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Combined Epicardial and Endocardial Ablation for Atrial Fibrillation: Best Practices and Guide to Hybrid Convergent Procedures

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Abstract

The absence of strategies to consistently and effectively address non-paroxysmal atrial fibrillation (AF) by nonpharmacologic interventions has represented a longstanding treatment gap. A combined epicardial/endocardial ablation strategy, the hybrid Convergent procedure, was developed in response to this clinical need. A subxiphoid incision is used to access the pericardial space facilitating an epicardial ablation directed at isolation of the posterior wall of the left atrium. This is followed by an endocardial ablation to complete isolation of the pulmonary veins and for additional ablation as needed. Experience gained with the hybrid Convergent procedure during the last decade has led to the development and adoption of strategies to optimize the technique and mitigate risks. Additionally, a surgical and electrophysiology "team" approach including comprehensive training is believed critical to successfully develop the hybrid Convergent program. A recently completed randomized clinical trial indicated that this ablation strategy is superior to an endocardial only approach for patients with persistent AF. In this review, we propose and describe best practice guidelines for hybrid Convergent ablation based on a combination of published data, author consensus, and expert opinion. A summary of clinical outcomes, emerging evidence, and future perspectives are also discussed.

Keywords: atrial fibrillation; hybrid Convergent ablation; epicardial ablation; endocardial ablation; persistent atrial fibrillation; pulmonary vein isolation; posterior wall isolation

Introduction

Atrial fibrillation (AF) is common and can lead to significant morbidity and impaired quality of life (QOL).[1] Treatment strategies include risk factor modification, prevention of thromboembolic events, medical management with rate and rhythm control drugs, and percutaneous endocardial catheter and surgical ablation.[1] Success of these strategies is variable and influenced in part by AF type and duration, extent of electrical and structural atrial remodeling, and mechanisms and patterns of arrhythmogenic sources. Rhythm control efforts by catheter ablation have a high success rate for paroxysmal AF,[2, 3] however less so for persistent AF.[4, 5] The potential for open-heart surgical ablation to treat non-paroxysmal AF is well described,[6] but typically performed as a component of another cardiac surgical procedure. However, most patients with persistent AF do not require open-heart surgery and historically have had more limited AF management options.

This treatment gap prompted the development of a minimally invasive, epicardial and endocardial ablation ("Convergent") procedure focused on patients with non-paroxysmal AF, combining advantages of both techniques.[7] During the last decade, this "hybrid" approach has garnered increasing acceptance in clinical practice, with several reports of promising antiarrhythmic outcomes in challenging disease states, as well as modifications to maximize safety and clinical outcomes.[7] One key aspect of this treatment strategy is that it harmonizes epicardial and endocardial ablation components to effectively target key drivers of AF, including the pulmonary veins (PVs) and the left atrial posterior wall (LAPW). The LAPW (or "PV myocardium") shares similar embryologic origins and electrophysiologic properties with the PVs,[8] is predisposed to develop fibrosis,[9] and thus recognized as an important source of AF. However, its isolation with standard endocardial catheter ablation alone is associated with suboptimal durability and significant risk of proarrhythmic atrial flutters,[10, 11] non-transmural lesion creation,[12] suboptimal long-term efficacy,[13] and risks associated with outward delivery of radiofrequency (RF) energy including thermal injury.

The recently completed CONVERGE randomized clinical trial[14] demonstrated a substantially advantageous AF outcome following hybrid ablation versus endocardial-only ablation in nonparoxysmal AF, which we believe will fuel greater interest in this combined treatment strategy. Based on the authors' substantial combined experience, herein we describe key technical and programmatic components of the procedure distinct from traditional ablative strategies and best practices critical for implementation of a successful combined surgical and electrophysiological AF program. Lastly, we discuss emerging evidence and future perspectives of this hybrid approach.

Hybrid Convergent procedure overview

The hybrid Convergent procedure is a minimally invasive, closed-chest procedure performed on the beating heart that combines epicardial RF ablation—focused on the LAPW—followed by complementary endocardial catheter ablation. The epicardial component seeks to debulk as much of the LAPW as can be accessed, principally limited by the oblique sinus. Posterior segments of the PV ostia/antra may also be reached and ablated in most cases. The endocardial component supplements the epicardial lesions around the pericardial reflections and any incompletely ablated LAPW areas, and addresses any remaining gaps between the PV and LAPW lesion sets (including anterior segments), ensuring PV electrical isolation. The endocardial component can also include a cavo-tricuspid flutter line and addresses any other substrate believed to be contributory to the clinical presentation.

In the hybrid Convergent procedure, a closed-irrigation, unipolar RF catheter device (EPi-Sense Guided Coagulation System, AtriCure, Inc., Mason, OH) is used for epicardial ablation under endoscopic visualization. The device is inserted through a pericardioscopic cannula (SUBTLE, AtriCure, Inc.) to reach the LAPW and maneuvered in the pericardial space using the cannula and endoscope (Figure 1). During ablation, epicardial tissue is suctioned by vacuum onto the RF coil on one side of the device, stabilizing the device on the atrium and optimizing energy delivery. Saline perfusion within the device maintains

tissue hydration and provides insulation and cooling. The RF energy delivery achieves coagulation as the temperature approaches 60°C, but does not reach excessive temperatures such that tissue vaporization occurs. Each lesion is created by a 90-second application of alternating current via an impedance-based power control algorithm. Lesions are overlapped across the entire LAPW to promote contiguity and transmurality, and thus minimize gaps with the intention of creating a homogeneous region of electrical silence. Endocardial catheter ablation is then performed through a standard femoral approach. Figure 2 illustrates the spectrum of hybrid Convergent approach lesion sets.

Practical planning for hybrid Convergent procedures

Multidisciplinary Convergent "team." Hybrid Convergent ablation combines expertise from cardiothoracic surgery and electrophysiology. Coordination and collaboration among the multidisciplinary team members are paramount to a successful program. Each institution may have an individualized setup, but detailed planning is required and may involve changes to existing workflows. Ideally, a designated navigator acts as the liaison between the patient and hospital staff, coordinates patient education and staff training, and facilitates stakeholder discussions. Staff training on pre- and post-operative care should also occur well in advance of the first case to allow for adjustments and changes to the standard protocols. Peri-operative coordination is crucial as it may involve modification of medical therapies, and mitigation of post-operative complications as compared to catheter-only ablation. Post-operative recovery may occur in the surgical ward, ICU, or cardiac care unit depending on institution; resource availability should be considered beforehand. Interdepartmental education of nursing staff and advance practice providers are other important considerations.

Single Length of Stay (LOS) versus Dual LOS (or staged) programs. One major decision is whether the epicardial and endocardial portions will be performed within one or two hospital admissions. Within Single LOS, epicardial and endocardial procedures can occur back-to-back in the same or separate suites,

or over sequential days. If using a single suite, the lab arrangement will need to be organized and planned in advance to accommodate staff, primary operator, associated equipment/devices and imaging systems for both procedures (Figure 3). For Dual LOS, the epicardial component typically occurs in the cardiac OR and the endocardial component is scheduled, depending on institution, approximately 31 to 90 days later in the electrophysiology lab (Figure 4).

