The Cox-Maze Procedure: What Lesions and Why Associated Presentation given by Dr. Damiano at the AATS 2021 Annual Meeting

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Title: The Cox-Maze Procedure: What Lesions and Why

Associated Presentation given by Dr. Damiano at the AATS 2021 Annual Meeting

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Glossary of Abbreviations

AF, atrial fibrillation;
ATA, atrial tachyarrhythmia;
AVN, atrioventricular node;
CHB, complete heart block;
CMP, Cox-Maze procedure;
CPB, cardiopulmonary bypass;
IVC, inferior vena cava;
LA, left atrium;
LAA, left atrial appendage;
PPM, postoperative pacemaker;
PV, pulmonary veins;
PVI, pulmonary vein isolation;
RA, right atrium;
RAA, right atrial appendage;
RCT, randomized controlled trial;
RF, radiofrequency;
SAN, sinoatrial node complex;
SSS, sick sinus syndrome;
SVC, superior vena cava;
Central Picture: The Cox-Maze biatrial lesion set, including the posterior left atrial box.

Central Message: In a successful Maze: 1) all lesions must be fully transmural; 2) the entirety of the posterior left atrium must be isolated; and 3) the left atrial appendage must be excluded.

Keywords:
- Cox-Maze Procedure
- Atrial fibrillation
- Left atrial appendage
- Pulmonary vein isolation
- Surgical ablation
Introduction

The Cox-Maze procedure (CMP) is the most effective treatment for atrial fibrillation (AF).

Despite this, many patients with AF undergoing cardiac surgery for other pathologies are not offered a concomitant CMP, while other patients with lone-AF are not offered surgical intervention at all.¹ Part of the original reticence to perform the CMP lay in the technical complexity of the “cut-and-sew” Maze (i.e. the CMP III) – in which multiple incisions were made in both atria to create conduction block. The introduction of radiofrequency and cryoablation devices has made the latest iteration of the CMP – the CMP-IV – not only technically simpler but also more time-efficient, thereby decreasing cardiopulmonary bypass times and procedural morbidity and mortality.² However, the number of CMPs performed today still falls short of the number of patients who would benefit from this procedure. It has been estimated that approximately one third of patients undergoing mitral valve surgery who have a history of AF do not receive the CMP.¹ This is despite multiple societies’ recommendations for the management of AF, including a class 1A recommendation from the Society of Thoracic Surgery.³

Lingering hesitancy to perform the CMP is in part due to surgeon inexperience and lack of comfort, but may also be due to a lack of understanding of the foundational concepts of the Maze, and an unfamiliarity with the location and function of each individual lesion.

This article aims to provide a clear description of the biatrial lesion set and the importance of the individual lesions. We aim to do this in three parts: 1) a description of the goals of the CMP, 2) a description of the criteria required for successful lesions, and 3) a description of each lesion and
its importance/function. We will end with a brief discussion of the various ablation modalities available with which to make Maze lesions. This is not a step-by-step description of how to perform the Maze - our group has published multiple articles describing our operative technique in detail, both via sternotomy (Video 1) and via right minithoracotomy (Video 2). Instead, our goal is to enable a conceptual understanding of the electrical rationale for a biatrial CMP.

GOAL OF THE COX-MAZE PROCEDURE

The major goal of the CMP is termination of AF and restoration of normal sinus rhythm. A secondary goal is the excision or exclusion of the left atrial appendage (LAA) in order to prevent strokes, the most dreaded complication of AF. The intended hemodynamic outcomes are 1) restoration of the atrial kick with subsequent improvement in cardiac output and amelioration of heart failure, and 2) cessation of stagnant blood flow in the fibrillating left atrium (LA) that serves as a nidus for thromboemboli.

