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ORIGINAL ARTICLE

A Swedish consensus on the surgical treatment of concomitant atrial fibrillation

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Abstract
Atrial fibrillation (AF) is a common arrhythmia among patients scheduled for open heart surgery and is associated with increased morbidity and mortality. According to international guidelines, symptomatic and selected asymptomatic patients should be offered concomitant surgical AF ablation in conjunction with valvular or coronary surgery. The gold standard in AF surgery is the Cox Maze III (“cut-and-sew”) procedure, with surgical incisions in both atria according to a specified pattern, in order to prevent AF reentry circuits from developing. Over 90% of patients treated with the Cox Maze III procedure are free of AF after 1 year. Recent developments in ablation technology have introduced several energy sources capable of creating nonconducting atrial wall lesions. In addition, simplified lesion patterns have been suggested, but results with these techniques have been unsatisfactory. There is a clear need for standardization in AF surgery. The Swedish Arrhythmia Surgery Group, represented by surgeons from all Swedish units for cardiothoracic surgery, has therefore reached a consensus on surgical treatment of concomitant AF. This consensus emphasizes adherence to the lesion pattern in the Cox Maze III procedure and the use of biatrial lesions in nonparoxysmal AF.

Key words: *atrial fibrillation, cardiac surgery, consensus*

Introduction

Atrial fibrillation (AF) is the most common arrhythmia seen in clinical practice and is associated with an increased long-term risk of stroke, heart failure, and all-cause mortality. The prevalence of AF is 0.5–1% in people under 50 years of age, increasing to 8–10% in people above 80 years of age (1,2). It is estimated that in the Swedish population there are 180,000 people with a diagnosis of AF. Among patients scheduled for cardiac surgery, the prevalence of AF is 6–10%, but may be higher in mitral valve patients.

Understanding of AF genesis has improved substantially during the last 20 years. The recognition of mechanisms such as pulmonary vein trigger potentials and macro-reentry circuits leading to AF has led to the development of invasive treatment by percutaneous catheter technique or surgery. The goal of all invasive methods is to restore sinus rhythm by electrical isolation or ablation of the atrial tissue responsible for AF genesis or perpetuation.

In patients with AF undergoing open heart surgery, surgical ablation is most commonly performed in conjunction with mitral valve procedures, but is also used in aortic valve and coronary surgery, as well as repair of atrial septal defect (ASD). Successful perioperative ablation has been shown to improve postoperative myocardial function (3) and quality of life (4). It has also been reported to give less postoperative

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morbidity (5), lower incidence of thromboembolic events and valve-related morbidity (6,7), less postoperative tricuspid insufficiency (8,9), and improved long-term survival (7,10). According to international guidelines, all cardiac surgery patients with symptomatic AF should be offered concomitant perioperative ablation (1,11). Concomitant AF surgery has not been associated with increased surgical mortality (12). However, there is an increased risk of atypical atrial arrhythmias if the ablation is performed incorrectly or incompletely (13). Today, the use of different types of energy sources and ablation patterns has given rise to a plethora of techniques, sometimes leading to confusing or inferior results. Specifically, anatomical patterns of ablation lesion sets vary substantially in different studies, and the rationale behind choice of lesion set in connection with type of AF is often unclear or missing.

There is, at present, a clear need for recommendations based on the best available evidence in AF surgery regarding which type of anatomical lesion set is appropriate for which type of AF. The Swedish Arrhythmia Surgery Group, a subgroup of the Swedish Association for Thoracic and Cardiovascular Surgery consisting of arrhythmia surgeons from all Swedish units for cardiothoracic surgery, has reached a consensus with recommendations regarding concomitant AF surgery in Sweden. This consensus document is intended to guide surgeons and others involved in surgical ablation and to standardize therapy according to current knowledge.

The Cox Maze III procedure

The foundation of AF surgery is the Maze procedure, developed and introduced by James L. Cox in 1992 (14,15) after extensive electrophysiological studies. The theoretical background to the Maze procedure is the focal activation and multiple wavelet hypothesis introduced by Moe (16). According to this hypothesis, AF is caused by focal triggers in the atria leading to macro-reentry circuits with different refractory times and conduction velocities. By dividing the atrial wall in a specified pattern ("cut-and-sew"), the transmission of impulses from the sinus node to the AV node is forced into a maze with only one possible route, and the atrial area necessary for maintenance of AF is reduced (Figure 1). The final version of the surgical development, the Cox Maze III procedure, has shown the best results with over 90% of patients free of AF after 1 year (14,17). It is worth noting that this procedure includes complete pulmonary vein isolation. Because of these superior results, Cox Maze III is the "gold standard" in the surgical treatment of all types of atrial fibrillation and atrial flutter. However, the procedure is technically demanding and has been performed in only a limited number of centers. Since 1994, over 500 Cox Maze III procedures have been performed in Sweden in four centers, and the method is still in use.

