, are able to improve freedom of AF is unclear at this stage.

## Is Pulmonary Vein Isolation Mandatory In Surgical Ablation Of AF?

The fact that all surgical AF ablation techniques include PV isolation makes it difficult to question its need in AF surgery. There are, however, some indirect arguments to support its necessity.

There a few differences between surgical and catheter ablation techniques for ablation of AF. First, a variety of different lesion sets are performed, including right atrial lesions, extensive left atrial lesions including full isolation of the posterior left atrium (box-lesion), addition of a trigonum or mitral isthmus line and left atrial appendage exclusion. In theory, those additional lesions might be responsible for AF termination even if the PVs are not fully electrically isolated. The left atrial appendage, for example, harbors triggers that can play a role in initiation or recurrence of AF.[16, 70] Next to the prevention of cloths, surgical exclusion of the left atrial appendage performed by amputation, stapler or epicardial occluding device (clip), will also electrically isolate the left atrial appendage, thereby preventing its triggers to persist. An endocardial left atrial appendage occluding device, however, will not result in electrical isolation. Secondly, the devices used to perform AF ablation are different. In several stand-alone or concomitant surgical AF procedures, cryo-ablation is performed on the arrested heart, thereby preventing the heat sink effect of endocardial (warm) blood. Also, in surgical treatment of AF, bipolar RF devices can be used to perform PV isolation (both on the beating and the arrested heart) and to create linear lesion on the arrested heart. Those bipolar devices differ from unipolar devices in the fact that RF energy is applied from two sides with the target tissue in between. In a porcine animal study, ablation of the PVs and the left atrial appendage using a bipolar RF clamp resulted in 100% acute isolation and at 30 days.[71] Microscopic evaluation of the ablation lines showed that all lesions were transmural in a total of 209 samples.[71] Bugge et al compared a bipolar clamping device with a handheld unipolar device in a sheep model and showed that in atrial tissue continuous transmural lesions were achieved more often with the bipolar than with the unipolar device (92.3 vs. 33.3%).[37] Off course these results coming from animal studies cannot be translated one-on-one into clinical practice, but they at least suggest the superiority of bipolar compared to unipolar RF devices in creating transmural lesions. As such, it might be more representative to study the success of substrate modification techniques in addition to PV isolation in AF patients who undergo surgical PV isolation using bipolar RF devices, rather than in patients undergoing percutaneous PV isolation.

There are some indirect arguments that PV isolation is mandatory in AF surgery. Surgical PV isolation using bipolar RF devices is at least as effective as catheter ablation.[72-74] De Maat et al. reported that video-assisted PV isolation in patients with paroxysmal AF resulted in 69% freedom from atrial arrhythmias off AAD after a mean follow-up of 5 years.[75] These results do not prove that PV isolation is a must in surgical AF ablation, but they do show that surgical PV isolation is an adequate therapy to treat paroxysmal AF. In non-paroxysmal forms of AF, additional lesions are often required to maintain sinus rhythm. In permanent AF patients with left atrial dilatation and valvular disease, PV isolation seems necessary but not sufficient to regain sinus rhythm.[76] Gaita et al. assigned patients undergoing valve surgery to 3 different groups: cryo-isolation of the PV's only, cryo-isolation of the PV's in combination with interconnecting lines between the PV ostia and the right and left lower PVs down to the mitral annulus (reversed 'U' lesion) and cryo-isolation of the PV's in combination with interconnecting lines between the PV ostia and the left lower PV down to the mitral annulus ('7' lesion).[76] A subset of patients underwent an electrophysiological study at 3 months.[76] First of all, the 'U' lesion was never achieved; in general only 65% of linear lesions or PV isolation using cryo-energy was achieved in this patient population.[76] Complete PV isolation alone resulted in 25% sinus rhythm, whereas PV isolation in combination with a complete '7' lesion (intended '7' lesion or incomplete 'reversed U' lesion) resulted in 86% sinus rhythm at 2 years off AAD.[76] In a mixed population of paroxysmal and persistent AF patients undergoing the Cox-Maze IV procedure, higher freedom of AF at 3 and 6 months and a trend towards higher freedom of AF at 12 months was reported in patients where, in addition to PV isolation, a complete posterior left atrial isolation ('box-lesion') was performed compared to a line between the inferior PVs only.[77] This suggests that in certain patients, the posterior left atrium harbors triggers that (re-)initiate AF, and that in those patients PV isolation alone is not sufficient.[77] Off course, full posterior left atrial isolation also results in reduction of the available conducting critical mass. In contrast, in a large randomized multicenter study involving patients with persistent and longstanding persistent AF, Gillinov et al. reported no differences in freedom of AF at 1 year between patients undergoing PV isolation alone compared to patients undergoing a biatrial Cox-Maze procedure.[78] However, the reported success rate of the maze group is in this study is lower than expected.[79] Furthermore, a variety of bipolar and unipolar radiofrequency and cryothermy was used (bipolar PV isolation was only performed in 43%).[78]