Respective outcomes from single and dual LOS have not been formally compared. We believe the key ablation undertaking is epicardial and complete LAPW isolation. Thus, the epicardial portion is the initial component of all hybrid approaches (prior to systemic anticoagulation during the endocardial phase). The endocardial component, whether performed early or later, complements the epicardial component by touching up the LAPW lesion set if needed based on an electro-anatomic map; and by performing additional ablation as needed based on individual patient procedure and clinical characteristics, such as PV isolation in a first-time patient. Institutional logistics, reimbursement patterns, and physician and patient preferences and needs will largely influence the optimal local procedure scenario. Especially at the outset, we recommend surgeons and electrophysiologists attend at least part of the other procedure to understand each other's contribution. Feedback from the electrophysiologist on the LAPW lesion set may be particularly helpful during the surgical learning phase.

Patient selection

Patient eligibility. Prior to implementation, patient selection criteria should be thoughtfully considered and agreed upon by the team. In general, patients should have symptomatic, drug-refractory, persistent or long-standing persistent AF. Initial hybrid convergent procedure for paroxysmal AF is not recommended given the good success rate of endocardial PVI. A program could consider

patients who have failed previous catheter ablation; some centers focus on patients considered to be PVI non-responders to facilitate non-PV ablation of the LAPW.

Hybrid Convergent ablation was applied as a *de novo* procedure in the CONVERGE clinical trial,[14] and for patients with enlarged atria (>4-5 cm), high BMI, and longer duration of longstanding persistent AF. Given that catheter ablation improves outcomes in heart failure patients with persistent AF,[15] patients with heart failure and reduced ejection fraction could potentially be considered; some reports have included low ejection fraction subgroups.[16, 17]

Contraindications and restrictions. We consider contraindications to hybrid Convergent ablation to include thrombus in the left atrial appendage, previous sternotomy/heart surgery, unstable coronary artery disease, stroke or myocardial infarction within 3 months, history of significant Barrett's esophagitis, active infection or sepsis, and pregnancy (Figure 5). Those requiring structural cardiac surgery are rather considered as candidates for concomitant surgical ablation, however physicians may consider patients with mild to moderate valvular disease for hybrid Convergent. We recommend applying more stringent selection criteria for the initial patients when a hybrid Convergent program is launched, or with a new team. After experience on these "optimal" patients, relative restriction criteria and future patient eligibility can be re-assessed and adjusted.

Preadmission testing. After initial selection, preadmission testing should be performed for additional screening (Figure 6). Exact testing should be agreed upon by the cardiothoracic surgeon and electrophysiologist, but commonly includes a CT or MRI to evaluate anatomy and PV stenosis (if prior ablation), transthoracic (TTE) or transesophageal echocardiogram (TEE) to evaluate mitral regurgitation, thrombus in the left atrium (LA) and LAA, LA size, and left ventricular ejection fraction (LVEF). Baseline EKG and ambulatory ECG monitoring are typically performed. Basic pre-operative laboratory tests and anticoagulation status should be evaluated. An ischemia workup can be considered in select patients.

Peri- and post-operative medication strategies and follow-up

Specific aspects of peri- and post-operative medication strategies will vary institutionally and for single versus dual LOS. A comprehensive anticoagulation protocol including preoperative, intra-operative and post-operative anti-coagulation management should be formally planned to prevent potential thromboembolic events. While we describe our basic approach to medical therapy below, in Figure 6 and Supplement, each institutional team must have a plan in place for anticoagulation, anti-inflammatory medication, and pain management.

Peri-operative anticoagulation strategy. Consensus on the specific peri-operative anticoagulation regimen does not exist, however there is consensus supported by evidence, that time off of anticoagulation should be minimized. Patients should remain on oral anticoagulation in the weeks prior to the procedure to avoid thrombus formation. Often, direct oral anticoagulants (DOACs) are suspended 24 to 48 hours (depending on dosage and renal function) prior to the procedure. For patients on warfarin, INR levels should remain within a therapeutic range, and should undergo bridging with low molecular weight heparin when the INR falls below 2.0 after warfarin discontinuation. As with conventional catheter ablation, the patient should be fully heparinized to the electrophysiology lab standard during endocardial instrumentation of the LA.

Post-operative medication regimen. Anticoagulation can usually be resumed the evening of the procedure unless otherwise indicated by risk or complexity of the case, or early or excessive postoperative bleeding. Post-operative pain and pericarditis can be managed through several strategies described in Figure 6 and Supplement depending on co-existing morbidities. Long-term anticoagulation following the procedure should be as indicated by AF and ablation guidelines, and should not be discontinued in the two months following the procedure.

Clinical follow-up. Specific follow-up and rhythm monitoring will vary institutionally. Surgical follow-up usually occurs 1-4 weeks after the single LOS or epicardial procedure and with electrophysiology 1-3 months after the single LOS or endocardial procedure. A crucial follow-up step specific to hybrid Convergent procedures is consideration of a TTE performed approximately 2-4 weeks following the procedure (unless indicated earlier by symptoms) in most or all patients to screen for inflammatory-mediated pericardial effusions and Dressler's syndrome (Figure 6).

Cardiothoracic surgery team: key components of the hybrid Convergent procedure

Detailed surgical considerations and operative technique have been reported.[18] We describe here general factors relevant to the surgical portion of the hybrid Convergent procedure. Device instructions for use should be followed for patient preparation, device setup, and pericardial access. Anatomical landmarks and the LAPW are shown in Figure 7.

Epicardial ablation. Prior to ablation, the relative position of the ablation device should be assessed, utilizing the black arrows and dots to orient the electrodes toward the epicardium and away from the posterior pericardium (Figure 1). The cannula can be retracted slightly after device positioning. The vacuum is then engaged to draw epicardial tissue into the device before ablation; it should not be active when moving the device. The pericardial space is irrigated through the cannula to limit temperature rises; baseline temperature should be noted and continuously monitored. The TEE (and NG/OG tube if applicable) should be removed or retracted during ablation to avoid interference with temperature monitoring. Each ablation is applied for 90 seconds and an impedance drop of at least 10% (on the RF generator) should be observed during the first 20 seconds, indicating adequate contact between the catheter and heart.