The core tenet of the CMP is that a pattern of lesions made in both atria block the conduction of aberrant electrical impulses, both by isolating arrhythmogenic foci and by interrupting micro- and macro-reentrant circuits, thereby preventing sustained AF. The ultimate effect is to create a constrained pathway through which electrical impulses travel from the sinoatrial node complex (SAN) to the atrioventricular node (AVN) and activate the majority of atrial tissue with the crucial exception of the posterior LA (including the region of the pulmonary veins [PV]). The posterior LA is isolated in its entirety given this area’s propensity for developing arrhythmogenic foci.
REQUIRED CRITERIA FOR SUCCESSFUL LESIONS

There are specific criteria a lesion must meet in order to consistently and reproducibly block electrical conduction. Even if all lesions of the CMP are made, if each individual lesion does not meet these criteria, the CMP as a whole may be incomplete and ineffective. Fortunately, these criteria are straightforward, and are as follows:

1) **Each lesion must be transmural throughout its entirety.** Our laboratory and others have shown that even a very small gap in a lesion can allow conduction of aberrant electrical impulses. Furthermore, these small gaps may actually be pro-arrhythmic given that they often result in slow conduction of these impulses, increasing the likelihood of maintaining reentrant circuits.

2) **Each lesion must originate from and/or end in tissue that is not electrically conductive.** Electrically non-conductive tissue can either be another lesion or tissue that is natively non-conductive such as a valve annulus or vena cava. This is necessary to block conduction, particularly of the rotors and micro- and macro-reentrant circuits that may be needed to sustain AF. Lesions that are not anchored on at least one side by electrically non-conductive tissue can actually serve as a nidus for re-entrant circuits which can rotate around the lesions creating atypical atrial flutters.

We will handle the latter criteria first - where to place your lesions, and why. The complete biatrial CMP lesion set is described below - management of the LAA, isolation of the posterior LA, completion of the LA lesion set, and the right atrial (RA) lesion set - with numbering in parentheses corresponding to figure 1. By ordering the lesion sets and their descriptions in this manner, we aim to focus on the conceptual importance of each lesion/set of lesions and how the
final pattern of ablation lines in the biatrial CMP restricts electrical wavefronts to prevent
arrhythmias. Of note, this is different from the order in which we create these lesions intraoperatively, which is dictated primarily by the practicalities of anatomy and operative approach. A brief description of our operative procedure (i.e. a list of the lesions in the order in which we create them intraoperatively) can be found in supplemental table 1.

DISCUSSION OF COX-MAZE LESIONS

LAA1-2 - Manage the left atrial appendage

The management of the LAA is essential to performing a CMP. Most importantly, since the majority of thromboembolic strokes in AF patients originate in the LAA, removal of the LAA significantly decreases the risk of stroke or systemic embolism. This has been observed both in retrospective case series and prospective, randomized trials. In our experience, we have found either excision or application of an epicardial exclusion device (AtriClip®, AtriCure Inc., Mason OH, USA) to be the most effective means of eliminating the LAA. Unfortunately, stapler exclusion, oversewing, and ligation have had reasonably high failure rates. The appendage clip has had very promising intraoperative and late success rates of both complete LAA occlusion and safety. In our hands, and in either minimally-invasive or beating-heart applications, clipping the LAA is the most reasonable approach.

Whether the LAA is excised or clipped, it is important to leave no stump, as residual LAA tissue (in communication with the LA) has been shown to be prothrombotic. Even in the absence of a
stump, the LAA exclusion line - if not properly anchored in electrically non-conductive tissue - can still serve as a nidus for a flutter circuit.\footnote{7} Given this, we also create a lesion from the excluded LAA to the left PV lesion (as described below), connecting the LAA exclusion to the electrically-excluded posterior LA.

**Left atrial lesion set (Fig.2)**

**L1-4 - Isolation of the posterior left atrium - The Box**

This is the single most important part of the CMP. The posterior LA - including the PVs - has consistently been identified as important to both the initiation and maintenance of AF. Catheter-based electrophysiologic studies have shown that between 87-96\% of ectopic atrial foci in AF patients are located within this region.\footnote{15,16} Moreover, our data has shown that without complete isolation of the posterior LA, the remainder of the CMP lesions only lead to a 33\% freedom from recurrent atrial tachyarrhythmias (ATAs) at 5 years.\footnote{17}

