Surgical ablation of arrhythmias

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The surgical approach was the earliest therapeutic ablation of hyperkinetic arrhythmias. Following the progressive improvements in electrophysiological mapping and operative techniques, new surgical approaches have been developed for the treatment of those arrhythmias related to ectopic phenomena or reentry mechanisms. These procedures have been proven to be highly effective but the associated morbidity and mortality were unacceptably high. More recent and advanced techniques of transcatheter ablation have revolutionized the treatment of these arrhythmias and now represent the treatment of choice in the majority of cases.

However, the significant reduction in the operative risk and the improvement in patient outcome with respect to the past, thanks to a better patient selection and to advances in the surgical and myocardial protection techniques, make do that the surgical approach to some forms of arrhythmias is still valid, especially in those cases requiring associated surgery: atrial tachyarrhythmias in patients with congenital heart disease, post-ischemic ventricular tachycardias in patients who necessitate myocardial revascularization, and/or ventricular remodeling and chronic or paroxysmal atrial fibrillation in patients who require cardiac surgery.

New techniques such as radiofrequency, microwaves and cryoablation guarantee the creation of linear and transmural lesions with minimum damage to the cardiac structures and appear very interesting as they are surgically simple and associated with shorter procedure times and less complications.

The possibility of performing the ablative procedure completely on the epicardial surface may open the way for atrial fibrillation surgery on a totally beating heart and for procedures that are ever less invasive thus enabling treatment of patients without associated surgical indications.

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Historically speaking, the surgical approach was the earliest therapeutic ablation of hyperkinetic arrhythmias. In 1968 Dr. Will Sealy and colleagues successfully performed the surgical interruption of an accessory pathway in a fisherman from North Carolina with Wolff-Parkinson-White syndrome and this introduced a new era of non-pharmacological therapy for a wide range of arrhythmias[1]. On the basis of successive improvements in electrophysiological mapping and operative techniques, surgical techniques have been developed for the treatment of those arrhythmias related to ectopic phenomena or reentry mechanisms[2-5]. Computerized processing of the bioelectrical signals enabled the foci or the anatomical structure of the reentry circuits to be isolated and allows isochronous or isopotential mapping of the endocardial or epicardial surfaces which guided the selective abolition of the structures responsible for the arrhythmias with minimum damage to the surrounding cardiac tissue.

These procedures have been proven to be highly effective but the associated morbidity and mortality were unacceptable and non-surgical treatments were developed; the interplay between the electrophysiological and the surgical experience led to the development of the more recent and advanced techniques of transcatheter ablation[6-9] which revolutionized the treatment of these arrhythmias and which now represent the treatment of choice in the majority of cases. However, this treatment has not totally "taken over" from the surgical approach, especially in those cases requiring associated surgery.

The arrhythmias that are today treated surgically are: 1) atrial tachyarrhythmias in patients with congenital heart disease, 2) some forms of ventricular arrhythmias, and 3) atrial fibrillation (AF), which currently constitutes the main indication for antiarrhythmic surgical procedures.

Atrial tachyarrhythmias in patients with congenital heart disease

Even if these arrhythmias are not relevant from an epidemiological point of view

they do represent an interesting area and they may manifest either before or after surgical correction of cardiac malformations. At the preoperative stage the most frequent arrhythmias are AF and atrial flutter with the most common cause being atrial dilation and volume or pressure overload, while in the postoperative stage most of the arrhythmias appear as intra-atrial reentry tachycardia, the cause of which is an iatrogenic arrhythmogenic substrate related to the scars and the patches that may alter the conduction of the electrical impulses and so facilitate the reentry phenomenon[10-13].

Faced with the poor results offered by medical prophylactic treatment, surgical treatment of these arrhythmias seems to be effective.

There are many anatomical substrates which may cause intra-atrial reentry tachycardia in patients who have undergone surgery for the correction of a congenital heart disease: scars, patches, areas of fibrosis related to atrial dilation and the natural barriers such as the atrioventricular valve and the orifices of the vena cava and the pulmonary veins (PV) all constitute areas of the atrial wall in which the reentry circuit may develop[13-15]. Paradoxically, any successful ablation of the circuit of these arrhythmias may give rise to new arrhythmic circuits which are critically dependent on other areas of the atrial myocardium[12-14].

At our institution, between September 1999 and November 2001, 23 consecutive patients with atrial arrhythmias and congenital heart disease underwent elective open-heart surgery combined with intraoperative ablation[16]. Of the 20 surviving patients (2 patients died of a low cardiac output syndrome and 1 patient died of pulmonary infection), 16 were discharged in normal sinus rhythm (SR) and 4 with a pacemaker implanted for atrial sinus node dysfunction (the most common intraoperative complication). At 22-month follow-up, 5 patients (25%) presented with atrial tachycardia relapse which was responsive to drug treatment. Single drug prophylactic treatment was sufficient for the prevention of recurrences, while many drugs had been ineffective preoperatively.

Ventricular tachycardias

Most sustained ventricular tachycardias (VT) are related to the presence of post-infarct scars and are associated with a mechanism of intraventricular reentry. It has now been well documented that in patients with significant left ventricular dysfunction, these arrhythmias are associated with a high risk of sudden death.

The first attempts of a surgical approach to VT refractory to prophylactic medical treatment in patients with previous myocardial infarction date back to 1978[17,18]. The need to develop surgical techniques for the treatment of these arrhythmias derived from the evidence of the negative prognosis of patients with infarct scars and recurrent episodes of sustained VT associated with the unsatisfactory results of antiarrhythmic prophylaxis[19,20]. In the following 10 years many cardiology departments developed programs of antiarrhythmia surgery and regularly carried out antiarrhythmia procedures. Unfortunately, there was no uniformity regarding patient selection criteria and surgical techniques used[21-25].

The first attempts of surgery were aimed at patients with episodes of refractory VT and with a well-defined aneurysmal dilation of the left ventricle as a result of a previous myocardial infarction. This procedure consisted of a circular endocardial ventriculotomy, as proposed by Guiraudon et al.[17], and consisted of an almost transmural and circular complete incision around the passage area between the necrotic and the healthy myocardium. The clinical results were unsatisfactory in terms of arrhythmia recurrence, intraoperative mortality and medium- and long-term mortality. Added to this was the observation that this technique often involved a worsening of the functional deficit of the left ventricle[17].