Lesion sets. At minimum, the epicardial ablation should include parallel, connecting lesions across the LAPW extending from the left and right pericardial reflections at the PV/LA junction. The total

number of ablations (typically 20-30) depends on the patient and atrial size. The extent of the superior ablation row will be dictated by the pericardial reflection along the transverse sinus: the EPi-Sense catheter should be advanced as cephalad as possible until resistance is met, which indicates contact with the pericardial reflection. Often while placing the first row of ablation lines the catheter will catch on the spine and deflect the catheter and cannula. It is important to mentally visualize these effects on ablation and avoid gaps. It is not uncommon to see preserved myocardial voltage in the shape of "V" at the roof of the endocardial map as a result of the transverse pericardial reflections or protrusion of the vertebral column preventing an appropriate purchase of the myocardium by the catheter. To that end, the lesion set should be systematic (as viewed from the surgeon's visual perspective), starting as superior right as possible (vicinity of posterior surface of the left superior PV) and then move to left (to the posterior surface of the right superior PV). Once the first row is completed, the second row is started just below the first lesion and carried over to the left.

The inferior border of ablation is the caudal margin of the inferior PVs. The coronary sinus (CS) is easily visualized in the 3 o'clock region or on the left side of the patient's heart, but is more difficult to visualize as it courses across the posterior LA towards the IVC. Imagining its oblique course is helpful to determine the inferior extent of the lesion set. The surgeon must continually observe the inferior margin of both inferior PVs and the CS in order to avoid ablation of the left atrial isthmus. Inadvertent ablation of this area can predispose the patient to post-operative atypical flutter. A healthy 2-cm margin should be maintained from the CS. As one approaches the inferior aspect of the lesion set there often is significant epicardial fat that may limit the effectiveness of these lesions.

Whether or not to place lesions anterior to the left and right PVs should be discussed between the surgeon and electrophysiologist. These advanced lesions may be addressed once the team becomes proficient with LAPW ablation. Most electrophysiologists feel comfortable that the endocardial ablation set will isolate the PVs and that the value and focus of the epicardial ablation is on the LAPW.

When encountering suboptimal RF delivery, first troubleshoot the catheter making sure suction is adequate and tissue apposition as well as vacuum are maintained. Repeating the lesion is also an advisable next step. Barring a technical issue, it is important to persist as the resulting map can often be surprisingly good despite suboptimal lesion appearance. The device's sensing feature can also be utilized to confirm electrical quiescence.

Tissue fibrosis, epicardial or intramyocardial fat, and esophageal temperature rise can affect ablation quality. In cases of fibrosis or fat, the starting impedance may be high and/or the power delivery will vary throughout the duration of the burn. Epicardial fat can be visually recognized by the surgeon and if power delivery does not exceed 10W for more than a few seconds, the ablation should be aborted and the catheter repositioned, even if only by a few millimeters. Ablations that achieve only moderate power delivery can be repeated in the same position without moving the catheter. Esophageal temperature can rise very rapidly in some cases, and should be constantly monitored and ablation stopped if the temperature increases by 0.5-1.0 degree Celsius. Copious irrigation of the field with room temperature saline and repeating ablation will usually allow for adequate ablation.

Completing the epicardial procedure. When ablation is complete, a drain is advanced through the cannula under direction visualization into the pericardial space. The drain can be passed through the subxiphoid or lateral incision. The drain should remain in place until its output is less than 50-100 cc during a 24-hour period. The wound is irrigated, and local anesthetic or anti-inflammatory medications can be administered. The wound is then closed in layers.

Electrophysiology team: key considerations for the hybrid Convergent procedure

Strategic considerations. It is generally agreed that the goals of the endocardial lesion set are in part to create a gapless connection with the epicardial lesion set and to eliminate electrical activity in the desired region of LA substrate. Prior to endocardial ablation, the extent of epicardial ablation is

assessed by performing an endocardial voltage map, preferably in sinus rhythm (SR) or with atrial pacing. The lowest possible voltage gate is recommended to avoid false assumptions of ablated tissue.

Understanding pericardial reflections. Epicardial ablation is performed in the oblique sinus without dissection of the reflections. The pulmonary venous recess and transverse sinus form the limits of the oblique sinus. The pericardial space differs greatly between patients.[19] The greatest variability is seen at the superior aspect of the pericardial space. The roof of the pericardial space does not correspond with a conventional roof line. Connection of the superior margin of the pericardial reflection with the endocardial "roof" is generally the area most likely to require additive endocardial ablation lesions. Endocardial isolation of the superior PVs is mandatory following epicardial ablation; they are rarely ablated from the epicardial space.

The endocardial lesion set. Transmural extension of epicardial lesions to the endocardium can be hampered by epicardial fat, device apposition difficulty due to a prominent vertebral column, pericardial adhesions, or an unsuitable approach angle into the pericardium. Thus, the operator may need to extend the lesion sets from the margins of the pericardium to areas directly along the LAPW. An endocardial electro-anatomic map can be done to determine the completeness of epicardial (and then endocardial) ablation lesion sets and determine if, how, and where additional endocardial ablation is needed.

Adequacy and safety of LAPW endocardial ablation are beyond the scope of this manuscript. Risk mitigation protocols are strongly recommended to decrease the likelihood of atrio-esophageal fistula, cardiac perforation, and phrenic nerve injury.

There are several endocardial ablation endpoints that should be met with the procedure. Demonstration of PV isolation is mandatory. A wide area circumferential ablation lesion set is recommended to adequately bridge the gap connecting the epicardial lesion set (Figure 2). If

endocardial mapping reveals that the epicardial lesion set does not reach the superior aspect of the LA's anatomical PW, it may be reasonable to create a "roof line" connecting the superior PVs for sufficient critical mass of ablated tissue. However, proximity of the esophagus, phrenic nerve, and spinal prominence may preclude completion. Any endocardial lesion risking collateral injury should be performed carefully weighing the benefit of the lesion against the risk. The inferior extent of the LAPW lesion set is largely governed by the epicardial ablation, which is intentionally limited to the inferior aspect of the inferior PVs. This is understood to minimize potentiality for iatrogenic arrhythmias.

The hybrid Convergent procedure is fundamentally an anatomically-focused treatment strategy. Success of the procedure is reflected in rhythm outcomes after a 2-3 month blanking period and completion of both endocardial and epicardial lesions. It is our group's experience that the inability to develop or maintain SR at the procedure's conclusion should not be viewed as a failure and is not indicative of reduced efficacy. Isoproterenol administration or rhythm challenge exercises may be used to guide additional ablation. If macrorentrant tachycardia is observed, additional linear ablation may be considered. Figure 8 shows ablation map examples.

Understanding tissue thickness and epicardial-endocardial dissociation. The observation that endocardial and epicardial conduction differs in AF has raised concerns with ablation strategies that do not create transmural lesions. The degree of disparity between the endocardium and epicardium may promote and sustain fibrillatory conduction.[20] Accordingly, overlap between the epicardial and endocardial lesion sets is preferred to avoid arrhythmogenic gaps and ensure transmurality.

Endocardial energy sources. There are several endocardial ablation approaches targeting the PVs and the left and right atria using different techniques and energy sources: irrigated ablation catheter using RF energy and various balloon-based systems (cryoenergy, laser or RF). Most published data, including the CONVERGE trial, used RF catheter ablation in hybrid Convergent procedures. There

are limited but very promising data published using endocardial cryoballoon ablation in hybrid Convergent procedures.[21, 22] Currently, there are no recommendations for the preferred endocardial energy source in hybrid procedures. However, lesion sets that accomplish large area ablation are preferred over strategic linear lesions as the creation of gaps has the potential of invalidating large areas of substrate mitigation.