A complete box electrically isolates the whole posterior LA by encompassing the entirety of the PVs and most, if not all, of the posterior LA tissue between the PVs. The term “pulmonary vein isolation” (PVI) is inconsistently used, but in the context of surgical ablation most commonly refers to creating two separate ablation lesions - one around the left-sided PVs, one around the right-sided PVs - that are not connected to each other. This results in electrical isolation of the left and right PVs, but does not isolate any of the rest of the posterior LA between the PVs (Fig.3). When so defined, **PVI has been shown to be an inadequate treatment for AF, with success rates no different than catheter ablation but with greater morbidity.** Two relatively recent randomized controlled trials (RCTs) comparing catheter-based to surgical PVI support
this conclusion.\textsuperscript{18,19} Our data on an incomplete box also document the inadequacy of PVI, given the 33\% rate of ATA freedom among patients whom all had exit-block-confirmed PVIs.\textsuperscript{17} The potential role for the box isolation as a stand-alone lesion has not been established, as no clinical trial has yet addressed this question.

\textit{L5 - Connecting line to the mitral annulus, coronary sinus lesion}

A linear lesion connecting the box to the mitral annulus - which is electrically non-conductive - should be created. This has been termed the “LA isthmus line” and is critical in order to prevent both typical and atypical LA flutter.\textsuperscript{20} The coronary sinus should also be ablated at this level. If the latter is not performed, the coronary sinus can conduct aberrant electrical signals leading to LA flutter around the mitral annulus.\textsuperscript{21}

\textit{Right atrial lesion set (Fig.4)}

The goal of the RA lesion set is to create a complete line of block from the superior to the inferior vena cavae, connect this line to the natively-non-conductive tissue of the tricuspid annulus, and further connect the annulus to the right atrial appendage (RAA), while not damaging either the SAN or AVN. There is good evidence to support the importance of the RA (particularly the cavotricuspid isthmus) in the initiation and maintenance of typical atrial flutter as well as AF.\textsuperscript{22,23} We have shown that up to a third of AF drivers originate in the RA.\textsuperscript{23} Moreover, the best late results of surgical ablation have been shown after biatrial lesion sets.\textsuperscript{17}

An in-depth discussion of the need for postoperative pacemaker (PPM) is beyond the scope of this paper, particularly in regards to performing a biatrial CMP in combination with other cardiac
surgery, and ultimately is dependent on surgeon experience and patient selection. It is important to note that the two main indications for PPM placement after a biatrial CMP are sick sinus syndrome (SSS) and complete heart block (CHB). CHB after a CMP is most likely secondary to intraoperative AVN injury that occurred during a concomitant procedure, i.e. not due to the CMP itself. The CMP does not include any ablation in the immediate area of the AVN. SSS is most likely present at baseline and simply uncovered (rather than caused) by the CMP. The incidence of SSS increases with patient age, and duration of preoperative AF. Over the past decade, we have found that about 12% of our post-CMP patients require PPM placement, with about half of these patients requiring PPM for SSS and the other half for CHB.\textsuperscript{24} We do not test SAN or AVN function intraoperatively; all patients have temporary pacing wires placed prior to closure, which are removed or replaced postoperatively once patients have had time to recover from potentially transient postoperative rhythm abnormalities. There is a high incidence of early junctional rhythms due to SAN dysfunction, and we recommend waiting at least 5 days prior to making a decision regarding permanent PPM.

\textbf{R1 - Right atriotomy}

The right atriotomy should have a relatively perpendicular orientation in relation to the axis of the superior and inferior vena cavae. An atriotomy is transmural, and therefore is electrically non-conductive. We only perform a right atriotomy via a sternotomy - when performing the CMP via a right minithoracotomy, we create all right sided lesions through purse-string stab-incisions.

\textbf{R2-3 - Vena cavae lesions}
The vena cavae lesions form a continuous straight line which is perpendicular to the atriotomy and which connects the superior vena cava (SVC; R2) and the inferior vena cava (IVC; R3). These lesions are made as posterior and lateral as possible to avoid injury to the SAN near the SVC-RA junction and the pericardial reflection by the IVC. These lesions must extend several centimeters onto the vena cavae in order to ensure the combined vena cavae line in its entirety starts and ends in electrically non-conductive tissue.