It was then clear that the surgical approach had to be guided by intraoperative mapping in order to locate the arrhythmic substrate and hence reduce the surgical "demolition" which adversely affected ventricular function in the long term[18,26-30].

Intraoperative mapping became increasingly sophisticated thanks to the use of computerized systems, developed in collaboration with electrophysiologists, which allowed for the rapid acquisition and interpretation of the signals during VT. These systems, through the use of "multielectrode retinas" placed on the surface of the epicardium and in the ventricular cavity, enabled intraoperative mapping and hence the identification, during induced VT, of the area where the diastolic activation occurred first, corresponding to the site of origin of the arrhythmia in the endocardial tissue, in such a way as to guide the surgical resection.

The move from circular endocardial ventriculotomy to endomyocardial resection proposed by Josephson and colleagues[31] dramatically improved the outcome of the surgical treatment of VT. This technique necessitated the removal of the area around the border between the endocardial scar and the normal myocardium and was guided by direct visual recognition of the normal and abnormal or scarred endocardial tissue. Having gained access to the left ventricle through an incision at the level of the aneurysmal and scarred region and performed a small aneurysmectomy, the surgeon was able to visually identify the fibrotic endocardium stretching from the scar to the normal myocardium. The endocardial components of the arrhythmic circuits are effectively interrupted by resecting the subendocardium which goes from the compact scarred aneurysmal tissue to the normal tissue[32].

The more precise the mapping of the arrhythmic focus, the more effective the removal of the arrhythmogenic foci at the subendocardial level. For the ablative

treatment of such foci, cryoablation (CRYO), by applying a temperature of -60°C for about 2 min in the area of the focus, was shown to be particularly useful. CRYO creates a homogeneous necrosis of the myocardial tissue while maintaining the connective structure and has been shown to be invaluable when the arrhythmic focus involves the papillary muscles because it does not compromise their function.

Once the arrhythmic focus is treated, the ventricular wall is reconstructed using an autologous pericardial patch which permits the physiological remodeling of the left ventricle as well as associated operations such as myocardial revascularization or valve replacement.

The results of these approaches, reported in a collaborative study which involved a total of 665 patients, were reasonably acceptable with a relatively low intraoperative mortality (average 12%), a long-term survival (5 years) of 57% and an arrhythmia recurrence of 10%[33]. More or less matching data also emerge from wider case studies in which intraoperative mortality was 10%, survival at 2, 5 and 10 years was 75, 66 and 59% respectively, and VT recurrence was 5-10%.

A review of the data of these studies has shown that the most significant prognostic factor in clinical practice and that which would change the surgical "strategy" turned out to be a low preoperative ejection fraction (< 25%): it was both the main determinant of the risk of early death (31 vs 1%) and also the most significant prognostic factor for long-term survival (64 vs 91% at 1 year, 49 vs 75% at 5 years, and 35 vs 75% at 10 years)[29].

In the 1990's, the rapid expansion of transcatheter ablation and above all the advent of implantable cardioverter-defibrillators with their documented efficacy in the prevention of arrhythmic death obviously modified the approach to these patients and offered a solution to clinical problems which was better accepted by the patients, more easily performed, and burdened by a lower risk than that associated with antiarrhythmic surgery. As a consequence, the number of patients undergoing arrhythmia surgery rapidly dropped everywhere[34] and by the end of the 1990's many surgical treatments of arrhythmias were considered as obsolete[35].

However, many centers continued to use the surgical approach for VT. Better results and a reduction in mortality were achieved thanks to an improved patient selection: patients with severe left ventricular depression who had shown the highest incidence of operative and postoperative mortality[36] were excluded. This improved outcome was also due to the advances in the surgical techniques of reconstruction of left ventricular geometry and in techniques for myocardial protection[37-39].

The majority of the most recent large scale trials showed an operative mortality rate < 5% with a survival rate at 5 years reaching 85%, and an extremely low incidence of arrhythmia relapse and sudden death[40].

Considering the surgical approach to arrhythmias in patients with previous myocardial infarction, which is generally well defined and standardized, the necessity of intraoperative mapping has recently been questioned: some authors consider it to be still essential but others feel that it is obsolete and replaceable with an extensive use of CRYO.

To conclude, the remarkable reduction in the operative risk and the improvement in patient outcome have made the surgical treatment of VT a valid alternative in patients who are unresponsive to other antiarrhythmic therapies and to transcatheter ablation procedures or in those with post-ischemic VT who necessitate myocardial revascularization or ventricular remodeling. However, in patients with significant left ventricular dysfunction the operative risk is still too high and a defibrillator implant is preferable.

Atrial fibrillation

From an epidemiological point of view, AF is the most significant arrhythmia in clinical practice, and its pathophysiology is particularly complex. According to Moe's theory[41], confirmed by a series of clinical and experimental evidence, AF is secondary to numerous reentrant circuits which take place in areas of anatomical or functional block; the number of such reentrant circuits is variable and depends on the extension of the atrial surface and influences the maintenance of the arrhythmia.

The frequency of this arrhythmia and its common association with valvulopathy with a surgical indication has encouraged the development of various surgical treatments for AF and therefore of many important operative case studies.

The first surgical approach to AF was proposed in 1980 by Williams et al.[42] and consisted of the isolation of the left atrium in such a way as to confine the AF to the posterior cuff of the left atrium; the rest of the heart remained in SR and a regular ventricular rhythm was restored along with normal hemodynamics thanks to the capacity of the left ventricle to immediately adapt to the right output, maintaining a normal cardiac output despite the left atrial/left ventricular asynchrony. In spite of the high success rate (80%), this approach has now been completely abandoned, also owing to the fact that the persistence of left AF did not vary the risk of thromboembolic complications.