Safety considerations

Potential adverse events can be mitigated through vigilance and simple solutions (Figure 6). Thermal injuries to the esophagus can be avoided through careful device orientation, esophageal temperature monitoring, and prophylactic irrigation of the pericardial space. Late pericardial effusions due to Dressler's syndrome and cardiac tamponade can be prevented through pericardial drains,[23, 24] prophylactic medications (colchicine, steroids and/or NSAIDs),[18, 25] patient education on symptoms, and TTE surveillance at approximately 2-4 weeks.[18] Complications can arise from both epicardial and endocardial procedures, and experienced investigators have reported a learning curve after which complications decreased using such strategies.[23, 26]

Clinical outcomes

Single and multi-center studies have reported freedom from AF or any atrial tachyarrhythmia to be 66% to 95% at one year following the hybrid Convergent procedure, with 52% to 81% arrhythmia-free without AADs.[7] A report of 81% of patients in SR after four years suggests favorable durability but additional long-term data are necessary.[23] These results are especially encouraging since the procedure has been frequently utilized in the most refractory patient populations. Risk mitigation and evolution from the epicardial box lesion set to LAPW homogenization are believed to improve procedural safety and efficacy. The shift from a transabdominal to a subxiphoid approach has eliminated concerns

regarding rare abdominal complications[26]. Prospective patient registries of hybrid Convergent ablation are useful to facilitate outcomes reporting.[22, 27]

Future directions

The prospective, multi-center, randomized controlled clinical trial, CONVERGE (NCT01984346), demonstrated superiority of the hybrid Convergent approach versus an endocardial-only approach for treating nonparoxysmal AF[14]. The hybrid approach achieved one-year freedom of atrial arrhythmias absent new/increased dose of previously failed class I/III antiarrhythmic drugs in 67.7% versus 50.0% using conventional techniques (p = 0.036). Further questions remain given the heterogeneity of endocardial approaches and adoption of additional epicardial procedures. Despite variety in current endocardial ablation sets, there is agreement among users to move towards an agreed upon endocardial lesion set(s). Given the potential contribution of arrhythmogenic impulses emanating from the LAA in persistent AF[28] there is increasing interest in LAA electrical isolation. While one can attempt to do this with ablation, concerns exist regarding durability and the prothrombotic risk without mechanical closure.[29] The hybrid Convergent approach with transthoracic epicardial placement of an AtriClip offers both mechanical and electrical LAA isolation,[30] with favorable results in early experience.[16, 18, 31] Future studies are needed to evaluate whether addition of LAA exclusion and electrical isolation improves clinical outcomes and the best technical approach. Additional endpoints are worth investigating, such as cost-efficacy, AF burden, formal QOL measurements, stroke, and change in LVEF or symptoms in heart failure patients. Further, hybrid ablation strategy adoption may be sensitive to costs for program start-up and maintenance, but a cost-efficacy analysis found the hybrid Convergent strategy to be superior to catheter ablation due to better rhythm control and fewer repeat procedures.[32]

Conclusion

The hybrid Convergent procedure is an emerging technique to address nonparoxysmal AF that can be deployed safely and effectively with careful planning, a coordinated team approach, appropriately selected patients, and a full understanding and implementation of risk mitigation tactics. As adoption and experience with the procedure grows, revisiting and revising the suggested workflows illustrated in this paper will be important for optimizing clinical outcomes.

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Figure 1. Unipolar radiofrequency device for epicardial ablation. A unipolar radiofrequency device inserted inside a pericardioscopic cannula (with endoscope, not shown) is used to make left atrial posterior wall linear ablations. Arrows and dots orient the radiofrequency coil towards the epicardium.

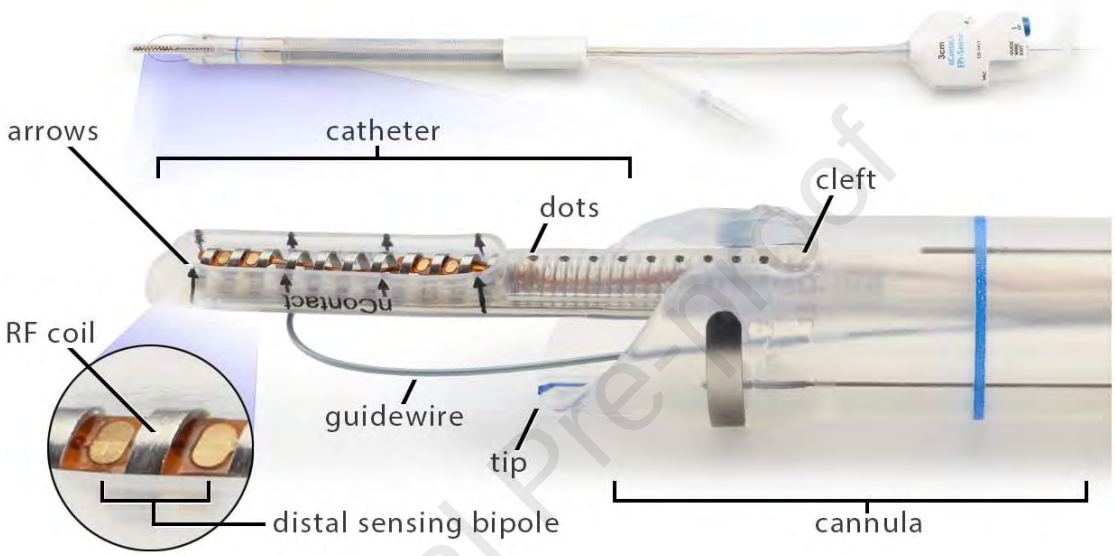


Figure 2. Hybrid Convergent lesion set. Left atrial epicardial/endocardial ablation patterns (left) and lesion set variations (insets). Posterior wall linear lesions are made using the unipolar radiofrequency device. Endocardial ablation is performed to isolate the pulmonary veins (PVs) and address gaps (red circles). Cryoablation PVI is shown in blue. LIPV: left inferior pulmonary vein; LSPV: left superior pulmonary vein; PW: posterior wall; RIPV: right inferior pulmonary vein; RSPV: right superior pulmonary vein; WACA: wide area circumferential ablation