**R4 - Connecting line from the right atriotomy to the tricuspid annulus, at the 2 o’clock position relative to the valve**

This connecting line anchors the previous RA lesions (R1-3) to the electrically inactive tissue of the tricuspid annulus (the first pair of anchors being the SVC and IVC). This forms a cavotricuspid isthmus ablation, and is therefore important for the prevention of atrial flutter.

**R5 - Connecting line from the tricuspid annulus (10 o’clock position) to the RAA**

This lesion completes the line of block across the RA, connecting the tricuspid annulus anchor to the RAA. This theoretically prevents rotation of macro-reentrant circuits around the RAA, and may be particularly important in patients with RA enlargement. RA access to allow for creation of this lesion is gained via a small purse-string stab-incision at the base of the RAA.

**R6 - Connecting line from the RAA to the RA free wall**

We routinely create a final additional lesion from the base of the RAA onto the RA free wall down the aortic side of the RAA to avoid the SAN. Access for this lesion is gained via the same small incision used for lesion R5.
We will now discuss the second key criteria for a successful CMP lesion - transmularity throughout the entirety of the lesion. We will briefly discuss how this can be achieved with our recommended ablation devices, either a bipolar radiofrequency (RF) clamp or cryoablation.

ENSURING TRANSMURALITY / THE USE OF VARIOUS ABLATION DEVICES

Every Cox-Maze lesion must be transmural throughout its entirety. This can be achieved by using any of the following techniques, either in isolation or in combination: surgical incisions, bipolar RF ablation, cryoablation. It is our practice to use a combination of these techniques, with each of the three methods matched to specific lesions in order to facilitate performance of the procedure. All 3 modalities are effective if used properly.

Transmularity is always assured with an incision. However, this is the most technically difficult and time-consuming option. We therefore minimize its use to only what is required to gain access to the interior of the atria. Our right atriotomy performs double-duty as an atriotomy and as an ablation lesion. We make our left atriotomy to connect to the posterior box.

Extensive experience in our laboratory has shown that the only devices that reliably create transmural lesions are bipolar RF clamps (as opposed to unipolar RF probes) and cryoablation. Both achieve an over 99% rate of transmularity as judged histologically in animal models. Bipolar RF clamps require access to the interior of the atria - and therefore cardiopulmonary bypass (CPB) - except for the right and left PV lesions which can be created by encircling within
the clamp as large a cuff of LA tissue as possible around the base of the PV ostia from the
exterior of the atrium, therefore ablating two layers of atrial wall simultaneously. Creating an
oval around each set of PVs (left and right) is not strictly necessary as the superior and inferior
connecting lesions (L3 and L4) will effectively exclude all tissue between the PVs (compare the
two adequate box lesions in figure 3). However, we recommend treating the PVs in this fashion
when using bipolar RF clamps, as it is possible to do so on the beating-heart on CPB but prior to
cross-clamping. This in turn allows for exit-block testing to confirm PV isolation and appropriate
function of the RF clamp. A novel device has recently been introduced to the market making it
possible to perform the entirety of the LA box exclusion with a single application and without
opening the LA – our laboratory has found that the Atricure EnCompass RF clamp (AtriCure
Inc., Mason OH, USA) reliably creates transmural lesions in a porcine model. However, there
are no currently available data on the clinical effectiveness of this clamp.

Cryoablation energy can be applied via a flexible linear probe, and therefore can be used to
‘draw’ a lesion onto either the epicardial or endocardial surface of the atrium. Cryoablation has
been shown to be most effective while on CPB from the endocardial surface. This is likely due
to the heat sink of warm intracavitary blood counteracting the cooling needed to facilitate
transmural lesions, in addition to the insulating nature of epicardial fat. In a porcine beating-heart
model in which the posterior LA box was created using epicardial cryoablation in 13 animals,
none of the box lesions were fully transmural.