In 1985 Guiraudon et al.[43] described the "Corridor" procedure, a complex open-heart technique which treated the arrhythmia by excluding the maximum quantity possible of atrial surface and by isolating a strip of the atrial septum which guaranteed electrical continuity between the atrial sinus node and the atrioventricular node so ensuring the regularity of the heart beat.

However, the persistence of the AF precluded the possibility of atrioventricular synchronicity and, even with this approach, left the thromboembolic risk unaltered; this procedure has also been virtually abandoned.

In 1991 Cox et al.[44] introduced a clinical procedure called "Maze" which was destined to change the history of the interventional treatment of AF. It was first applied to the field of idiopathic AF and was then transposed to the field of AF secondary to mitral valvulopathy which was the clinical area where it was more widely applied.

The aim of the procedure was to obtain the compartmentalization of the atrial wall in such a way that the area of each "isolated unit" was insufficient to support the reentry circuits and AF termination would be achieved. Compartmentalization was guided, from a strictly surgical point of view, by experimental evidence obtained by Cox using high-definition computerized mapping, which demonstrated how AF had a random onset but was maintained more easily around flat areas characterized by functional block or areas of anatomical block such as a block of the vena cava, PV or the coronary sinus, the auricular appendices or the ostia of the atrioventricular valves.

On the pathophysiological bases proposed by Cox, variations in the procedure, aimed at facilitating the technique and reducing complications and procedural times, have been introduced over the years. The Maze II procedure was studied to improve the chronotropic function of the atrial sinus node and to diminish the time for postoperative interatrial conduction which was noted to cause left atrial dysfunction in some patients. This approach turned out to be technically difficult and was subsequently modified to the Maze III procedure[45,46].

Regardless of the various modifications, the Maze procedure essentially included the isolation of the PV block, the amputation of the auricular appendage and the incision of a barrier aimed at preventing any possible reentry mechanisms around the vena cava, the ostia of the atrioventricular valves and the fossa ovalis (Fig. 1)[47]. The atrial electrical activation occurs in an ordered and sequential manner through a narrow and tortuous atrial path (labyrinth) which guided the impulses of the atrial sinus node through the atria up to the atrioventricular node.

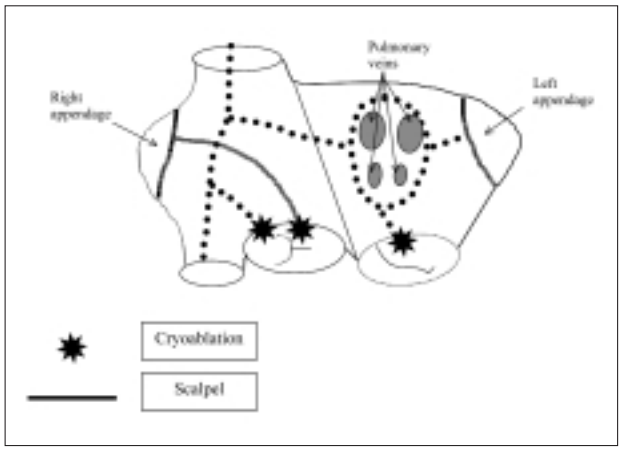

Figure 1. *The "Maze" procedure: schematic image showing the surgical technique. From ANMCO[47], modified.*

Worldwide experience shows variable results (Table I)[47-54], with a percentage for SR restoration ranging between 50 and 100%. If we consider just the latest version (Maze III), which was widely applied, we have a percentage of SR restoration ranging between 85 and 98% with slightly lower values in the treatment of AF associated with valvulopathy compared to isolated AF, probably in relation to the different atrial electrophysiological characteristics of the two clinical contexts.

One of the largest case series on the treatment of AF with the Maze procedure or one of its variants is that of the Cleveland Clinic in which, since 1991, more than 1000 patients have undergone surgical ablation during an operation on the mitral valve (only 7% of the operations were carried out in patients with "lone" AF). The procedure was highly effective with a success rate of 90% (98% in the treatment of isolated AF).

While the Maze procedure is highly effective, it is long and complex and entails an increased time of aortic clamping. The results depend directly on the skill of the operator and are burdened by an increase in operative mortality and by frequent complications (postoperative bleeding related to the number and length of atrial incisions, dysfunction of the atrial sinus node and the atrioventricular node making definitive implant of the pacemaker necessary, water retention resulting from a deficit in the natriuretic hormone due to the extensive

Table I. Maze operation results.

Author	No. patients	Efficacy (%)	Mortality (%)
Kobayashi et al.[48]	220-63	65-82	1.8
Kim et al.[49]	32	81	–
Cox[50]	201	79	?
Pasic et al.[51]	15	100	–
Izumoto et al.[52]	87	79	4.6
Isobe and Kawashima[53]	30	90	–
Fukada et al.[54]	29	66	–

From ANMCO[47], modified.

atrial lesions). In addition, SR maintenance does not always translate in the recovery of an adequate contractile function of the atrium[55,56].

The surgical treatment of AF starts from these historical bases and differs according to the particular clinical context in which the arrhythmia develops, each of which has a different "electrophysiology".

In patients with paroxysmal arrhythmic episodes, AF is started repeatedly and its induction depends on a trigger that has now been localized in the PV ostium in around 90% of patients[57]; the premature events which originate in the PV spread to the left atrium and induce the formation of multiple macroreentrant circuits causing AF which, once started, continues until there is spontaneous or pharmacological interruption, or other interventions on the macrocircuits.

If SR is not restored, the atria continue to fibrillate indefinitely. AF becomes continuous when the reentrant macrocircuits in the atrial myocardium are able to sustain themselves (according to Allessie[58] electrical and anatomical remodeling); continuous AF no longer needs a trigger to be re-induced repeatedly and so it does not depend on the PV focus for its induction or perpetuation.

Surgical treatment. Encirclement of the PV alone limits the trigger inside the PV and is sufficient of the treatment of most patients (90%) with intermittent AF. However, this is not effective or is insufficient in patients in whom the trigger is not in the PV (around 10% of patients with intermittent AF) and in patients with continuous AF the perpetuation of which does not depend on the PV focus.

The only way to ablate atrial macroreentries, and to allow the resulting SR to activate the entire atrial myocardium and ensure atrial contractile function, is to perform a Maze procedure or one of its variants.

