We are IntechOpen,
the world's leading publisher of Open Access books
Built by scientists, for scientists

6,900
Open access books available

186,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Surgical Treatment of Atrial Fibrillation

Manoraj Navaratnarajah, Suvitesh Luthra and Sunil Ohri

Abstract

The concepts, techniques and evidence relating to surgical ablation of atrial fibrillation are discussed in detail. The historical background to surgical ablation is covered in brief, along with the electrophysiological basis underpinning its effective useage. The epidemiology of surgically treated atrial fibrillation and the current guidelines relating to its use are analysed. Safety aspects and perspectives on its ongoing future use are discussed. Modern surgical technologies and approaches are reviewed, along with the relevant advantages and disadvantages of each. The surgical techniques relating to left atrial appendage intervention are also reviewed, along with the relevant literature and evidence relating to reduction in thromboembolic risk and need for anticoagulation.

Keywords: MAZE, left trial appendage, surgical ablation

1. Epidemiology of atrial fibrillation

Atrial fibrillation (AF) is the most common type of cardiac arrhythmia and remains a major cause of stroke, heart failure (HF), sudden death, and cardiovascular morbidity. Importantly, with an ever-ageing population, the prevalence of AF is increasing, and predicted to rise steeply in the future [1]. AF impairs functional status, cognitive function and reduces the quality of life [2]. Age, sex, race, and geographical location, as well as other modifiable risk factors (diabetes, hypertension, lung disease, obesity and alcohol use) determine the prevalence of AF. The overall prevalence of AF is approximately 1%, but rises significantly with age. In those over 75 years old it has been shown to be greater than 10%, and greater than 15% in those over 85 [3, 4].

As such, the proportion of patients presenting for cardiac surgery in AF, or with a history of AF is also expanding. AF detrimentally affects prognosis in patients with severe valvular heart disease [5], and those undergoing surgery or transcatheter interventions for aortic or mitral valve disease, and in combination with valvular heart disease, increases thromboembolic risk significantly [6, 7]. As with congestive HF, valvular disease and AF share a dynamic interaction that sustain one another, driven by the detrimental effects of volume and pressure overload, maladaptive neurohumoral activation, cardiac fibrosis and a deleterious tachy-cardiomyopathy. Therefore, it is intuitive that immense attention has been, and continues to be focussed upon the potential likely benefits of surgical correction of AF, as part of both concomitant AND stand-alone procedures.

1.1 Atrial fibrillation in surgical patients

The prevalence of pre-operative AF varies with the encountered cardiac pathology, and this, together with surgical procedure type, influences the likelihood of concomitant surgical AF ablation. In the surgical population, the prevalence is greatly skewed towards mitral valve disease, because this pathology invokes the greatest degree of left atrial (LA) distension [8]. An AF prevalence of 30% is reported in mitral valve surgical patients, and only 14% and 6% in patients undergoing aortic valve or isolated coronary surgery, respectively [9]. Analysis of US registry data from the early 2000s showed that the prospect of concomitant AF ablation was greatest in mitral valve patients (~60%) and double that in aortic valve (~30%) and coronary artery bypass (~25%) surgical patients [10]. The chapter will focus upon the anatomical and physiological principles underlying surgical AF ablation, the technical and surgical aspects regarding specific anatomical lesion sets and their complications. Current evidence and guidelines supporting the use of surgical AF ablation, during both concomitant cardiac surgery and stand-alone surgery will also be reviewed.
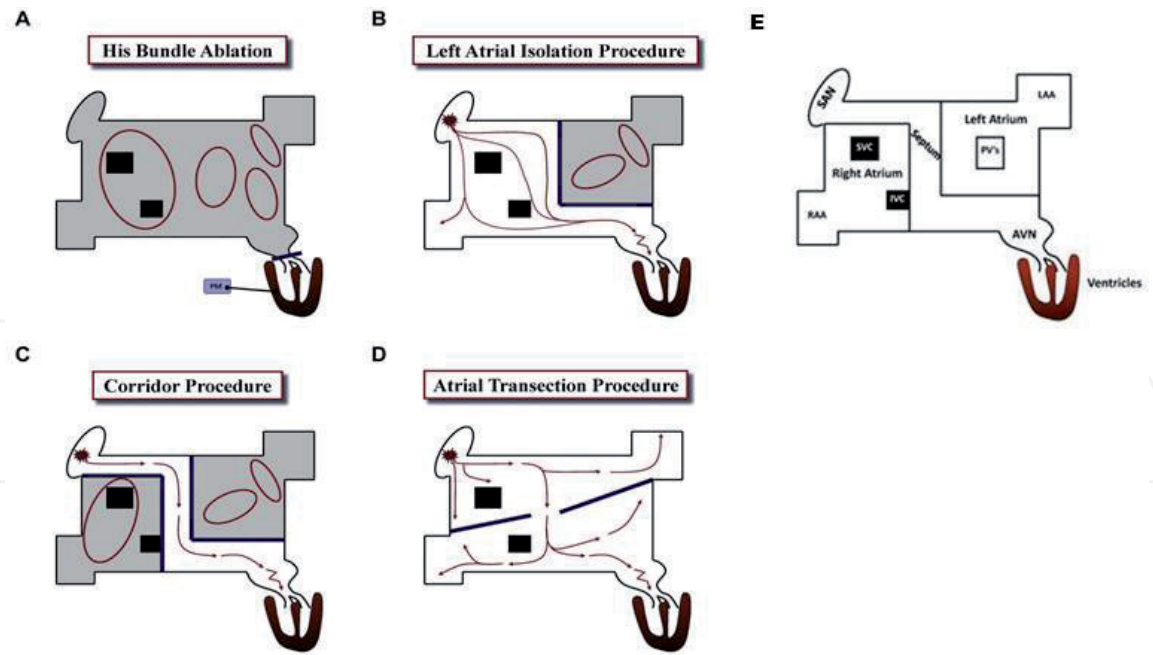
2. Principles underlying surgical treatment of atrial fibrillation