We make the majority of our CMP lesions using bipolar RF clamps. We do however use a
cryoprobe to extend lesions to both valve annuli. This is done primarily to eliminate the risk of
RF-associated thermal injury to the valve apparatus. Cryothermy (as applied via cryoprobe) does not denature protein or degrade the extracellular matrix, rendering it safe around valvular tissue.\textsuperscript{31} We additionally favor the cryoprobe in this region given the difficulty in clamping up to the valve annuli due to the bulk of the atrioventricular groove and the presence of coronary arteries in this area.\textsuperscript{31} It is important to note that neither bipolar RF nor cryotherapy is safe to use on the coronary arteries.\textsuperscript{31} We use cryotherapy in this region on the beating heart \emph{only} – warm coronary blood flow, in addition to the epicardial fat around the RCA, protects the RCA from injury.

Whatever energy method is used, it is imperative that the surgeon understand the capabilities of their chosen device. Specific parameters must be met when using each of these devices in order to consistently produce transmural lesions. Our laboratory showed that when using bipolar RF clamps, each lesion should be ablated \emph{twice}, without un-clamping the targeted tissue in between ablations in order to ensure greater than 99\% transmurality of lesions.\textsuperscript{26} In order to ensure 100\% transmurality, our practice is to perform each lesion 2-3 times, with each lesion ablated twice without unclamping, and slightly rotating the clamp between each double-ablation. It is also important to ensure all char is cleaned off the clamp jaws between each set of ablations when using a non-irrigated RF clamp. When using any type of clamp, it is important to ensure excellent tissue contact and avoid tissue bunching. Anything that impairs conductance between the two electrodes - such as air, fat, char, or intravenous or cardioplegia catheters - will prevent transmural lesion creation.
Generally speaking, cryoablation probes require a single application duration of 3 minutes for nitrous oxide devices, and 2 minutes for argon probes.\textsuperscript{30,31} The probe needs to be in direct contact with atrial tissue along its entire surface - ice is an excellent insulator, so if there are any gaps between the probe and the tissue, the ice-ball that forms will insulate that area and lead to focal non-transmurality.

\textbf{Summary}

The CMP is the most effective treatment for AF, but is under-utilized in current practice. We recommend performing a complete biatrial Maze in the great majority of patients undergoing cardiac surgery who have a history of AF and are otherwise good surgical candidates. To ensure a good electrophysiologic result, surgeons must ensure that all lesions are fully transmural, and that all lesions both start and/or end in electrically inactive tissue. The LAA and the entirety of the posterior LA (including the PV ostia and the intervening tissue) must always be excluded. Surgeons must know the specific characteristics of whatever device they plan to use to create transmural lesions and modify their technique accordingly. If surgeons are able to meet these criteria and increase the appropriate use of this effective surgical treatment, this would make a significant positive impact for AF patients, not only by restoring sinus rhythm and reducing the risk of stroke but also by improving long-term survival.\textsuperscript{24}
Figure 1: Cox-Maze lesions. LAA1 - manage the left atrial appendage (LAA). LAA2 - connect the LAA exclusion to the Box. L1-4 - The Box - isolate the entirety of the posterior left atrium. L5 - connect the box to the mitral annulus and the coronary sinus. R1 - make a right atriotomy. R2-3 - create a line of block between the superior vena cava (SVC; R2) and the inferior vena cava (IVC; R3). R4 - connect the atriotomy to the tricuspid annulus at the 2 o’clock position (*this lesion does not cross the valve itself - it arches over the valve along the anterior wall of the right atrium - with the end of the lesion extending onto the valve annulus at the 2 o’clock position). R5 - connect the tricuspid annulus at the 10 o’clock position to the right atrial appendage (RAA). R6 - connect the RAA to the right atrial free wall, making sure to avoid the sinoatrial node complex (SAN). Additional abbreviation: PV - pulmonary vein.