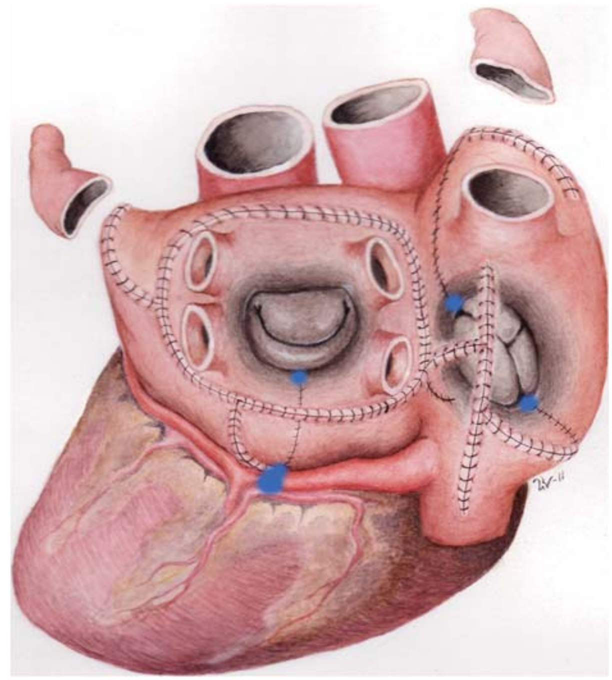

Figure 1. Cox Maze III surgery. Blue dots depict freezing points.

Percutaneous catheter ablation

The importance of the pulmonary veins as areas of focal triggers of paroxysmal AF was demonstrated by Haïssaguerre in 1998, which also initiated the development of catheter-based pulmonary vein isolation (18). In 90% of patients with paroxysmal AF, focal triggers in or near the pulmonary veins initiate AF, and by isolation of these, AF initiation is prevented. Today, percutaneous catheter ablation is recommended for paroxysmal symptomatic AF refractory to antiarrhythmic medication (11). In 2010, 1148 percutaneous catheter ablations of AF were performed in Sweden (http://www.ablationsregistret.se), and the estimated need in the coming years is 1500–2000 AF catheter ablations/year (19).

Surgical ablation of concomitant AF

The discovery of pulmonary vein potentials acting as triggers for AF has led to a rapid development of new devices for surgical ablation of AF. In order to replace the surgical incisions in the Cox Maze III procedure with transmural atrial wall lesions, different types of energy sources have been used, such as radiofrequency, cryoenergy, high-intensity focused ultrasound (HIFU), microwave, and laser. Simplified anatomical lesion sets restricted to the left atrium have also been proposed, which in some instances are erroneously called "mini-Maze" procedures. These procedures are simpler and faster than the original Cox Maze III but the results are inferior, with only 60–75% of patients free of AF after 1 year (17,20,21). It is now possible to achieve a complete Cox Maze III lesion set using heat and/or cryoenergy, thus replacing the "cut-and-sew" technique.

Minimally invasive AF ablation

Different types of endoscopic techniques of surgical AF ablation have been developed as an alternative to catheter ablation of nonparoxysmal AF in particular and are currently under evaluation in multiple studies. The indications are usually symptomatic AF refractory to medication and catheter ablation. Minimally invasive ablation is thus a type of stand-alone AF surgery and will not be further discussed in this consensus on concomitant AF surgery.

In conclusion, several types of treatment and anatomical lesion sets are currently in use, and there is a need for clear recommendations based on type of AF, atrial size, type of cardiac surgery, and the total risk profile of the patient.

Methods

The purpose of the Swedish Arrhythmia Surgery Group is to create recommendations based on the available literature in the field of AF surgery. The first part of these recommendations address the surgical treatment of concomitant AF, with the specific question being: which type of lesion set has proved to be most effective in treating which type of AF? The consensus was formed through a series of plenary sessions over an 18-month period, an extensive and systematic review of the literature, the gathering of expert opinions, and personal experience. The scientific evaluation is mainly based on systematic reviews (22–27) and large patient series with a total Swedish experience of more than 500 Cox Maze III procedures and 2000 concomitant surgical ablations of AF.