It is however possible that not all the lesion lines created in the orginal Maze III procedure, designed to permanently preclude the development of macroreentries within the atria, are always necessary to ablate AF. There is growing evidence that while continuous AF is sustained by multiple macroreentry circuits, only a limited number of sites in the left atrium are able to sustain such circuits[59]. Recent reports suggest that the septal lesions are not necessary and neither are those that extend into the left auricles which have been included in the Maze procedure in order to prevent reentry around the base of the auricles (an operative step the value of which has never been clinically proven).

If we consider that the septal and left auricular lesions are not critical for ablation of the AF, the essential lesions of the left atrium should be limited to the incisions encircling the PV and to the incision through the isthmus between the inferior PV and the mitral annulus.

In addition, the experimental observations of Allessie and colleagues[60] that the maintenance of the macroreentry circuits is possible in the left atrium but not in a non-dilated right atrium where the refractory periods are longer as the duration of the local refractory period determines the minimum size of an atrial macroreentry circuit, and the evidence that in the presence of mitral valvulopathy with dilation only of the left atrium AF tends to originate from this and only in a limited number of cases (20%) from the right atrium, suggest that AF treatment may be focused on the left atrium.

AF cannot reoccur if the macroreentries are prevented by lesions critically positioned in the left atrium; in the right atrium which is capable of sustaining only atrial flutter, a lesion at the level of the isthmus between the coronary sinus and the tricuspid valve will disable a critical area of the macroreentry circuit which sustains the vast majority of atrial flutters[61].

In conclusion, up to 90% of AF (paroxysmal or persistent) may be treated by means of appropriate isolation of the PV. With the aim of achieving a similar success rate in patients with continuous AF, it is essential to add other lesions in the left atrium, specifically a left atriotomy extending from the incision encircling the PV up to the posterior aspect of the mitral annulus, the ablation of the coronary sinus conduction at the same level and a lesion of the right atrial isthmus.

In the last few years many surgical techniques have been proposed for the treatment of AF in an effort to minimize the operative risks and to obtain satisfactory results regarding SR recovery and atrial contractility.

With catheters it is possible to recreate the Maze procedure constructing "labyrinths" through linear lesions and many authors have elaborated their own modified version of the Maze procedure, although it is very rare to find two authors who use the same technique (Fig. 2).

The various attempts to simplify the Maze procedure have led to the use of different types of energy to eliminate AF in patients who undergo cardiac surgery to create ablation lines in the left and right atria whilst avoiding the "cut and sew" approach.

New technologies such as radiofrequency (RF), microwaves and CRYO[62-66], introduced into clinical practice and applied to open-heart surgery using an ablation pattern which is based on the same concepts as the Maze procedure, guarantee the creation of linear and transmural lesions with minimal damage to the cardiac structures and appear very interesting as they are surgically simple and associated with shorter procedure times and less complications.

Irrespective of the technique used, it is known that the left atrial posterior wall, which is crucial in the etiology and maintenance of AF, and the PV ostia are involved in all the approaches, regardless of the type of energy used and the different "operating patterns". Even though long-term results on consistent populations are not yet available, the advent of these new technologies has widened the surgical indications since

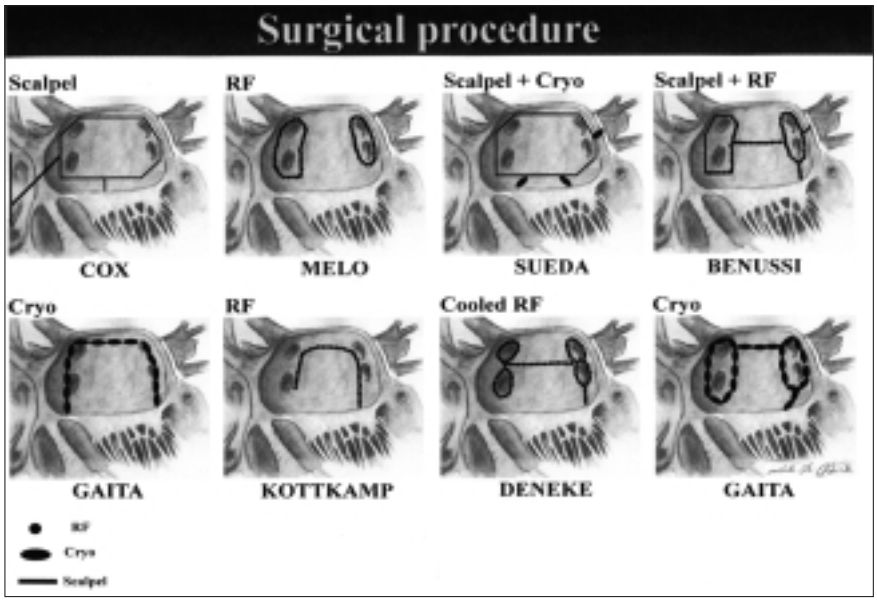

Figure 2. *Schematic image showing the different surgical approaches to the treatment of atrial fibrillation. Cryo = cryoablation; RF = radiofrequency. Courtesy of Arrhythmologic Center, Civic Hospital, Asti.*

it is possible to perform a Maze procedure with significantly reduced ischemia times.

Probably the most well known and widely used approach is RF ablation: this technique allows for a reduction in both the operative time and the risk of bleeding and is today a valid tool which allows for ablation even when access is limited, as in case of minimally invasive surgery. During aortic clamping and after left atriotomy the following surgical procedures are carried out at the left atrial level (Fig. 3)[47]:
- amputation of the left auricle;
- lesion lines using RF around the outlet of the left and right PV, between the right and left PV, between the left PV and the left auricles, between the right PV and the mitral ostium;
- CRYO both inside and outside the mitral annulus.

This approach is similar to that employed for the treatment of the left atrium in the Maze procedure, with the difference that the area between the PV is recovered. If right atrial dilation coexists, the following Maze procedures pertaining to the right atrium are carried out using RF:
- amputation of the right auricle;
- lesion lines using RF from the superior to the inferior vena cava, from this line to the fossa ovalis, from the same line to the tricuspid annulus, from the right auricle to the tricuspid annulus;
- CRYO on the tricuspid annulus.