A large variety of surgical strategies have evolved over past decades for the treatment of AF. As such, standardisation of terminology is difficult and comparison of studies can prove impossible. Anti-arrhythmic procedures are divided into two broad categories: (A) isolation or (B) ablation procedures. Initial surgical procedures were isolation procedures, aimed at confining the arrhythmia to a specific region of the heart [11]. Ablation was not carried out at this early time, as there was insufficient knowledge relating to the electrophysiological mechanisms driving AF. Isolation procedures such as LA isolation and the corridor operation will not be reviewed further in this chapter as they are irrelevant to current clinical practice.
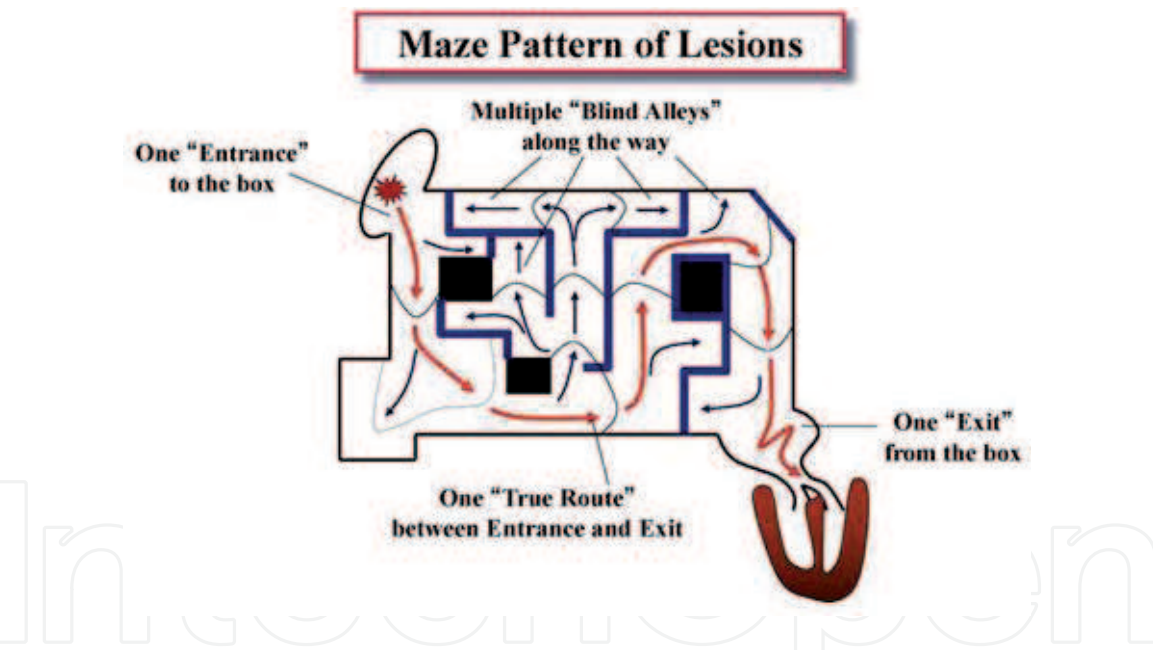
Starting in the 1980s, several procedures were developed in an effort to treat AF, including LA isolation (A), corridor operation (B), and atrial transection (C) (**Figure 1**). The first attempt to surgically ablate AF was made via the atrial transection procedure in 1986 [12]. This procedure failed after 5 months in the 1 patient in which it was performed. Transection was based upon on the flawed belief that AF was caused by two macro-re-entrant circuits; one around the SVC and IVC orifices and one around the pulmonary veins and the orifice of the LA appendage (LAA). With improving knowledge of the mechanisms driving AF the MAZE procedure and pulmonary vein isolation (PVI) subsequently evolved, and formed the foundation of modern surgical treatment of AF. These two procedures form the main focus of this chapter.