Results

Prevailing indications for surgical ablation of concomitant AF (11,28)

1. Patients with symptomatic AF undergoing cardiac surgery procedures.
2. Patients with asymptomatic AF undergoing cardiac surgery in whom the ablation can be performed with minimal risk.

The decision to perform a surgical ablation should be based on an individual assessment of each patient's medical history, type of AF, and risk profile. It may be reasonable to refrain from a surgical ablation procedure in combination with complex cardiac surgery in certain patients.

Decision process

The cost of a concomitant surgical ablation in Sweden is approximately $2000–5000, and the follow-up protocol is extensive. The decision process should therefore involve both the responsible surgeon and the referring cardiologist.

Type of AF

Atrial fibrillation is classified as paroxysmal, persistent, longstanding persistent, or permanent according to the 2006 ACC/AHA/ESC guidelines (1). From an interventional perspective, the most important difference is between an AF that resolves spontaneously (paroxysmal AF) and an AF that does not (nonparoxysmal AF) (13). In the present recommendations, AF is therefore classified as *paroxysmal* or *nonparoxysmal* (= persistent/longstanding persistent/permanent).

Atrial size and duration of AF

In general, enlargement of the left atrium is correlated with a lower long-term freedom from AF after ablation surgery (29). Although there are no definite limits, and methods of sizing the left atrium are imperfect, a left atrial anteroposterior diameter of > 7 cm has been suggested as a relative contraindication to AF ablation surgery (30). An enlarged *right* atrium can potentially harbor multiple macro-reentrant circuits, leading to postoperative ablation failure if only the left atrium is ablated (13). In these circumstances, biatrial ablation (see below) should be considered. Down-sizing of an enlarged left atrium should be considered if the left atrium is opened as part of the procedure and preferably as an oval-shaped excision along the lower margin of the surgical incision. Down-sizing of an enlarged right atrium is likewise recommended as an oval-shaped excision along the margin of the vertical incision. The down-sizing helps restore the relationship between the size of the macro-reentrant circuits and the distance between the surgical lesions. The duration of AF is not correlated with long-term freedom from AF after ablation surgery (30) and is therefore of minor importance in decision making regarding AF surgery.

Surgical lesion set

In these recommendations, there are three basic types of surgical lesion sets (Table I and Figures 2–4). All lesions adhere to the principles and pattern of the Cox Maze III procedure. The left atrium can be ablated endocardially (lesion set 1, Figure 2) or epicardially (lesion set 2, Figure 3). An epicardial ablation should be performed with the heart unloaded during cardiac arrest to avoid the warming/cooling effect of circulating blood. Biatrial ablation is a combination of lesion sets 1 or 2 and 3. If these lesion sets are applied, no other lesion (e.g. a right atrial "flutter line") should be added, as this may lead to inadvertent complete isolation of parts of the atria.

Choice of lesion set in concomitant AF surgery

The choice of lesion set is based on the type of AF and other surgery planned (Table II). The concomitant surgery is classified into three categories: surgery not necessitating a left atriotomy, mitral valve surgery, and surgery for an atrial septal defect. In the first category, it is possible to ablate the left atrium epicardially, an endocardial approach requiring an additional left atriotomy being the alternative. In mitral valve surgery, an endocardial surgical ablation of the left atrium is convenient, and in case of an enlarged right atrium, a biatrial ablation is recommended even in the case of paroxysmal AF. In surgery for atrial septal defect, the right atrium is always enlarged and prone to macro-reentrant circuits, and therefore a biatrial surgical ablation should always be performed. It should be emphasized that these are the minimum recommendations—it is not incorrect to perform a biatrial surgical ablation in a patient with paroxysmal AF.

Table I. Surgical lesion sets in concomitant AF ablation surgery.

Type number	Location	Anatomical description	Figure
1	Endocardium of the left atrium	Box lesion of the pulmonary veins + mitral/coronary sinus line + line to the left atrial appendage	2
2	Epicardium of the left atrium	Epicardial pulmonary vein isolation + connecting line + mitral/coronary sinus line + line to the left atrial appendage	3
3	Endo/ epicardium of the right atrium	Line between superior and inferior caval vein + inferior and superior line to tricuspid annulus	4

AF = atrial fibrillation.