Figure 2: Left atrial Cox-Maze lesion set. A - Left atrial (LA) lesion set via a sternotomy approach. White lines indicate lesions made by bipolar radiofrequency ablation, the blue oval indicates a lesion made by cryoablation. B - LA lesion set via a right minithoracotomy. Red lines indicate lesions made by bipolar radiofrequency ablation, blue ovals indicate lesions made by cryoablation. Not pictured in B is the LA appendage (LAA) exclusion, which we perform using an epicardial approach via the transverse sinus.
Figure 3: The Box - Adequate exclusion of the entire posterior left atrium. A satisfactory result with long-term efficacy relies on isolation of the entire posterior left atrium. Specifically, a box-shaped area of tissue, incorporating the ostia of all pulmonary veins and the intervening posterior left atrial wall, must be electrically excluded via a continuous and fully transmural circumferential line of ablation. Note that this box does not need to be made with a single application of a device, but can be constructed from a number of applications.

Figure 4. Right atrial Cox-Maze lesion set. A - Right atrial (RA) lesion set via a sternotomy approach. White lines indicate lesions made by bipolar radiofrequency ablation, blue ovals indicate lesions made by cryoablation. B - RA lesion set via a right minithoracotomy. Red lines indicate lesions made by bipolar radiofrequency ablation, blue ovals indicate lesions made by cryoablation, black arrows indicate the three purse-string stab-incisions.
VIDEO LEGENDS

Video 1: Operative Video of the Cox-Maze IV Procedure Performed via Sternotomy

Video 2: Operative Video of the Cox-Maze IV Procedure Performed via Right Minithoracotomy
REFERENCES


31. MacGregor, R. M., Melby, S. J., Schuessler, R. B. & Damiano, R. J. Energy Sources for the
Pulmonary Vein Isolation
Without exclusion of the entire posterior left atrium

INADEQUATE

“The Box”
Exclusion of the entire posterior left atrium

ADEQUATE
Supplemental Table 1. Steps of the Cox-Maze procedure as we perform it. Lesions are listed in the order in which we typically perform them, with adjustments made for the operative approach, i.e. sternotomy or right minithoracotomy. Our standard practice is to perform the latter. Numbering listed in parentheses corresponds to numbering used in figure 1.

