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The Five-Box Thoracoscopic Maze Procedure

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Purpose. **Comprehensive treatment of atrial fibrillation requires both compartmentalization of the posterior left atrium and connecting ablations to the mitral annulus to interrupt perimitral macro reentry and to isolate the arrhythmogenic left atrial substrate. We present a new procedure that compartmentalizes virtually all arrhythmogenic anatomy etiologic in atrial fibrillation, enabling simple verification by demonstration of bidirectional block.**

Description. **Through a totally thoracoscopic approach, complete dissection of the transverse sinus and exposure of the left atrial floor enables the creation of contiguous compartments connecting to the anterior mitral trigone and isolating the posterior left atrium. The result is a comprehensive electrophysiologic replication of the Cox Maze left atrial lesion pattern.**

Evaluation. **Each compartment is verified in real time using bidirectional block with a probe placed on the untreated atrium inside the compartment.**

Conclusions. **Interruption of perimitral macro reentry in two perpendicularly oriented planes in a totally thoracoscopic procedure results in an operation with efficacy approximating the Cox Maze benchmark.**

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Modern procedures for atrial fibrillation derive their efficacy from three basic principles: compartmentalization of known arrhythmogenic areas, autonomic de-innervation, and debulking of atrial substrate to prevent macro reentry. Procedures lacking connecting ablations to the mitral valve annulus suffer a large decrement in curative outcomes in all types of atrial fibrillation, even paroxysmal [1, 2]. Further, compartmentalization of the posterior left atrium within wide pulmonary vein antral ablations positively affects treatment of advanced atrial fibrillation [3, 4].

Technology

Recent advances in operative technique have enabled the delivery of a comprehensive ablation pattern to treat the left atrial substrate using a totally thoracoscopic approach, with significant efficacy in nonparoxysmal atrial fibrillation [5]. Previously, the transmurality of connecting ablation lines to the mitral annulus has been verified with electrocardiogram attenuation, or more recently, activation sequencing [6]. However, electrocardiogram attenuation is compromised by the artifact of temporary myocardial stunning; activation sequencing involves diagnostic lead placement in poorly accessible regions of the dome of the left atrium, thereby limiting its applicability to a totally thoracoscopic approach.

We therefore present a totally thoracoscopic procedure that consistently applies bidirectional block as the standard for confirming transmurality in a complete, five-compartment lesion pattern. In particular, left atrial compartments produce interruption of perimitral macro reentry in two perpendicularly oriented planes relative to the mitral annulus, comprising not only a connection to the mitral annulus but also isolation of the posterior left atrium. Thus, a more complete replication of the original left atrial Cox Maze lesion set is achieved.

Technique

This report was sanctioned by the Institutional Review Boards of the Medical Centers of the Ohio State University and the University of Pittsburgh.

The study cohort comprised 48 patients (28 men) aged 60 ± 6 years (range, 47 to 82 years). Each had symptomatic, longstanding persistent atrial fibrillation, documented for a mean of 4.3 years (range, 1 to 20 years) before the procedure and resistant to efforts at type I/III antiarrhythmic drug suppression with or without electrical cardioversion. Thirteen patients had previously undergone one or more attempts at percutaneous left atrial ablation. The mean left atrial diameter was 4.5 cm (range, 3.4 to 6.3 cm). The mean left ventricular ejection fraction

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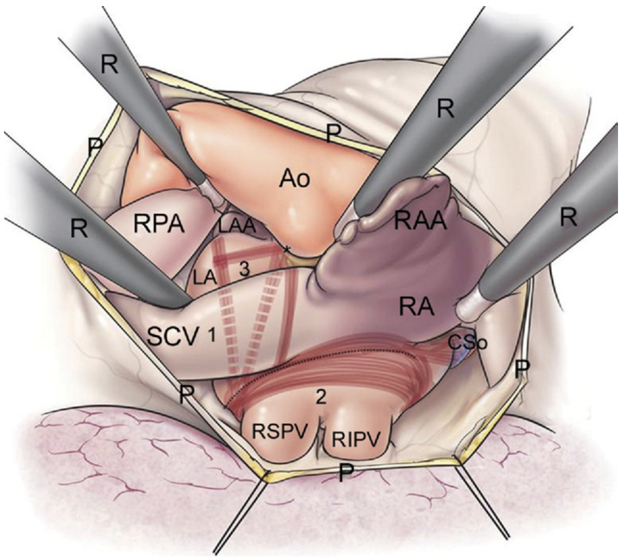

Fig 1. A large enclosed triangle is created on the dome of the left atrium (LA) posterior to the interatrial septum, consisting of a transmitral line originating from the noncoronary aortic root, a transverse roof line between the superior pulmonary antra, and a line from the apex of the transmitral line to the right pulmonary antrum. Note the ablations isolating the superior vena cava and distal coronary sinus. (Ao = aorta; CSo = coronary sinus; LAA = left atrial appendage; P = pericardium; R = retractor; RA = right atrium; RAA = right atrial appendage; RIPV = right inferior pulmonary vein; RPA = right pulmonary artery; RSPV = right superior pulmonary vein.)

was 0.534 (range, 0.15 to 0.65). One patient had undergone a remote thymectomy through a median sternotomy; otherwise, none had a history of an open chest procedure.