Compared to the surgical techniques employed previously, intraoperative ablation with RF reduces the aortic clamping time and the risk of postoperative bleeding, and allows for the recuperation of the maximum area of the atrial surface possible, including the segment between the PV, whilst avoiding the loss related to scarring.

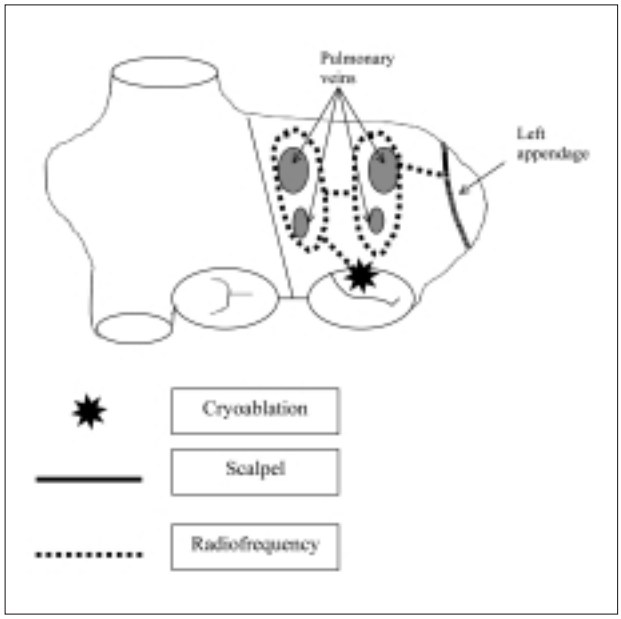

Figure 3. *Intrasurgical ablation with radiofrequency: schematic image showing the surgical technique. From ANMCO[47], modified.*

Compared to the transcatheter procedure, it has the great advantage that it can be applied with normal vision, so avoiding the transseptal approach. Besides, continuous and complete ablation lines can be carried out in around 5 min.

The experience reported by Suarez et al.[67] is illustrative of the history of the surgical approach to AF in the last 15 years. From 1991 to December 2002, 156 patients underwent surgical treatment of AF in association with treatment for the underlying pathology. Up until 1995 isolation of the left atrium was the method

most often employed. In 1993, the first Maze procedure was carried out and since 1995 this technique has become the routine technique for the surgical treatment of AF. From May 2001 the traditional procedure described by Cox was modified and new sources of energy were introduced – RF and microwaves. Both were easily applied through endocardial and epicardial approaches so allowing the latter to extend the surgical indications also to those patients with a heart disease where the surgical approach does not require the atrial cavity to be opened.

Of the 156 patients, 71 were submitted to left atrial isolation, 31 to the Maze III procedure, 44 to RF ablation and 10 to microwave ablation. At follow-ups of 108, 85 and 16 months respectively 67.34, 88.5 and 84.23% of the patients (this last figure refers to treatment with RF and with microwaves) were found to be in SR.

These data show the high efficacy of treatments with RF and microwaves which are essentially similar to those of the Maze procedure and are confirmed by other groups[68,69]. In the experience of Venturini et al.[69], between November 1999 and January 2003 115 patients underwent surgery for valvulopathy with AF (paroxysmal in 31 patients and chronic in 84 patients); 66 patients underwent RF ablation and 49 microwave ablation.

The ablations with microwaves were performed through endocardial bilateral circular isolation of the PV ostia in the still heart (1-2 applications for the right PV and 3-4 to complete the left side). RF ablation entailed the epicardial bilateral circular isolation of the PV ostia. The right epicardial lesions were performed without cardiopulmonary bypass, the left lesions with cardiopulmonary bypass and on a beating heart, the endocardial lesions with aortic lesions and cardioplegic cardiac arrest.

The concomitant surgical procedures were mitral valvuloplasty in 25.2%, mitral replacement in 29.6% and replacement of the mitral-aortic valves in 45.2% of the patients.

There was no in-hospital mortality nor any case of bleeding necessitating redo surgery. Two patients were implanted with a definitive pacemaker and at a mean follow-up of 19.8 months one sudden death was recorded in a patient with dilated cardiomyopathy. At the last follow-up stable SR was reported in 74.8% of the patients.

With the aim of simplifying the Maze procedure and following the recent experiences of Haissaguerre et al.[57] suggesting that the PV are an important source of ectopic beats which frequently create AF paroxysms, the surgical team decided to perform just a separate encirclement of the right and left PVs. The percentage of SR at final follow-up (74.8%) was similar to that reported for other centers using different ablation lines. Despite the fact that more numerous case studies and longer follow-ups are needed, these data suggest that it is not necessary to use additional lines. What is more, their experience, which included many patients with chronic AF, showed how the PV play a key role not only in paroxysmal but also in permanent forms of AF.

Nascimbene et al.[70] reported on a series of 206 patients with AF (189 with persistent AF and 17 with paroxysmal AF) and candidates for elective cardiac surgery operated upon between February 1998 and August 2002. The technique used involved the combination of lesions applied with epicardial RF, endocardial RF lesions and a single standard left atriotomy lesion parallel to the interatrial sulcus and to the left auricular suture. The procedure was carried out on a beating heart and with extracorporeal circulation and involved a prevalently epicardial approach. This allows a significant reduction in the average cardiac arrest time, which is necessary for the open-heart ablation procedure but is limited by the impossibility of documenting the transmural lesions with certainty. This, however, could be overcome thanks to new devices currently being experimented.

At a follow-up of 2-4 years, 74% of the enrolled patients were in SR. These results are largely in line with those of the literature obtained with the various surgical approaches and in terms of efficacy this method is second only to the Maze procedure which has been shown to be the most effective technique in the definitive treatment of AF in patients with surgical indications for organic cardiac disease. If, however, we consider that the technique described above involves a greater efficiency in the restoration of the atrial contractile function (100 vs 63-90% with the Maze procedure), probably due to the limited number of incisions and the minimal electromechanical exclusion of the areas of the atrial wall, this greater efficacy of the Maze procedure may be considered only “apparent”.