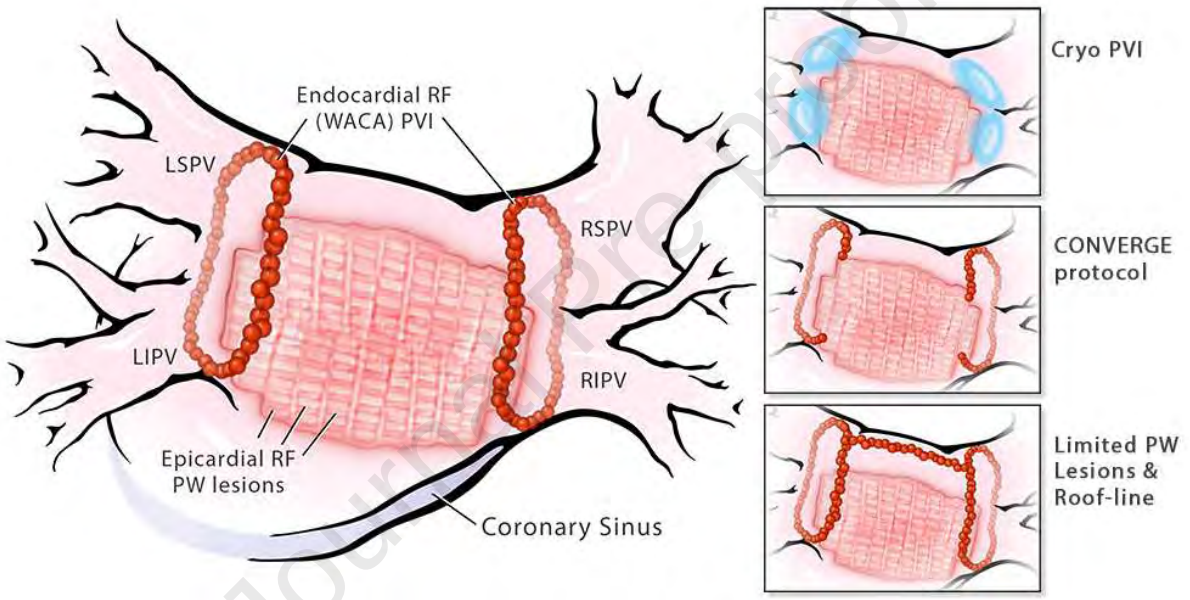


Figure 3. Hybrid operating room (OR)/electrophysiology (EP) laboratory set-up. Example set-up for a hybrid OR/EP lab with key equipment and personnel. Equipment shaded in blue must be within surgeon's view. TEE: transesophageal echo.

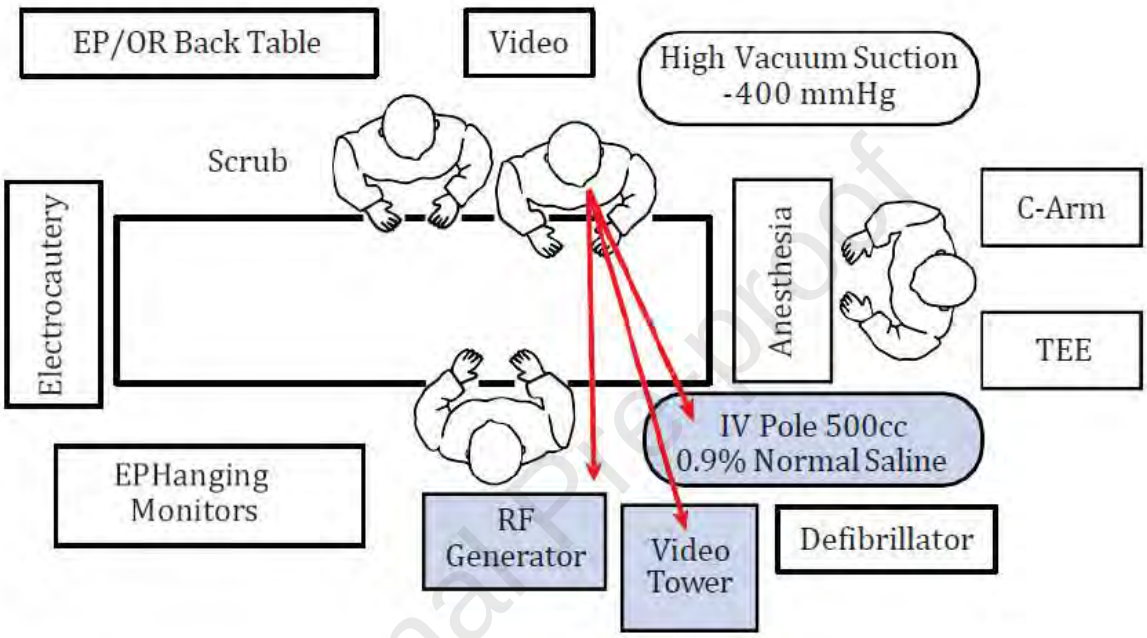


Figure 4. Epicardial and endocardial procedure scheduling. Key considerations of performing the epicardial/endocardial portions in a single hospitalization (1 LOS; same room in one day, separate rooms in one day, or on sequential day) or in two hospitalizations (2 LOS) scheduled 31 to 90 days apart.

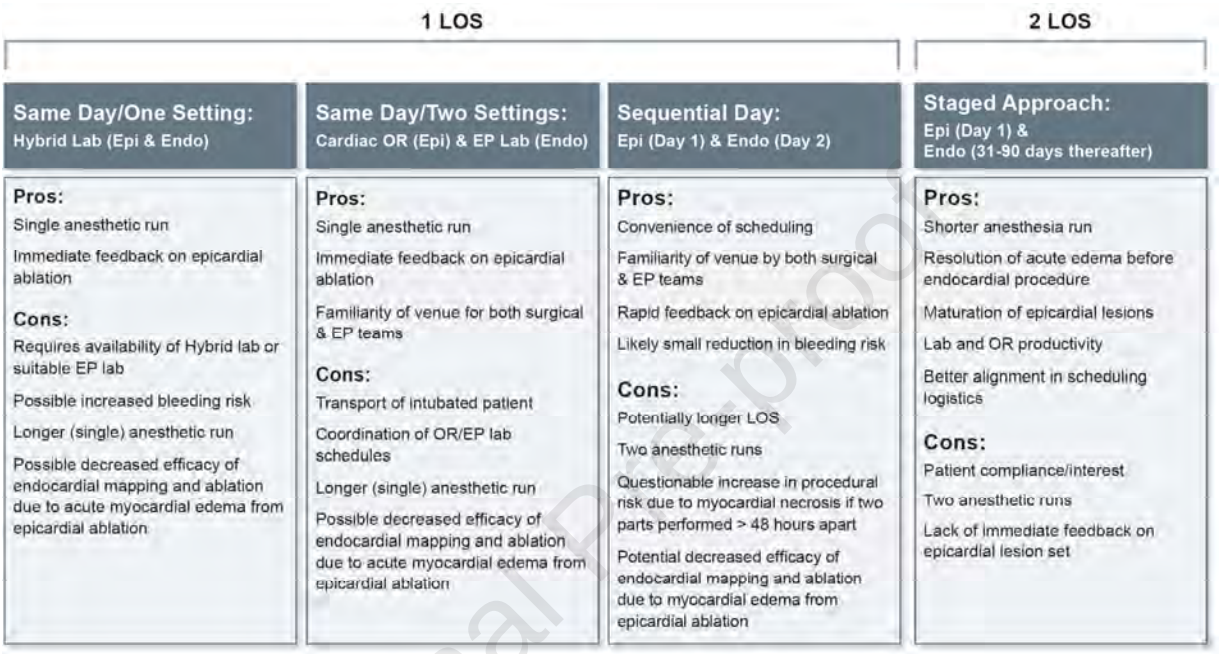


Figure 5. Absolute and relative restrictions for hybrid Convergent procedure. Contraindications (left panel) and relative restrictions by consensus within the Convergent team after acquired experience (right panel). BMI: body mass index; COPD: chronic obstructive pulmonary disease; CVA, cerebrovascular accident; LAA: left atrial appendage; LVEF: left ventricular fraction; MI: myocardial infarction; NYHA: New York Heart Association: TIA: transient ischemic attack.