<table>
<thead>
<tr>
<th>Sternotomy Approach</th>
<th>Right Minithoracotomy Approach</th>
</tr>
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<tbody>
<tr>
<td>→ Cardiopulmonary bypass, prior to aortic cross-clamping (beating heart)</td>
<td>→ Cardiopulmonary bypass, prior to aortic cross-clamping (beating heart)</td>
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<tr>
<td><strong>Left atrial lesion set - part 1</strong></td>
<td><strong>Left atrial lesion set - part 1</strong></td>
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<tr>
<td>Box Lesion 1: Right pulmonary vein lesion (L1)</td>
<td>Box Lesion 1: Right pulmonary vein lesion (L1)</td>
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<tr>
<td>→ Epicardial application of bipolar radiofrequency ablation, double tissue layer</td>
<td>→ Epicardial application of bipolar radiofrequency ablation, jaws of clamp hold a double layer of tissue</td>
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<td>Box Lesion 2: Left pulmonary vein lesion (L2)</td>
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<td>→ Epicardial application of bipolar radiofrequency ablation, double tissue layer</td>
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<td><strong>Right atrial lesion set</strong></td>
<td><strong>Right atrial lesion set</strong></td>
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<tr>
<td>→ One atriotomy, one purse-string stab-incision</td>
<td>→ 3 purse-string stab-incisions</td>
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<tr>
<td>Connecting line from the right atrial appendage to the right atrial free wall (R6)</td>
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<tr>
<td>→ Epicardial and endocardial application of bipolar radiofrequency ablation, single tissue layer</td>
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<tr>
<td>→ Made through purse-string stab-incision made at the base of the right atrial appendage</td>
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<tr>
<td><strong>Vena cavae lesions (R2, R3)</strong></td>
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<tr>
<td>→ Epicardial and endocardial application of bipolar radiofrequency ablation, jaws of clamp hold a single layer of tissue</td>
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<tr>
<td>→ Made through purse-string stab-incision placed just above the crista terminalis midway between the superior and inferior vena cavae. One ablation is carried up to the superior vena cava (R2), and the second is carried down to the inferior vena cava (R3)</td>
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<td><strong>Right atriotomy (R1)</strong></td>
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<tr>
<td>Connecting line from the vena cavae ablation to the tricuspid annulus (2 o’clock position; R1, R4)</td>
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<tr>
<td>→ Epicardial and endocardial application of bipolar radiofrequency ablation, single tissue layer</td>
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<td>→ Purse-string stab-incision made at the end</td>
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<tr>
<td>Procedure</td>
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<tr>
<td>Vena cavae lesions (R2, R3)</td>
<td>Connecting line from the right atrial appendage to the right atrial free wall (R6)</td>
</tr>
<tr>
<td>→ Epicardial and endocardial application of bipolar radiofrequency ablation, single tissue layer</td>
<td>→ Epicardial and endocardial application of bipolar radiofrequency ablation stopping short of the valve annulus; lesion completed to valve annulus with endocardial application of cryoablation; single tissue layer</td>
</tr>
<tr>
<td>→ Made through right atriotomy. One ablation is carried up to the superior vena cava (R2), and the second is carried down to the inferior vena cava (R3)</td>
<td>→ Made through purse-string stab-incision made at the base of the right atrial appendage</td>
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<tr>
<td>Connecting line from the right atriotomy to the tricuspid annulus (2 o’clock position; R4)</td>
<td>Connecting line from the right atrial appendage to the tricuspid annulus (10 o’clock position; R5)</td>
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<tr>
<td>→ Endocardial application of cryoablation, single tissue layer</td>
<td>→ Endocardial and epicardial application of bipolar radiofrequency ablation stopping short of the valve annulus; lesion completed to valve annulus with endocardial application of cryoablation; single tissue layer</td>
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<tr>
<td>→ Made through purse-string stab-incision previously made at the base of the right atrial appendage</td>
<td>→ Made through purse-string stab-incision made at the base of the right atrial appendage</td>
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<tr>
<td>→ Aorta cross clamped, heart arrested, left atrium opened via atriotomy</td>
<td>→ Aorta cross clamped, heart arrested, left atrium opened via atriotomy at exterior edge of previously made right pulmonary vein lesion</td>
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<tr>
<td><strong>Left atrial lesion set - part 2</strong></td>
<td><strong>Left atrial lesion set - part 2</strong></td>
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<tr>
<td>Connecting line from the left atrial appendage to the previously-made left pulmonary vein lesion (LAA2)</td>
<td>Box Lesions 3 &amp; 4: Connecting lines superiorly and inferiorly connecting the previously made right pulmonary vein lesion to where the left pulmonary vein lesion will be (L3, 4)</td>
</tr>
<tr>
<td>→ Epicardial application of bipolar radiofrequency ablation, double tissue layer</td>
<td>→ Endocardial and epicardial application of bipolar radiofrequency ablation, single tissue layer</td>
</tr>
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<td>→ Made through left atriotomy</td>
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| Left atrial appendage exclusion (*clip*; LAA1) | Box Lesion 2: Left pulmonary vein lesion (L2)  
→ Endocardial application of cryoablation, single tissue layer |
| Box Lesions 3 & 4: Connecting lines superiorly and inferiorly connecting the previously made pulmonary vein lesions (L3, 4)  
→ Endocardial and epicardial application of bipolar radiofrequency ablation, single tissue layer  
→ Made through left atriotomy | Connecting line from the base of the left atrial appendage to the previously-made left pulmonary vein lesion (LAA2)  
→ Endocardial application of cryoablation, single tissue layer |
| Connecting line to the mitral annulus, with coronary sinus lesion (L5)  
→ Endocardial and epicardial application of bipolar radiofrequency ablation stopping short of the valve annulus; lesion completed to valve annulus with endocardial application of cryoablation; single tissue layer  
→ Epicardial application of cryoablation across the coronary sinus; single tissue layer | Connecting line to the mitral annulus, with coronary sinus lesion (L5)  
→ Endocardial and epicardial application of bipolar radiofrequency ablation stopping short of the valve annulus; lesion completed to valve annulus with endocardial application of cryoablation; single tissue layer  
→ Epicardial application of cryoablation across the coronary sinus; single tissue layer |
| Left atrial appendage exclusion (*clip*; LAA1) |