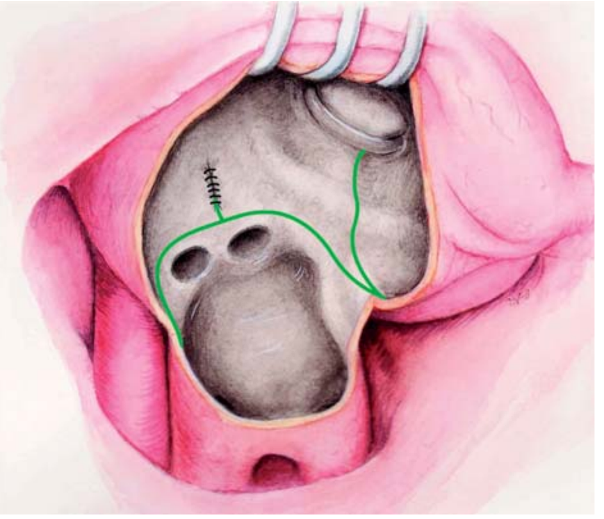

Figure 2. Endocardial ablation pattern in the left atrium.

Discussion

The proposed lesion sets in these recommendations adhere to the anatomical incisions in the Cox Maze III procedure. The reason for this is the superiority of the Cox Maze III procedure in sinus rhythm conversion rate in large patient series (31–35), and the fact that it is a procedure built on a solid electrophysiological basis. The recommendation of biatrial surgical ablation in nonparoxysmal AF is further supported in several systematic reviews (22,24,36) as well as a study on percutaneous catheter ablation of persistent AF (37). Two studies merit special comment. In a systematic review, Khargi et al. found no

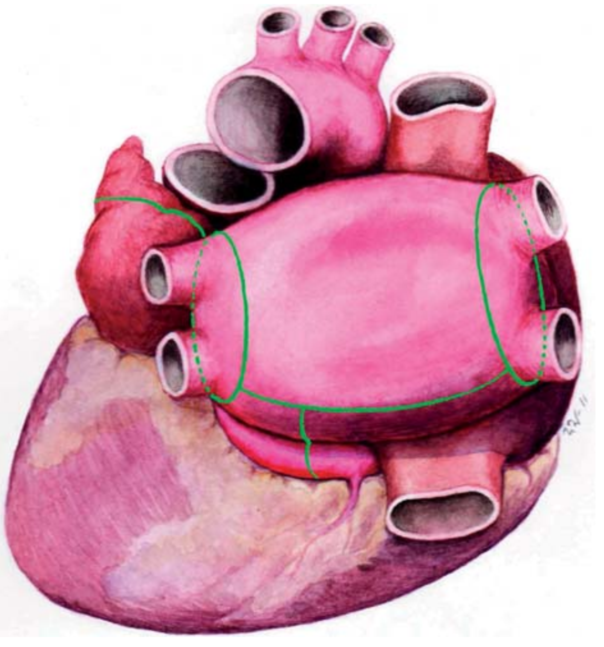

Figure 3. Epicardial ablation pattern in the left atrium.

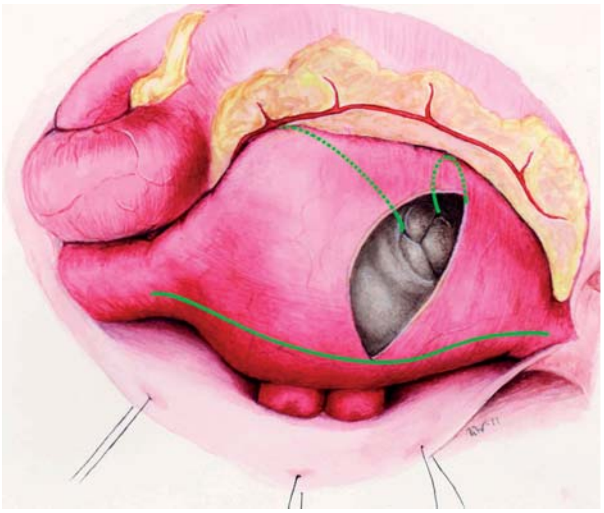

Figure 4. Endo- and epicardial ablation pattern in the right atrium.

difference in postoperative sinus rhythm conversion rate between the classical Cox Maze III procedure and a surgical ablation using alternative sources of energy (25). However, this review was neither a comparison between the Cox Maze III procedure or other lesion sets, nor a comparison between left sided or biatrial ablation and thus does not oppose the present recommendations. One randomized study compared “left atrial” to biatrial radiofrequency ablation in concomitant AF surgery and found no difference (38). However, the “left atrial” ablation was combined with a right cavo-tricuspid isthmus ablation, so this study was really a comparison between two biatrial ablation sets. It should also be noted that the so-called “Cox Maze III procedure” utilized in these studies did not always include the cryolesion of the coronary sinus. This could lead to a 10–15% incidence of atypical left atrial flutter, which we do not regard as a successful outcome. The results of these studies are interesting and warrant further investigation, but again do not oppose the present recommendations. In conclusion, no ablative lesion set has so far in the literature been shown to be more effective than the Cox Maze III biatrial lesion pattern.