All patients underwent the same procedure. After the induction of general anesthesia using a double-lumen endotracheal tube, a transesophageal transducer is placed in the esophagus. A defibrillator pad is placed on the right scapula. A large padded roll is placed underneath the left scapula. After the patient is prepared sterilely, a second, sterile defibrillator pad is placed on the anterior left chest just medial to the anterior axillary line at the inframammary fold.

Right Thoracoscopy

With the right lung deflated, the initial 10-mm port is placed in the sixth interspace in the anterior axillary line, roughly in a sagittal plane with the xiphoid. Under thoracoscopic guidance, a second 10-mm port is placed on a sagittal plane with the cephalad edge of the pulmonary hilum, anterior to the right phrenic nerve. A third 10-mm port is placed one interspace cephalad and 5-cm anterior to the middle port. A 5-mm port is placed over the aortic root, just lateral to the internal mammary pedicle. The pericardium is opened anterior to the right phrenic nerve, from the diaphragm to the refection on the superior vena cava, and retracted with stitches brought out posteriorly through the chest wall. The pericardiotomy and subsequent dissection is greatly facilitated by use of a harmonic scalpel (Harmonic Ace; Ethicon, Cincinnati, OH).

The superior vena cava is mobilized from the right pulmonary artery up to the junction with the azygous vein and is encircled with a flexible catheter, which is delivered through the upper medial port. Gentle anterior and cephalad retraction of the superior vena cava, with simultaneous retraction of the dome of the left atrium caudad, reveals areolar attachments of the superior vena cava to both the right pulmonary artery and dome of the left atrium, all of which are divided with the harmonic scalpel. The remaining areolar tissue overlying the dome of the left atrium and ensheathing the right pulmonary artery is similarly divided, resulting in the complete skeletonization of the transverse sinus leftward to the ligament of Marshall. The purposes for this extensive dissection of the dome of the left atrium include ensuring the transmurality of subsequent ablations and also the posterior positioning of the left atrial ablations relative to the interatrial septum to avoid Bachmann's bundle.

The dissection of the oblique sinus, right pulmonary antral isolation, and mapping and ablation of the epicardial autonomic ganglia are performed as previously reported [5]. With the thoracoscope shifted to the upper lateral port, retraction is applied to the right atrial appendage caudally and to the aorta medially, enabling clear visualization of the left-noncoronary commissure of the aortic root, where the fibrous confluence conjoins the anterior trigone of the mitral annulus. A linear bipolar ablation probe (CoolRail, Atricure, Westchester, OH) creates a line of ablations extending from the left-noncoronary commissure of the aortic root, traversing the right side of the base of the left atrial appendage (thereby avoiding the left main coronary artery), and terminating on the posteromedial dome of the left atrium.

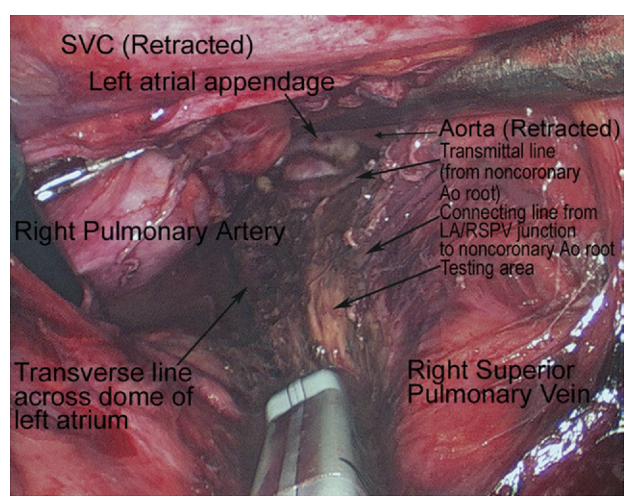

Fig 2. Intraoperative photo demonstrates the completed triangle on the dome of the left atrium posterior to the interatrial septum. Bidirectional block from within the box confirms the integrity of the key ablations connecting the superior interantral line with the mitral annulus. (Ao = aorta; LA = left atrium; RSPV = right superior vena cava; SVC = superior vena cava.)

