The effects of the Cox maze procedure on atrial function

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Objective: The effects of the Cox maze procedure on atrial function remain poorly defined. The purpose of this study was to investigate the effects of a modified Cox maze procedure on left and right atrial function in a porcine model.

Methods: After cardiac magnetic resonance imaging, 6 pigs underwent pericardiotomy (sham group), and 6 pigs underwent a modified Cox maze procedure (maze group) with bipolar radiofrequency ablation. The maze group had preablation and immediate postablation left and right atrial pressure–volume relations measured with conductance catheters. All pigs survived for 30 days. Magnetic resonance imaging was then repeated for both groups, and conductance catheter measurements were repeated for the right atrium in the maze group.

Results: Both groups had significantly higher left atrial volumes postoperatively. Magnetic resonance imaging–derived reservoir and booster pump functional parameters were reduced postoperatively for both groups, but there was no difference in these parameters between the groups. The maze group had significantly higher reduction in the medial and lateral left atrial wall contraction postoperatively. There was no change in immediate left atrial elastance or in the early and 30-day right atrial elastance after the Cox maze procedure. Although the initial left atrial stiffness increased after ablation, right atrial diastolic stiffness did not change initially or at 30 days.

Conclusions: Performing a pericardiotomy alone had a significant effect on atrial function that can be quantified by means of magnetic resonance imaging. The effects of the Cox maze procedure on left atrial function could only be detected by analyzing segmental wall motion. Understanding the precise physiologic effects of the Cox maze procedure on atrial function will help in developing less-damaging lesion sets for the surgical treatment of atrial fibrillation.

Supplemental material is available online.

Over the last 2 decades, the Cox maze procedure has remained the gold standard for the surgical treatment of atrial fibrillation (AF).[1] The final iteration of this procedure was termed the Cox maze III procedure. It offered the first successful surgical treatment for patients with medically refractory AF. Although this cut-and-sew Cox maze procedure had excellent results, with long-term cure rates of well over 90%, it was not widely adopted by most cardiac surgeons because of its technical complexity, invasiveness, and associated morbidity.[2]

The introduction of surgical ablation technology has dramatically changed the field of AF surgery.[3,4] Centers around the world have replaced the classic surgical incisions of the Cox maze procedure with ablation lines on the atria using various energy sources. This has simplified the operation and made it more accessible to cardiac surgeons around the world. After extensive investigation, our laboratory has shown that bipolar radiofrequency (RF) ablation can safely create reliable transmural lesions and be used to replace most of the surgical incisions of the original cut-and-sew Cox maze III procedure.[5-7]

A bipolar RF ablation-assisted Cox maze procedure, termed the Cox maze IV procedure, has been used exclusively at our institution since 2002. Early and midterm clinical experiences with the Cox maze IV procedure have shown excellent results, with significantly shorter cardiopulmonary bypass and cross-clamp times.[8-12] A recent propensity analysis performed by our group on patients who underwent the Cox maze III versus Cox maze IV procedures found no difference in freedom from AF recurrence at 1 year.[13]

Despite the clinical success of the Cox maze procedure in restoring sinus rhythm, the procedure has been shown in previous studies with echocardiography to have a negative effect on atrial function.[14,15] However, there has not been any comprehensive experimental investigation of the effect of the Cox maze procedure on the right atrium (RA) and left atrium (LA) by using a more sophisticated and load-independent methodology. Regional wall motion has not been examined, despite the fact that the multiple incisions or ablation lines cross, isolate, or both large areas of the RA and LA. With the rapidly increasing popularity of surgical

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Abbreviations and Acronyms

AF = atrial fibrillation
BSA = body surface area
LA = left atrium
LAA = left atrial appendage
LA_{AE} = left atrial active emptying percentage of total emptying
LA_{AEI} = left atrial active emptying index
LA_{CC} = left atrial volume change
LA_{EF} = left atrial active ejection fraction
LA_{EI} = left atrial active emptying index
LA_{max} = maximal left atrial volume
LA_{min} = minimal left atrial volume
LA_{PE} = left atrial passive percentage of total emptying
LA_{PEI} = left atrial passive emptying index
LA_{PTE} = left atrial percentage total emptying
$LA_{rel\ max}$ = relative maximal left atrial volume
$LA_{rel\ min}$ = relative minimal left atrial volume
LV = left ventricular
LVSV = left ventricular stroke volume
MRI = magnetic resonance imaging
PV = pulmonary vein
RA = right atrium
RF = radiofrequency

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intervention for AF, a better understanding of the effects of the Cox maze procedure on atrial function is urgently needed. This would have important implications regarding decisions to discontinue anticoagulation and might guide future development of less invasive surgical strategies.