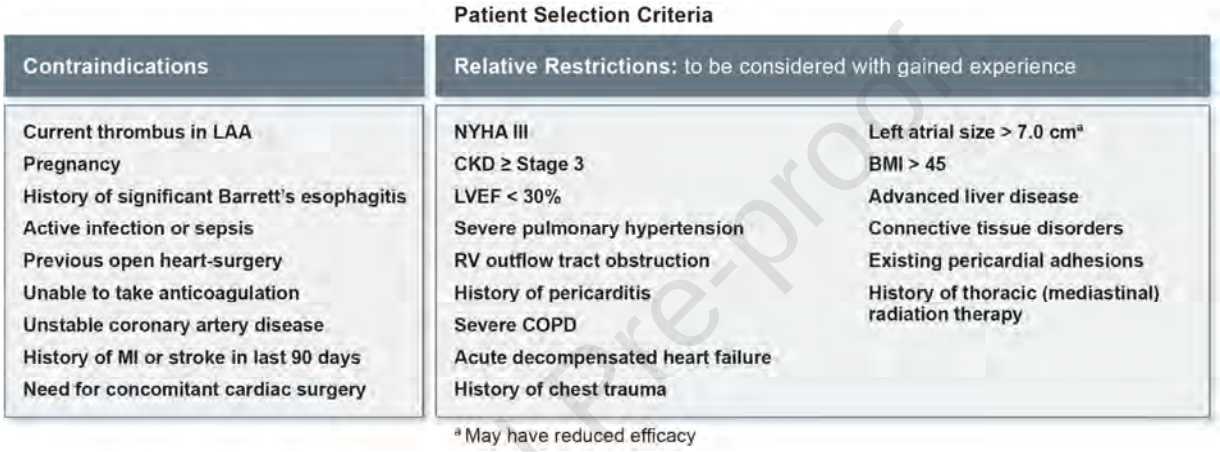


Figure 6. Key considerations before, during, and after hybrid Convergent ablation. Key safety risk mitigation strategies are highlighted in white. See Supplement for medication strategy options before, during and after the procedure. AAD: anti-arrhythmic drugs; DOAC: direct oral anticoagulation; ICD: implantable cardioverter device; LAA: left atrial appendage; NSAID: non-steroidal anti-inflammatory drugs; PPM: permanent pacemaker; TEE: transesophageal echocardiogram.

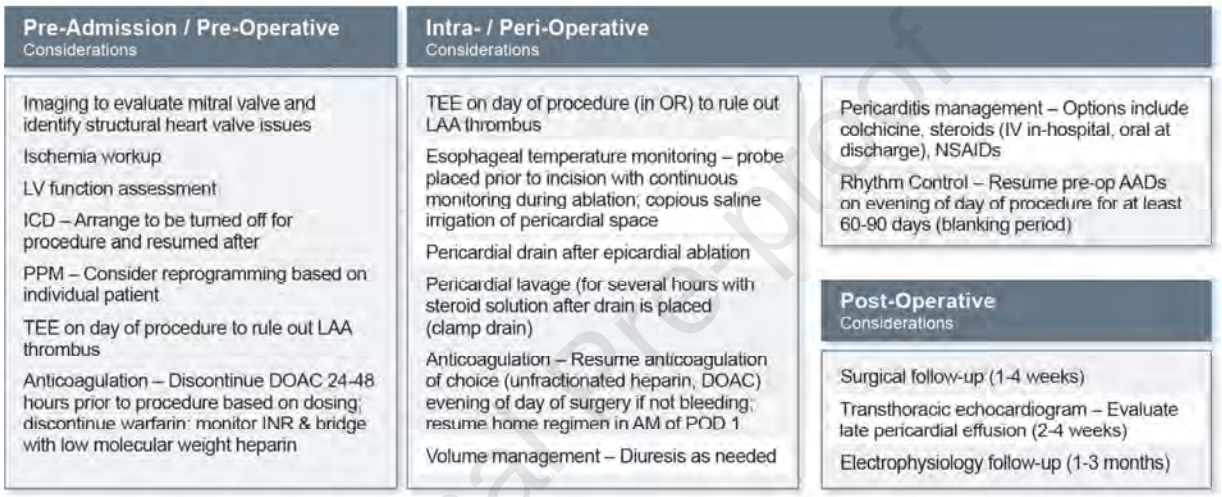


Figure 7. Ablation of the posterior left atrial wall. Endoscopic view of the posterior left atrial wall and lesions created with the unipolar RF device. Key anatomic features as viewed endoscopically through the cannula are shown. Left and right inferior pulmonary veins (LIPV, RIPV) and left and right superior pulmonary veins (LSPV, RSPV).