2.1 The MAZE concept

The MAZE concept underlying the classical MAZE procedure is best encapsulated by the words of Dr James Cox—'The cardinal feature of a classical MAZE procedure includes lines of conduction block that preclude macro-re-entry anywhere in either atrium while leaving both atria capable of activation by a sinus-generated impulse. Components essential to achieving this include appropriate lesions in *both* atria, the absence of gaps that allow electrical activity to bypass an intended line of block, and the absence of alternate pathways by which impulses can reach the intended maze exit'. 'The maze has one entrance site, one exit site and one true route between the entrance and exit' [13] (**Figure 2**). It must be stressed that numerous surgical ablation strategies are now in existence that do *not* strictly

Figure 1.
Schematic representation of AF isolation/ablation techniques. (A) His bundle ablation, (B) Left atrial isolation procedure, (C) Corridor procedure (D) Atrial transection procedure and (E) MAZE concept [13].
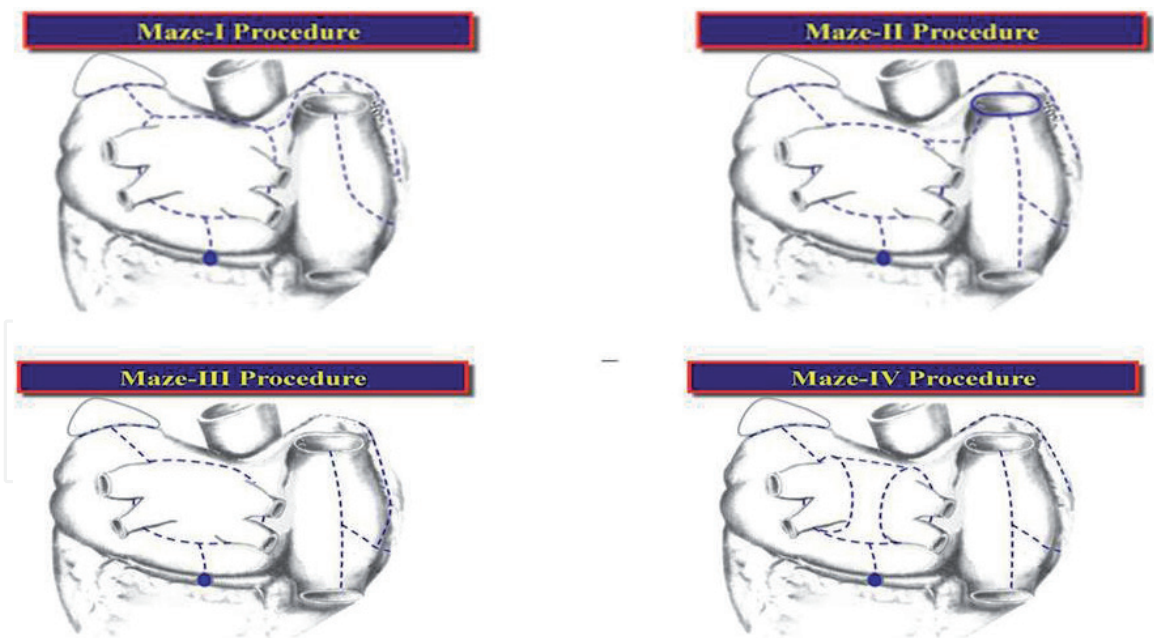

Figure 2.
Schematic representation of the surgical MAZE concept [13].

adhere to the MAZE concept described above, yet are described as 'MAZE' procedures. The implications of utilising this generic umbrella term, when comparing studies and drawing conclusions from study outcomes must be appreciated.

2.2 Surgical ablation lesion sets

The first MAZE-I procedure was performed in 1987. It abolished AF and re-established sinus rhythm (SR) effectively. However, the MAZE-I was associated with chronotropic incompetence in approximately 30% of patients, and intra-atrial conduction delay resulting in loss of LA transport due to simultaneous LA and left ventricle (LV) contraction [13]. These two undesirable effects of the MAZE-I procedure, led to modifications in the lesion set thus creating the MAZE

Figure 3.
Versions of the surgical MAZE procedure [13].