Electrophysiological evaluation after bipolar RF PV isolation has been scarcely performed. Kron et al performed an electrophysiological study in 13 patients (69% paroxysmal AF) with recurrent atrial tachyarrhythmias at a mean of 214±162 days after minimal invasive surgical ablation of the PVs using bipolar RF, the parasympathetic ganglionated plexi and the ligament of Marshall.[80] In these 13 failures, 50% of examined PVs reconnected; in 7/8 patients with recurrent AF either 2 or 3 PVs were reconnected and in 6/8 patients, the left superior PV was reconnected.[80] Zeng et al. reported on 8 patients (3 paroxysmal AF, 5 persistent AF) with recurrent atrial arrhythmias after minimal invasive PV isolation using bipolar RF and left atrial appendage exclusion by stapler.[81] An electrophysiological study revealed gaps at the PVs in 4 patients with recurrent AF, an ectopic focus between the left atrial appendage and left superior PV in a patient with atrial tachycardia, perimitral atrial flutters in 2 patients and a left atrial roof flutter in the remaining patient.[81] Trumello et al. performed percutaneous ablation on 36 patients with previous surgical ablation (7 biatrial maze, 18 left atrial ablation and 11 PV isolation).[82] Among other findings, 15 patients had reconnection around the PVs.[82] The authors underlined the importance of an appropriate energy source as two-thirds of patients with gaps around the PVs were initially treated using unipolar RF only.[82] Velagic et al reported on repeat catheter ablation in 14 patients out of 64 patients treated with a hybrid AF ablation including PV isolation with bipolar RF.[83] In all patients, conduction block of the PVs was confirmed by endocardial mapping with a Lasso catheter. [83] In only 5 patients PV reconnection was found and only 1 vein per patient reconnected.[83] Although these findings are not direct proof, they do strongly support the need for durable PV isolation in surgical AF ablation.

Hybrid AF ablation may help to detect and immediately treat conduction gaps that are not identified during epicardial ablation. The concept of hybrid AF ablation, as discussed before, consists of combining the advantages of an epicardial and endocardial approach.[38] It can be performed as a staged procedure or in one single procedure. On et al. reported on 97 patients (10.1% paroxysmal AF, 21.5% persistent AF, 68.3% long-standing persistent AF) who underwent staged hybrid AF ablation.[84] Surgery consisted of thoracoscopic PV isolation with a box lesion, ganglionated plexus ablation, division of the Marshall ligament and left atrial auricle resection.[84] In 61 patients an electrophysiological study was performed 5 days after surgery: cavotricuspid isthmus ablation was routinely performed in 56 patients, and mitral isthmus ablation and septal ablation because of preoperative atrial flutter.[84] In 15 patients PV conduction gaps were detected requiring additional ablation.[84] Using this staged approach, the freedom of AF after 1 year was 74% off AAD.[84] Pison et al reported on 26 patients (42% persistent AF) undergoing hybrid AF ablation in a single procedure.[38] Combining thoracoscopic surgical ablation (consisting of PV isolation, a box lesion +/- additional lesions) with endocardial validation and touch-up (if needed) of the epicardial lesions resulted in a single procedure success rate of 83% at 1 year, off AAD.[38] During the hybrid procedure, endocardial touch-up was necessary in 23% of patients because the epicardial lesions were not transmural, illustrating the immediate advantage of this approach.[38] Using meticulous rhythm follow-up, 4 failures were identified.[38] Of this 4 patients, 2 underwent an electrophysiological study: 1 conduction gap in the roofline and 1 atrial flutter but no reconnection of the PVs was documented.[38] In theory, endocardial validation of epicardial ablation lesions is superior to epicardial testing for several reasons. First, because of edema, epicardial testing of surgical ablation lines can lead to false negative results. Secondly, it can be challenging to adequately pace in between instead of on the performed ablation lines. Also, the border between conducting and non-conducting tissue at the distal sleeve of the pulmonary vein cannot be determined without sophisticated mapping techniques. Third, there is a timeframe of at least 30 minutes between epicardial PV isolation and endocardial validation, which can help to unmask incomplete PV isolation. Last, endocardial testing of PV isolation allows electrophysiological mapping using validated techniques (e.g. Lasso catheter). Probably these advantages result in a more durable PV isolation and thereby contribute to a higher rate of AF freedom.

## Conclusion

PV isolation remains the cornerstone in AF ablation. In catheter ablation, durable PV isolation is mandatory as recurrences of AF go hand in hand with PV reconnection. In surgical ablation of AF, the necessity of PV isolation is more difficult to demonstrate, as reports on redo procedures after surgery are scarce. However, there are no obvious reasons why surgical ablation would differ from catheter ablation in necessitating PV isolation. Surgical ablation of AF seems superior to catheter ablation of AF, especially in the treatment of non-paroxysmal forms of AF. This seems, at least in part, to be due to the use of bipolar radiofrequency devices. As such, more durable PV isolation is to be expected in surgical AF ablation. Therefore the efficacy of additional substrate modification techniques should also be evaluated in patients undergoing surgical AF ablation, and not only in patients undergoing percutaneous ablation.

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