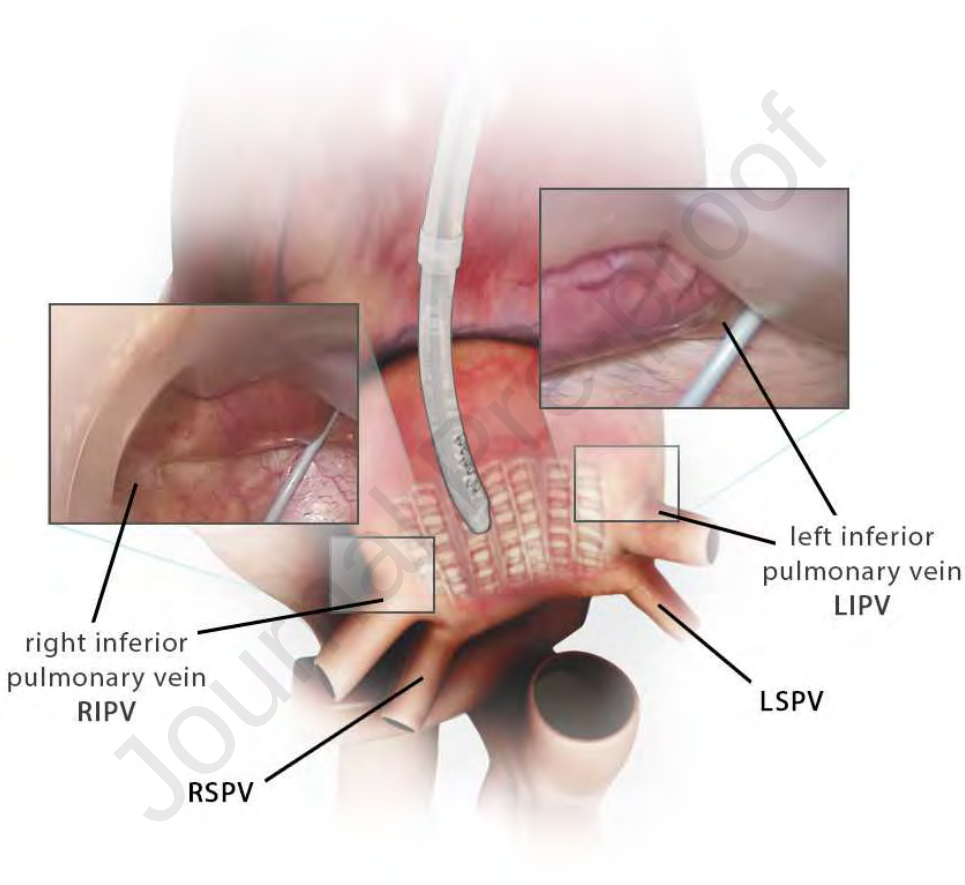
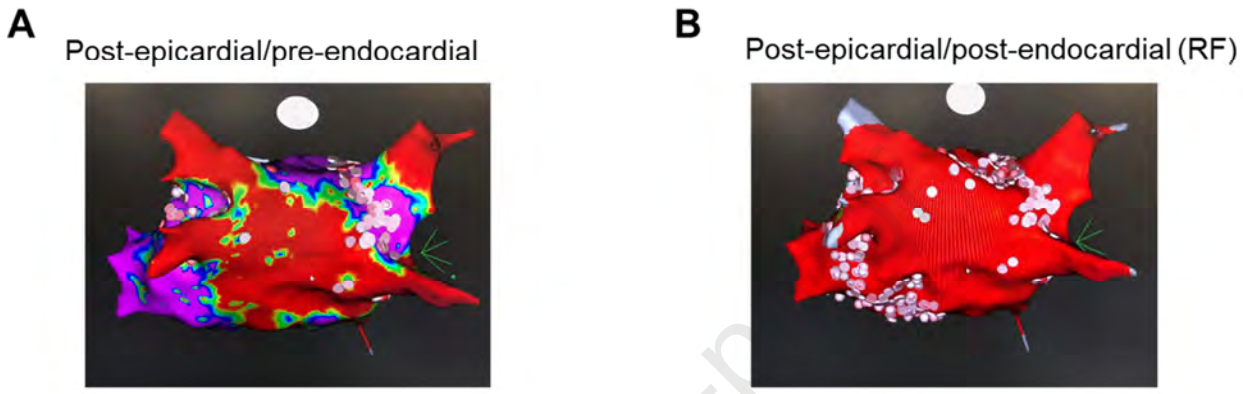
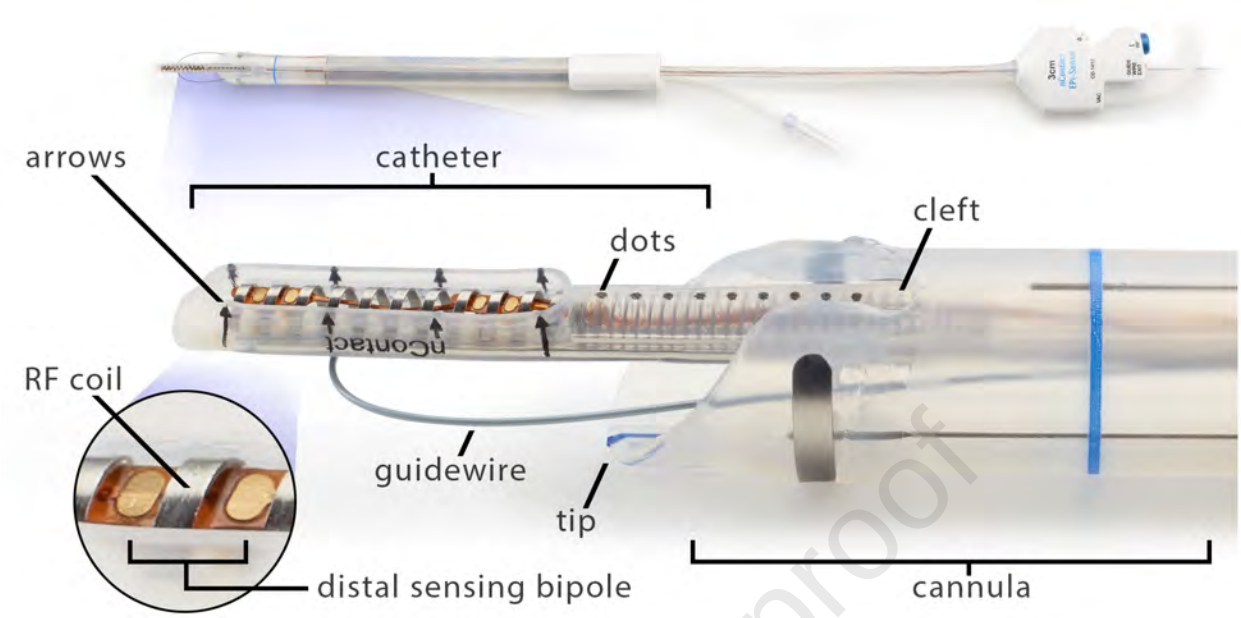
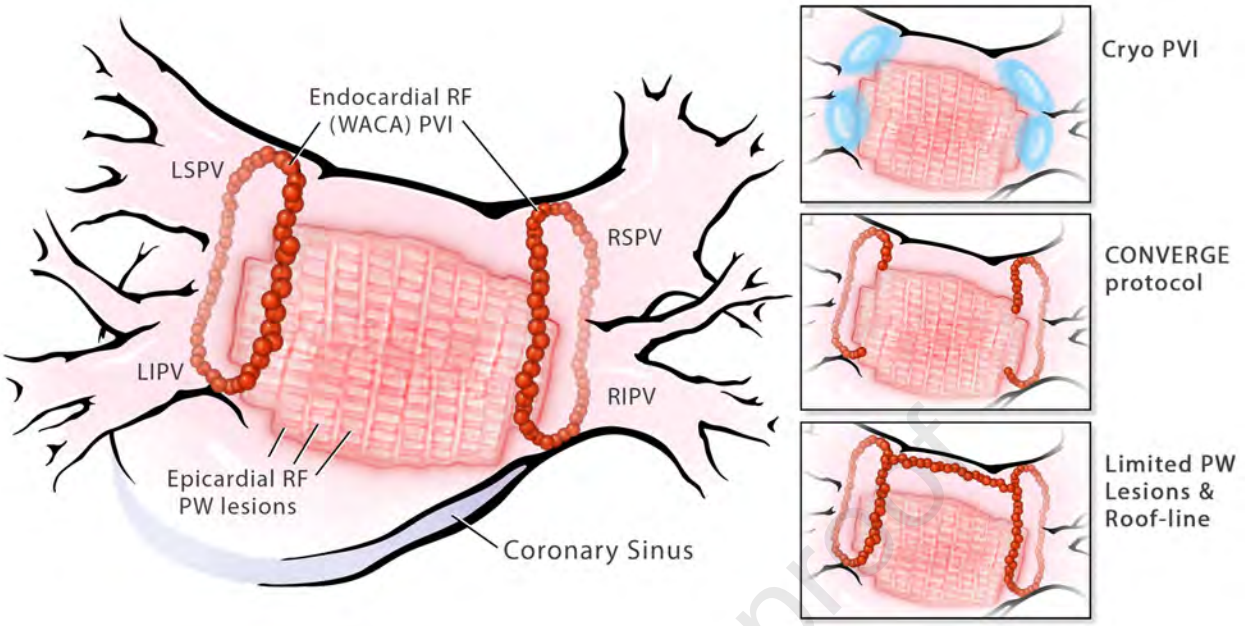
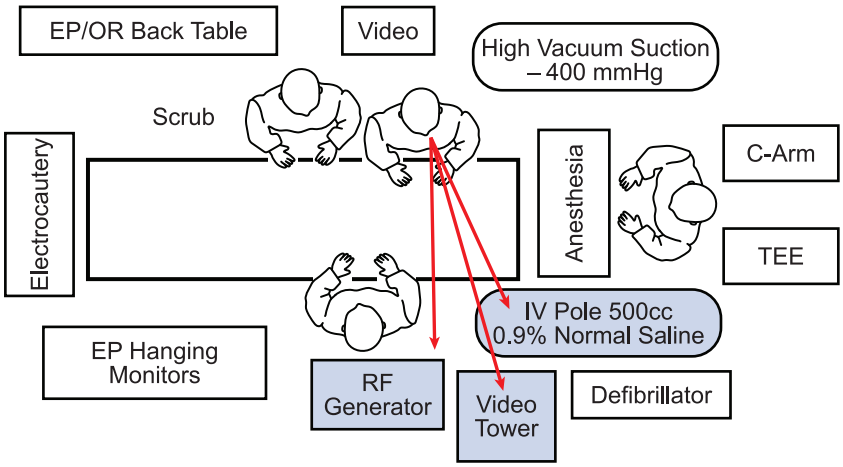