Similar results in terms of SR persistence in the follow-up are also confirmed in other experiences[71] with another source of energy for the surgical treatment of the AF. Manasse et al.[71] reported the results of a series of 95 patients with permanent or persistent AF (33%) who were submitted, from April 1998 to May 2002, to CRYO of the left posterior atrial wall concomitantly to surgery for valvulopathy. With an in-hospital mortality of 3.2%, 72.8% and 81.4% of the patients respectively were in SR at the time of discharge and at a mean follow-up of 3 years. This result was independent of the duration of the preoperative AF, of the dimensions of the left atrium and of the type of mitral valvulopathy.

As things currently stand, considering the relatively benign nature of the arrhythmia in the absence of any associated heart disease, the risk of complications (atrio-esophageal fistula, coronary lesions, etc.) should discourage an extensive use of surgical ablation in patients with “lone” AF. On the other hand, it should be proposed as routine in most patients with chronic or paroxysmal AF who must undergo cardiac surgery. The possibility of carrying out the ablative procedure com-

pletely on the epicardial surface may open the way for AF surgery on a totally beating heart and for procedures that are ever less invasive with the possibility of being able to offer treatment even to patients with "lone" AF.

References

1. Cobb FR, Blumenschein SD, Sealy WL, Boineau JP, Wagner GS, Wallace AG. Successful surgical interruption of the bundle of Kent in a patient with Wolff-Parkinson-White syndrome. Circulation 1968; 38: 1018-29.
2. Cox JL, Holman WL, Cain ME. Cryosurgical treatment of atrioventricular node reentrant tachycardia. Circulation 1987; 76: 1329-36.
3. Ross DL, Johnson DC, Denniss AR, Cooper MJ, Richards DA, Uther JB. Curative surgery for atrioventricular junctional ("AV nodal") reentrant tachycardia. J Am Coll Cardiol 1985; 6: 1383-92.
4. Lowe JE, Hendry PJ, Packer DL, Tang AS. Surgical management of chronic ectopic atrial tachycardia. Semin Thorac Cardiovasc Surg 1989; 1: 58-66.
5. Harken AH, Horowitz LN, Josephson ME. Comparison of standard aneurysmectomy and aneurysmecomy with directed endocardial resection for the treatment of recurrent sustained ventricular tachycardia. J Thorac Cardiovasc Surg 1980; 80: 527-34.
6. Salerno JA, Klersy C, Minzioni G, et al. Therapy of arrhythmias by ablation techniques with catheters and with surgical techniques. Cardiologia 1988; 33: 237-41.
7. Borggrefe M, Budde T, Podczeck A, Breithardt G. High frequency alternating current ablation of an accessory pathway in humans. J Am Coll Cardiol 1987; 10: 576-82.
8. Lavergne T, Guize L, Le Heuzey JY, et al. Transvenous ablation of the atrio-ventricular junction in human with high-frequency energy. (abstr) J Am Coll Cardiol 1987; 9 (Suppl A): 99.
9. Delise P, Bonso A, Raviele A, Cazzin R, Di Pede F, Piccolo E. Successful catheter ablation by radiofrequency energy of posteroseptal accessory pathway in a patient with drug refractory Wolff-Parkinson-White syndrome. Eur Heart J 1991; 12: 1321-5.
10. Van Hare GF, Lesh MD, Ross BA, Perry JC, Dorostkar PC. Mapping and radiofrequency ablation of intraatrial reentrant tachycardia after the Senning or Mustard procedure for transposition of the great arteries. Am J Cardiol 1996; 77: 985-91.
11. Gewillig M, Wyse RK, de Laval MR, Deanfield JE. Early and late arrhythmias after the Fontan operation: predisposing factors and clinical consequences. Br Heart J 1992; 67: 72-9.
12. Paul T, Windhagen-Mahnert B, Kriebel T, et al. Atrial reentrant tachycardia after surgery for congenital heart disease: endocardial mapping and radiofrequency catheter ablation using a normal, noncontact mapping system. Circulation 2001; 103: 2266-71.
13. Baker BM, Lindsay BD, Bomberg BJ, Frazier DW, Cain ME, Smith JM. Catheter ablation of clinical intraatrial reentrant tachycardias resulting from previous atrial surgery: localizing and transecting the critical isthmus. J Am Coll Cardiol 1996; 28: 411-7.
14. Delacretaz E, Ganz LI, Soejima K, et al. Multiple atrial macro-reentry circuits in adults with repaired congenital heart disease: entrainment mapping combined with three-dimensional electroanatomic mapping. J Am Coll Cardiol 2001; 37: 1665-76.
15. Cosio FG, Lopez Gil M, Goicolea A, Arribas F, Barroso JL. Radiofrequency ablation of the inferior vena cava-tricuspid valve isthmus in common atrial flutter. Am J Cardiol 1993; 71: 705-9.
16. Vignati G, Crupi G, Vanini V, Iorio F, Borghi A, Giusti S. Surgical treatment of arrhythmias related to congenital heart diseases. Ann Thorac Surg 2003; 75: 1194-9.
17. Guiraudon G, Fontaine G, Frank R, Escande G, Etienvent P, Cabrol C. Encircling endocardial ventriculotomy: a new surgical treatment for life-threatening ventricular tachycardias resistant to medical treatment following myocardial infarction. Ann Thorac Surg 1978; 26: 438-44.
18. Josephson ME, Harken AH, Horowitz LN. Endocardial excision: a new surgical technique for the treatment of recurrent ventricular tachycardia. Circulation 1979; 60: 1430-9.
19. Willems AR, Tijssen JG, van Capelle FJ, et al. Determinants of prognosis in symptomatic ventricular tachycardia or ventricular fibrillation late after myocardial infarction. The Dutch Ventricular Tachycardia Study Group of the Interuniversity Cardiology Institute of The Netherlands. J Am Coll Cardiol 1990; 16: 521-30.
20. Teo KK, Yusuf S, Furberg CD. Effects of prophylactic antiarrhythmic drug therapy in acute myocardial infarction. An overview of results from randomized controlled trials. JAMA 1993; 270: 1589-95.
21. Josephson ME, Harken AH, Horowitz LN. Long-term results of endocardial resection for sustained ventricular tachycardia in coronary disease patients. Am Heart J 1982; 104: 51-7.
22. Brodman R, Fisher JD, Johnston DR, et al. Results of electrophysiologically guided operation for drug-resistant recurrent ventricular tachycardia and ventricular fibrillation due to coronary artery disease. J Thorac Cardiovasc Surg 1984; 87: 431-8.
23. Garan H, Nguyen K, McGovern B, Buckley M, Ruskin JN. Perioperative and long-term results after electrophysiologically directed ventricular surgery for recurrent ventricular tachycardia. J Am Coll Cardiol 1986; 8: 201-9.
24. Martinelli L, Goggi C, Graffigna A, et al. The role of surgery in the treatment of post-infarction ventricular tachycardia. A 5 year experience. J Cardiovasc Surg (Torino) 1987; 28: 374-9.
25. Ostermeyer J, Kirklin JK, Borggrefe M, Cox JL, Breithardt G, Bircks W. Ten year electrophysiologically guided direct operations for malignant ischemic ventricular tachycardia - results. Thorac Cardiovasc Surg 1989; 37: 20-7.
26 Ostermeyer J, Breithardt G, Borggrefe M, Godehardt E, Seipel L, Bircks W. Surgical treatment of ventricular tachycardias. Complete versus partial encircling endocardial ventriculotomy. J Thorac Cardiovasc Surg 1984; 87: 517-25.
27. Camm J, Ward DE, Spurrel RA, Rees GM. Cryothermal mapping and cryoablation in the treatment of refractory cardiac arrhythmias. Circulation 1980; 63: 67-74.
28. Svenson RH, Gallagher JJ, Selle JG, Zimmern SH, Fedor JM, Robicsek F. Neodymium:YAG laser photocoagulation: a successful new map-guided technique for the intraoperative ablation of ventricular tachycardia. Circulation 1987; 76: 1319-28.
29. Viganò M, Martinelli L, Salerno JA, et al. Ventricular tachycardia in post-myocardial infarction patients. Results of surgical therapy. Eur Heart J 1986; 7 (Suppl A): 165-8.
30. Gallagher JJ, Kasell JH, Cox JL, Smith WM, Ideker RE, Smith WM. Techniques of intraoperative electrophysiologic mapping. Am J Cardiol 1982; 49: 221-40.
31. Hargrove WC, Miller JM, Vassallo JA, Josephson ME. Improved results in the operative management of ventricular tachycardia related to inferior wall infarction: importance of