Table II. Choice of lesion set depending on type of surgery and type of atrial fibrillation.

Type of surgery	Paroxysmal AF	Nonparoxysmal AF
Aortic valve surgery	Left sided ablation (1 or 2)	Biatrial ablation (1 + 3 or 2 + 3)
Coronary artery surgery		
Other open heart surgery without left atriotomy		
Mitral valve surgery	Left sided ablation (1)	Biatrial ablation (1 + 3)
Atrial septal defect surgery	Biatrial ablation (1 + 3)	Biatrial ablation (1 + 3)

AF = atrial fibrillation.

If the recommended lesion set is applied, it is important not to add any other lesions, for example, a cavo-tricuspid isthmus line to prevent right atrial flutter. This is due to the fact that in the maze concept, the electrical impulse is propagated in a forced direction to cover most of the atria. By adding new lesions to the maze pattern, the route may be blocked, leading to isolated parts of the atria (13). Moreover, the right-sided lesions in the Cox Maze III procedure are designed to prevent right atrial flutter.

In the classical cut-and-sew Cox Maze III procedure, all lesions are by definition transmural. However, the use of various energy sources and surgical ablation devices raises the question of whether transmurality is achieved. It is the opinion of the Swedish Arrhythmia Surgery Group that all lesions should be transmural, as nontransmural lesions are either ineffective or arrhythmogenic (36). Induced tachyarrhythmia due to nontransmural lesions are often highly symptomatic and resistant to medical treatment. There are five main energy sources that have been used in concomitant surgical ablation: radiofrequency, cryoenergy, high-focused intensity ultrasound (HIFU), microwave, and laser. Laser and microwave probes have been withdrawn from the market for commercial reasons and/or inefficiency, and HIFU has not been as effective as radiofrequency or cryoenergy (39). Both radiofrequency and cryoenergy have been used to achieve the lesions of the Cox Maze III procedure (30,40,41). The Swedish Arrhythmia Surgery Group does not recommend any specific energy source, but emphasizes that all lesions should be accomplished with full transmurality. Specifically, an epicardial ablation should be performed with the heart unloaded during cardiac arrest.

In the Cox Maze III procedure, the left atrial appendage (LAA) is excised and closed from inside the left atrium. Today, the LAA can be closed from the outside using stapling techniques, a purse-string suture, or newly-designed occluding devices. While there is a potential benefit in prevention of stroke, incomplete closure may paradoxically lead to an increased stroke risk (42). It is the opinion of the Swedish Arrhythmia Surgery Group that the safest closure of the LAA is from the inside, but since an incomplete LAA closure is hazardous, the Group has refrained from any specific recommendations regarding LAA closure, and leaves the decision to the responsible surgeon. If the LAA is closed, it is mandatory to check with perioperative ultrasound that a complete exclusion has been achieved and that no residual blood flow exists (43).

It is recommended that the follow-up after concomitant surgical AF ablation follows the same principles as after percutaneous catheter ablation of AF. Rhythm is monitored by frequent out-patient visits, Holter recordings, remote mobile phone ECG recordings, or implantable event recorders. Antiarrhythmic medication and electroconversion, if necessary, are usually recommended for the first 3 months postoperatively (44), and anticoagulation with warfarin is usually continued for at least 6 months. Withdrawal of anticoagulation requires that freedom from AF is documented by long-term monitoring. It should be noted that many patients with concomitant AF undergoing heart surgery have other indications for warfarin medication. Furthermore, discontinuation of warfarin after percutaneous catheter ablation is not recommended in patients with a CHADS2 score >2 (28).

Limitations

There is a lack of large randomized studies comparing lesion sets and different energy sources in concomitant AF surgery. The present recommendations are based on large patient series and systematic reviews. From an evidence-based medicine perspective, a consensus report has low scientific value (45). However, it is our hope that a standardized national surgical AF ablation algorithm will offer a better basis for future studies. Furthermore, in daily practice, there is a clear need for recommendations based on the best available evidence. The purpose of these recommendations is to clarify the principles and improve the quality of concomitant AF surgery in Sweden.

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