The purpose of this study was to investigate the acute and chronic effects of the Cox maze procedure on atrial function in a chronic porcine model. Cardiac magnetic resonance imaging (MRI) was used to noninvasively assess global and regional LA function. In addition, conductance catheters were used to measure the dynamic atrial elastance and stiffness, as derived from pressure–volume relationships. A unique aspect of this study was the use of a sham group to control for the functional effects of pericardiotomy alone.

MATERIALS AND METHODS

Experimental Protocol

Twelve domestic pigs weighing 60 to 75 kg were used in this study. All animals received humane care in compliance with the ''Guide for the care and use of laboratory animals'' published by the National Institutes of Health (National Institutes of Health publication no. 85-23, revised 1985). The study was also approved by the Washington University School of Medicine Animal Studies Committee. A baseline cardiac MRI was obtained from each pig after achievement of general anesthesia. After this MRI, pigs were given at least 2 days to recover from anesthesia before undergoing surgical intervention.

The animals were divided into 2 groups. The sham group included 6 pigs that underwent median sternotomy and pericardiotomy only. This was done as a control for the study because in previous studies pericardiotomy has been shown to have a significant effect on atrial function. The second group, the maze group, included 6 pigs that underwent a modified Cox maze procedure.

After the baseline MRI, each pig in the maze group (n = 6) underwent a modified Cox maze procedure on the beating heart without cardiopulmonary bypass, as previously described (Figure 1).[6] The animals were premedicated, intubated, and anesthetized with 2% to 4% isoflurane and were continuously monitored. Median sternotomy was performed, and the heart was exposed through a pericardiotomy after administering amiodarone (150-mg bolus administered intravenously) to prevent arrhythmias.

The pigs were fully heparinized (350 U/kg administered intravenously), and the activated clotting time was maintained at greater than 250 seconds. By using conductance catheters, preablation pressure–volume relationships were sequentially measured for the RA and LA, as described below. The modified Cox maze ablation set was then performed. Immediate electrical isolation was documented by pacing just distal to the ablation lines at the right and left pulmonary veins (PVs) and at the LA appendage (LAA) at a stimulus strength of 20 mA. Conductance catheter measurements were then repeated for both atria immediately after the ablations. The pericardium was closed, and the sternum was reapproximated. The animals were closely monitored for 48 hours and kept alive for 30 days. Daily aspirin, 81 mg administered orally, was given, beginning on the first day after the operation. No antiarrhythmic drugs were administered during this period.

At 30 days postoperatively, all animals in both groups underwent a follow-up cardiac MRI study to assess the chronic changes in LA function. Immediately after the MRI, each animal underwent redo median sternotomy. The animals were given full heparinization again, and conductance catheter measurements were taken for the RA for the maze group. Conductance catheter measurements were not taken for the LA for the maze group because accurate inflows could not be quantified, as with the RA, which is required for calibrating the pressure–volume relations. Chronic electrical isolation was confirmed by failure to capture by means of epicardial pacing (20 mA and 5-ms pulse duration) of the right and left PVs and the LAA distal to the ablation lines. Finally, AF induction was attempted in both groups by means of 2 trials of rapid pacing from the RA free wall for 30 seconds (20 mA, 400 ms, and 150 beats/min). If unsuccessful, 2 trails of burst pacing were performed from the RA free wall with 8 S1 at a cycle length of 150 ms, followed by a single extra stimulus S2 of 90 ms. If still unsuccessful, 2.5 mg of neostigmine administered intravenously was given as a bolus, and the rapid pacing protocol was repeated, followed by burst pacing. At the conclusion of the study, the animal was killed, and the heart was removed en bloc for histologic assessment.

Modified Cox Maze Procedure

The modified Cox maze procedure performed in the maze group represented all of the atrial lesions in the Cox maze IV procedure used clinically (Figure 1). All lesions were performed without cardiopulmonary bypass by using bipolar RF ablation, as described in a previous publication.[5-7]

Bipolar RF Ablation Device

The bipolar RF ablation system, Atricure Isolator II (Atricure, Inc, Cincinnati, Ohio), was comprised of an ablation clamp and an ablation and sensing unit. The clamp consisted of 2 jaws in parallel with opposing electrodes clamped on target tissue during ablation. Energy was delivered from the ablation and sensing unit to the instrument by using an algorithm based on the assessment of tissue conductance every 10 Hz.[5,6] Full-thickness ablation was determined when the tissue conductance decreased to a specified level and remained there for 3 seconds. A laptop computer was used to collect the time, current, voltage, impedance, conductance, energy, power, and temperature in real time. The temperature was recorded by using a thermocouple located 1 mm from the edge of the electrode in the jaw of the clamp device.