the annular isthmus. J Thorac Cardiovasc Surg 1986; 92: 726-32.
32. Marchlinski FE, Josephson ME. Surgical treatment of ventricular tachyarrhythmias. In: Platia EV, ed. Non-pharmacologic management of cardiac arrhythmias. Philadelphia, PA: Lippincott, 1987: 340-63.
33. Borggrefe M, Podczek, A, Ostermeyer J, Breithardt G, and the Surgical Ablation Registry. Long-term results of electrophysiologically guided antitachycardia surgery for ventricular tachyarrhythmias: a collaborative report on 665 patients. In: Breithardt G, Borggrefe M, Zipes DP, eds. Nonpharmacological therapy of tachyarrhythmias. Mount Kisko, NY: Futura Publishing Company, 1988: 109-32.
34. van Hemel NM, Kingma JH, Defauw JJ, et al. Continuation of antiarrhythmic drugs, or arrhythmia surgery after multiple drug failures. A randomized trial in the treatment of postinfarction ventricular tachycardia. Eur Heart J 1996; 17: 564-73.
35. Bourke JP, Hilton CJ, McComb JM, et al. Surgery for control of recurrent life-threatening ventricular tachyarrhythmias within two months of myocardial infarction. J Am Coll Cardiol 1990; 16: 42-8.
36. Lawrie GM, Pacifico A, Kaushik R, Nahas C, Earle N. Factors predictive of results of direct ablative operations for drug-refractory ventricular tachycardia. Analysis of 80 patients. J Thorac Cardiovasc Surg 1991; 101: 44-55.
37. Vigano M, Graffigna A, Salerno JA. Surgery of refractory ischemic arrhythmias. G Ital Cardiol 1992; 22: 373-80.
38. Cooley DA, Frazier OH, Duncan JM, Reul GJ, Krajcer Z. Intracavitary repair of ventricular aneurysm and regional dyskinesia. Ann Surg 1992; 215: 417-24.
39. Dor V, Sabatier M, Di Donato M, Montiglio F, Toso A, Maioli M. Efficacy of endoventricular patch plasty in large postinfarction akinetic scar and severe left ventricular dysfunction: comparison with a series of large dyskinetic scars. J Thorac Cardiovasc Surg 1998; 116: 50-9.
40. Page PL. Surgical treatment of ventricular tachycardia. Indications and results. Arch Mal Coeur Vaiss 1996; 89: 115-21.
41. Moe GK, Abildskov JA. Atrial fibrillation as a self-sustaining arrhythmia independent of focal discharge. Am Heart J 1959; 58: 59-70.
42. Williams JM, Ungerleider RM, Lofland GK, Cox JL. Left atrial isolation: new technique for the treatment of supraventricular arrhythmias. J Thorac Cardiovasc Surg 1980; 80: 373-80.
43. Guiraudon GM, Campbell CS, Jones DL, et al. Combined sino-atrial node atrio-ventricular node isolation: a surgical alternative to His bundle ablation in patients with atrial fibrillation. (abstr) Circulation 1985; 72: M-220.
44. Cox JL, Schuessler RB, D'Agostino HJ Jr, et al. The surgical treatment of atrial fibrillation. III. Development of a definitive surgical procedure. J Thorac Cardiovasc Surg 1991; 101: 569-83.
45. Cox JL, Boineau JP, Schuessler RB, Kater KM, Lappas DG. Five-year experience with the maze procedure for atrial fibrillation. Ann Thorac Surg 1993; 56: 814-24.
46. Cox JL, Jaquiss RD, Schuessler RB, Boineau JP. Modification of the maze procedure for atrial flutter and atrial fibrillation. II. Surgical technique of the maze III procedure. J Thorac Cardiovasc Surg 1995; 110: 485-95.
47. ANMCO. Trattato di cardiologia. Vol 3. San Donato Milanese: Excerpta Medica, 2000.
48. Kobayashi J, Kosakai Y, Nakano K, Sasako Y, Eishi K, Yamamoto F. Improved success rate of the maze procedure in mitral valve disease by new criteria for patients' selection. Eur J Cardiothorac Surg 1998; 13: 247-52.
49. Kim YJ, Sohn DW, Park DG, et al. Restoration of atrial mechanical function after maze operation in patients with structural heart disease. Am Heart J 1998; 136: 1070-4.
50. Cox JL. Atrial transport function after the maze procedure for atrial fibrillation: a 10-year clinical experience. Am Heart J 1998; 136: 934-6.
51. Pasic M, Musci M, Siniawski H, Edelmann B, Tedoriya T, Hetzer R. Transient sinus node dysfunction after the Cox-maze III procedure in patients with organic heart disease and chronic fixed atrial fibrillation. J Am Coll Cardiol 1998; 32: 1040-7.
52. Izumoto H, Kawazoe K, Kitahara H, Kamata J. Operative results after the Cox/maze procedure combined with a mitral valve operation. Ann Thorac Surg 1998; 66: 800-4.
53. Isobe F, Kawashima Y. The outcome and indications of the Cox maze III procedure for chronic atrial fibrillation with mitral valve disease. J Thorac Cardiovasc Surg 1998; 116: 220-7.
54. Fukada J, Morishita K, Komatsu K, et al. Is atrial fibrillation resulting from rheumatic mitral valve disease a proper indication for the maze procedure? Ann Thorac Surg 1998; 65: 1566-70.
55. Kalil RA, Maratia CB, D'Avila AD, Ludwig FB. Predictive factors for persistence of atrial fibrillation after mitral valve operation. Ann Thorac Surg 1999; 67: 614-7.
56. Izumoto H, Kawazope K, Eishi K, Kamata J. Medium-term results after the modified Cox/Maze procedure combined with other cardiac surgery. Eur J Cardiothorac Surg 2000; 17: 25-9.
57. Haissaguerre M, Jais P, Shah DC, et al. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. N Engl J Med 1998; 339: 659-6.
58. Allessie MA. Atrial fibrillation-induced electrical remodeling in humans: what is the next step? Cardiovasc Res 1999; 44: 10-2.
59. Harada A, Konishi T, Fukata M, Higuchi K, Sugimoto T, Ssaki K. Intraoperative map guided operation for atrial fibrillation due to mitral valve disease. Ann Thorac Surg 2000; 69: 446-50.
60. Lammers WJ, Schalij MJ, Kirchhof CJ, Allessie MA. Quantification of spatial inhomogeneity in conduction and initiation of reentrant atrial arrhythmias. Am J Physiol 1990; 259 (Part 2): H1254-H1263.
61. Nakagawa H, Lazzara R, Khastgir T, et al. Role of the tricuspid annulus and the Eustachian valve/ridge in atrial flutter. Relevance to catheter ablation of the septal isthmus and a new technique for rapid identification of ablation success. Circulation 1996; 94: 407-24.
62. Chen MC, Guo GB, Chang JP, Yeh KH, Fu M. Radiofrequency and cryoablation of atrial fibrillation in patients undergoing valvular operations. Ann Thorac Surg 1998; 65: 1666-72.
63. Knaut M, Spitzer FG, Karolyi L, et al. Intraoperative microwave ablation for curative treatment of atrial fibrillation in open heart surgery - the MICRO-STAF and MICRO-PASS pilot trial. MICROwave Application in Surgical treatment of Atrial Fibrillation. MICROwave Application for the Treatment of Atrial Fibrillation in Bypass-Surgery. Thorac Cardiovasc Surg 1999; 47 (Suppl 3): 379-84.
64. Patwardhan AM, Dave HH, Tamhane AA, et al. Intraoperative radiofrequency microbipolar coagulation to replace incisions of maze III procedure for correcting atrial fibrillation in patients with rheumatic valvular disease. Eur J Cardiothorac Surg 1997; 12: 627-33.
65. Melo J, Adragao PR, Neves J, et al. Electrosurgical treat-