Figure 8. **Voltage maps before and after ablation**. A. Voltage map post-epicardial/pre-endocardial ablation B. Voltage map following endocardial pulmonary vein isolation (thus completion of hybrid Convergent procedure) with an irrigated radiofrequency catheter.









1 LOS

2 LOS

Same Day/One Setting: Hybrid Lab (Epi & Endo)	Same Day/Two Settings: Cardiac OR (Epi) & EP Lab (Endo)	Sequential Day: Epi (Day 1) & Endo (Day 2)	Staged Approach: Epi (Day 1) & Endo (31-90 days thereafter)
Pros: Single anesthetic run Immediate feedback on epicardial ablation	**Pros:** Single anesthetic run Immediate feedback on epicardial ablation Familiarity of venue for both surgical & EP teams	**Pros:** Convenience of scheduling Familiarity of venue by both surgical & EP teams Rapid feedback on epicardial ablation Likely small reduction in bleeding risk	**Pros:** Shorter anesthesia run Resolution of acute edema before endocardial procedure Maturation of epicardial lesions Lab and OR productivity Better alignment in scheduling logistics
Cons: Requires availability of Hybrid lab or suitable EP lab Possible increased bleeding risk Longer (single) anesthetic run Possible decreased efficacy of endocardial mapping and ablation due to acute myocardial edema from epicardial ablation	**Cons:** Transport of intubated patient Coordination of OR/EP lab schedules Longer (single) anesthetic run Possible decreased efficacy of endocardial mapping and ablation due to acute myocardial edema from epicardial ablation	**Cons:** Potentially longer LOS Two anesthetic runs Questionable increase in procedural risk due to myocardial necrosis if two parts performed > 48 hours apart Potential decreased efficacy of endocardial mapping and ablation due to myocardial edema from epicardial ablation	**Cons:** Patient compliance/interest Two anesthetic runs Lack of immediate feedback on epicardial lesion set

Patient Selection Criteria

Contraindications	Relative Restrictions: to be considered with gained experience	
Current thrombus in LAA	NYHA III	Left atrial size > 7.0 cm[a]
Pregnancy	CKD ≥ Stage 3	BMI > 45
History of significant Barrett's esophagitis	LVEF < 30%	Advanced liver disease
Active infection or sepsis	Severe pulmonary hypertension	Connective tissue disorders
Previous open heart-surgery	RV outflow tract obstruction	Existing pericardial adhesions
Unable to take anticoagulation	History of pericarditis	History of thoracic (mediastinal) radiation therapy
Unstable coronary artery disease	Severe COPD	
History of MI or stroke in last 90 days	Acute decompensated heart failure	
Need for concomitant cardiac surgery	History of chest trauma	

[a] May have reduced efficacy

Pre-Admission / Pre-Operative Considerations

- Imaging to evaluate mitral valve and identify structural heart valve issues
- Ischemia workup
- LV function assessment
- ICD – Arrange to be turned off for procedure and resumed after
- PPM – Consider reprogramming based on individual patient
- TEE on day of procedure to rule out LAA thrombus
- Anticoagulation – Discontinue DOAC 24-48 hours prior to procedure based on dosing; discontinue warfarin: monitor INR & bridge with low molecular weight heparin

Intra- / Peri-Operative Considerations

- TEE on day of procedure (in OR) to rule out LAA thrombus
- Esophageal temperature monitoring – probe placed prior to incision with continuous monitoring during ablation; copious saline irrigation of pericardial space
- Pericardial drain after epicardial ablation
- Pericardial lavage for several hours with steroid solution after drain is placed (clamp drain)
- Anticoagulation – Resume anticoagulation of choice (unfractionated heparin, DOAC) evening of day of surgery if not bleeding; resume home regimen in AM of POD 1.
- Volume management – Diuresis as needed

Post-Operative Considerations

- Pericarditis management – Options include colchicine, steroids (IV in-hospital, oral at discharge), NSAIDs
- Rhythm Control – Resume pre-op AADs on evening of day of procedure for at least 60-90 days (blanking period)

- Surgical follow-up (1-4 weeks)
- Transthoracic echocardiogram – Evaluate late pericardial effusion (2-4 weeks)
- Electrophysiology follow-up (1-3 months)