NEW TECHNOLOGY

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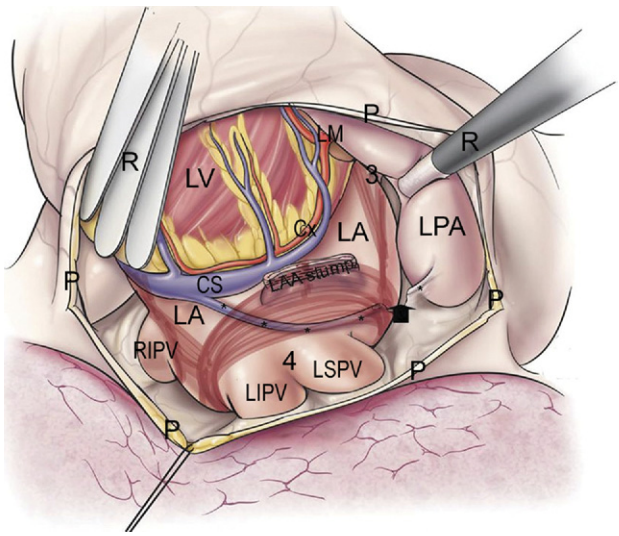

Fig 3. With the apex elevated, the enclosure of the posterior left atrium is completed with linear ablations connecting the inferior pulmonary veins. The ablations on the dome of the left atrium, including the junction of the transmitral line with the superior interantral line, and traversing the distal coronary sinus, are easily visualized. (CS = coronary sinus; Cx = circumflex; LA = left atrium; LAA = left atrial appendage; LIPV = left inferior pulmonary vein; LM = left main; LPA = left pulmonary artery; LSPV = left superior pulmonary vein; LV = left ventricle; P = pericardium; R = retractor; RIPV = right inferior pulmonary vein.)

Real-time transesophageal echocardiography confirms correct positioning of the ablation probe on the anterior mitral trigone. An initial presumption of transmurality for any given ablation is made only when output power on the ablation generator falls to approximately 15 watts, indicating a rise in tissue impedance. Repetitive, overlapping ablations are required to achieve this initial end point.

The thoracoscope is placed back into the middle port. With the superior vena cava again retracted with the flexible catheter, and with gentle caudad retraction of the left atrial dome, the previously created transmitral line is easily visualized through the transverse sinus. A second line of ablations is performed from the base of the transmitral line across the posterior dome of the left atrium, terminating onto the right superior pulmonary vein. Finally, a third line of ablations is performed from the apex of the transmitral line to the medial end of the second line at the right superior pulmonary vein. The three lines constitute an enclosed triangle on the dome of the left atrium that is safely posterior to the interatrial septum and Bachmann's bundle (Fig 1). The integrity of this compartment is verified by demonstration of bidirectional block using a probe placed on untreated atrium in the center of the triangle; exit block, in particular, is confirmed at 15 mA of amplitude (Fig 2).

Isolation of the superior vena cava is performed using a quadripolar radiofrequency clamp (Isolator Synergy; Atricure, Westchester, OH) 2 cm proximal to the sinoatrial node, with subsequent confirmation of bidirectional block. Additional linear ablations proceed from the interatrial groove anterior to the oblique sinus posteriorly into two trajectories: one traversing the distal coronary sinus just cephalad to the right atrioventricular groove, and one projected across the floor of the left atrium toward the left inferior pulmonary vein.

Left Thoracoscopy

The left pericardiotomy, division of the ligament of Marshall, mapping and ablation of the autonomic ganglia, and pulmonary antral isolation are performed as previously reported [5]. With an endoscopic fan retractor providing gentle caudad retraction on the left atrial appendage, the previously performed line of ablations across the transverse sinus is easily visualized and extended onto the left superior pulmonary vein. As a result, ablations connect to the left atrial appendage on both its medial and posterior aspects.

A five-fingered endoscopic fan retractor (Endo Retract II; Autosuture, Mansfield, MA) introduced through the upper lateral port gently retracts the apex anteromedially, enabling clear exposure of the inferior vena cava, oblique sinus, and right inferior pulmonary vein. The previous ablations performed in the oblique sinus from the right chest are clearly visualized. The linear probe creates a line of ablations connecting the caudal margins of the two pulmonary antral isolation boxes (Fig 3). A four-sided compartment perpendicular to the transmitral line is created on the posterior left atrium, comprising the pulmonary antral boxes on the sides and the superior and inferior interantral lines cephalad and caudad. As