ment of atrial fibrillation with a new intraoperative radiofrequency ablation catheter. Thorac Cardiovasc Surg 1999; 47 (Suppl 3): 370-2.
66. Mohr FW, Fabricius AM, Falk V, et al. Curative treatment of atrial fibrillation with intraoperative radiofrequency ablation: short-term and midterm results. J Thorac Cardiovasc Surg 2002; 123: 919-27.
67. Suarez SM, Chiappini B, Lo Forte A, Savini C, Marinelli G. Trattamento chirurgico della fibrillazione atriale: 11 anni di esperienza. In: Palmieri M, ed. Atti del IX Convegno Nazionale Clinica e Terapia delle Aritmie. Bologna, 2003: 115-27.
68. Wisser W, Khazen C, Deviatko E, et al. Microwave and radiofrequency ablation yield similar success rates for treatment of chronic atrial fibrillation. Eur J Cardiothorac Surg 2004; 25: 1011-7.
69. Venturini A, Cutaia V, Asta A, et al. Radiofrequency and microwave ablation of atrial fibrillation during open heart surgery: what are the long-term results? In: Raviele A, ed. Cardiac arrhythmias 2003. Milano: Springer-Verlag Italia, 2003: 215-20.
70. Nascimbene S, Benussi S, Calvi S, et al. Concomitant treatment of atrial fibrillation in open-heart surgery patients: late rhythm and functional results. Ital Heart J Suppl 2004; 5: 199-204.
71. Manasse E, Gaita F, Ghiselli S, et al. Cryoablation of the left posterior atrial wall: 95 patients and 3 years of mean follow-up. Eur J Cardiothorac Surg 2003; 24: 731-40.