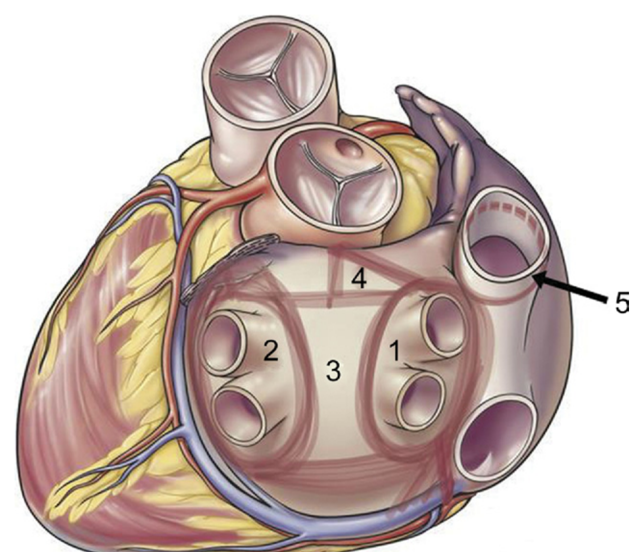

Fig 4. The complete five-box lesion pattern encompasses four contiguous compartments: the two pulmonary antra (1,2), the posterior left atrium (3), and an enclosed triangle on the dome of the left atrium incorporating the connection the anterior trigone of the mitral annulus (4), as well as the superior vena cava (5). Additional linear lesions connect both the left pulmonary antrum and the transmitral line to the base of the left atrial appendage, and the right pulmonary antrum to the coronary sinus.

before, the integrity of this compartment is verified with demonstration of bidirectional block on untreated atrium in the center of the box (Fig 4). Finally, the left atrial appendage is ligated, as previously described, under transesophageal echocardiographic guidance.

At the conclusion of each side of the operation, intercostal nerve blocks are performed using a reusable liquid nitrogen cryoprobe. Cryoablations of 60 seconds at –30°C are administered to the intercostal neurovascular bundle medial to each port site. We have observed a substantial, durable decrement in postoperative discomfort in our patients, with narcotic analgesics typically discontinued within 48 hours.

Clinical Experience

The mean operative time was 268 minutes (range, 225 to 378 min). Postoperative rhythm surveillance consists of 7 days of continuous self-actuated event monitoring (CardioNet, Conshohocken, PA) conducted at 3, 6, 13, and 24 months. Failure of the procedure is defined as any tachyarrhythmia lasting 30 seconds. All antiarrhythmia medications are discontinued by the end of the second postoperative month.

At the 3-month interval, 34 of 36 patients (94%) were free of atrial fibrillation. Interestingly, 1 patient, in whom the procedure failed, experienced a single symptomatic 10-minute episode of atrial fibrillation that self-terminated; the patient remained in sinus rhythm through the 6-month monitoring. The other patient was mapped and treated percutaneously for cavotricuspid flutter. At the 6-month interval, 19 of 19 patients were free of atrial fibrillation. At the 13-month interval, 4 of 4 patients were free of atrial fibrillation.

No perioperative deaths occurred. One patient underwent a median sternotomy for an injury to the right pulmonary artery. One patient required implantation of permanent pacemaker for a preexisting sick sinus syndrome.

Comment

Advances in linear ablation technology and thoracoscopic operative technique have enabled the deployment of a comprehensive lesion pattern to isolate virtually all arrhythmogenic substrate, with the exception of the right atrial isthmus, through a truly minimally invasive approach. This procedure uniquely replicates the cut-and-sew left atrial lesion set, with contiguous compartments connecting to the mitral annulus and isolating the posterior left atrium. In addition, bidirectional block, with exit block tested at 15 mA of power, serves as a simplified, uniform confirmation of the integrity of all compartments. Further, it enables a logical, intuitively appealing progression through an unambiguous, efficient verification of all technical end points. We anticipate that, in light of a convincing paradigm shift from lesion delivery toward lesion confirmation, standardization of epicardial ablation procedures may offer a clear benchmark in the treatment of advanced atrial fibrillation.

Disclosures and Freedom of Investigation

The authors were solely responsible for the investigative design and composition of the manuscript, and received no funds or material support for the study.

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Disclaimer

The Society of Thoracic Surgeons, the Southern Thoracic Surgical Association, and *The Annals of Thoracic Surgery* neither endorse nor discourage use of the new technology described in this article.

INVITED COMMENTARY

As we begin the third decade of the surgical treatment of atrial fibrillation (AF), surgeons are actively engaged in the development of new therapies to manage this arrhythmia. Efforts are broad and varied, including new lesion sets, new ablation technologies, and new approaches. Most advances are presented as small, single-center reports with limited follow-up. Validation of new operations can only be achieved through generation and examination of data. Sirak and colleagues [1] begin this process with their report of "The Five-Box Thoracoscopic Maze Procedure." This article begins to answer the key questions that will determine whether this therapy can be widely applied in patients with AF.

The authors provide a well-illustrated, clear description of the procedure. They answer the question: "How is it done?" A second, compelling question for surgeons is: Can I do this operation? The thoracoscopic procedure certainly requires expertise and training. Thoracoscopy is

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