II procedure. The anterior-superior LA and right atrium (RA) lesions were repositioned in a more posterior location. The Maze II was performed in less than 15 patients, due to extreme technical difficulty that required SVC transection above the RA to enhance LA exposure [13, 14]. The MAZE III included relocation of anterior lesion sets further posteriorly and a septal lesion to facilitate LA exposure, the latter being omitted subsequently in later iterations of the MAZE III. From 1992 onwards the surgical cut-and sew MAZE-III procedure was performed through a median sternotomy, and the lesion pattern became the standard pattern for MAZE procedures. As the name implies, all cardiac lesions were created by cutting the full thickness of the myocardium and then re-sewing the tissue together, thus inhibiting macro re-entry circuit conduction. It was not until 1997 when the original cut-and-sew MAZE-III procedure was replaced by cryosurgical MAZE-III procedure, where all surgical lesions were replaced by cryoablation lesions created by a linear cryoprobe [13]. The MAZE III was then superseded by the first MAZE IV procedure in 2002. Lesion sets were essentially identical, with lesions in the MAZE IV performed using a combination of bipolar radiofrequency clamps and linear cryoprobes [15] (**Figure 3**). Improved speed of execution resulted in less patient morbidity during the MAZE IV, and this is now the gold standard procedure in AF ablation. Surgical AF ablation is most commonly applied as a concomitant procedure during valve or coronary revascularization operations, but also as a primary or stand-alone procedure. The frequency of surgical ablation and durable achievement of SR is increasing, represented mainly by the MAZE III/IV procedures.

3. Surgical ablation energy sources

Numerous energy sources have evolved over the past two decades to replace the traditional 'cut and sew' technique that aim to replicate transmural lesions, whilst enabling a less time-consuming yet equally effective approach. A fundamental pre-requisite for successful AF ablation, is complete transmurality and continuity bilaterally, and a correct lesion pattern.

3.1 Radiofrequency ablation

Radiofrequency ablation (RFA) acts by conducting an alternating electrical current through the myocardium. The energy of this electrical current disperses through myocardial tissue as heat, causing coagulative necrosis, creating an area of non-conducting myocardium. RFA employs an alternating current at 350 kHz-1 MHz to heat tissue to 70–80°C for 1 min, creating a 3–6 mm lesion using unipolar or bipolar devices. Transmurality is indicated by electrical conductance and impedance monitoring. The efficacy of AF ablation during cardiac surgery using either unipolar [16–18], or bipolar ablation [19–21] technology, is well established. Overall, success rates in restoring SR are over 60%, measured at a variety of time points ranging from 12 to 60 months post procedure. However, there is limited evidence to conclude whether bipolar RFA is more effective than unipolar RFA (**Figure 4**).
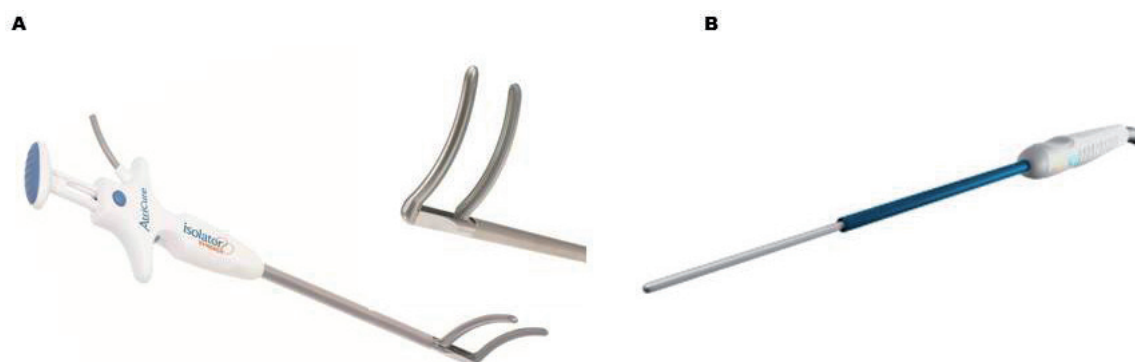
3.2 Cryoablation

Cryoablation works by using nitrous oxide as a cooling agent for 2 min at −60°C to produce a transmural lesion that can be visualised as an 'iceball'.
Tissue injury results by creation of ice crystals within cells disrupting the cell function and electrical conductivity. In addition, microvascular disruption causes cell death. Several studies have proven the efficacy of concomitant cryoablation in the treatment of AF. Cryoablation during concomitant cardiac surgery achieves good rates of SR, ranging from 60 to 80% at a variety of time points ranging from 12 to 60 months post procedure [22, 23] (**Figure 4**).

3.3 Microwave

Microwave ablation uses high-frequency electromagnetic radiation to induce oscillation of water molecules, and produces a well-demarcated lesion via thermal injury. Its main strength is the production of excellent epicardial lesions, thus promoting its use in minimally invasive techniques. A success rate ranging between 65 and 85% is observed over a variable follow up period between 6 and 12 months [24]. Long term success rates remain unclear and evidence relating to microwave ablation efficacy is limited. Thus far, bipolar RFA ablation and cryoablation have demonstrated superiority in terms of freedom from AF, AF recurrence rates, and microwave ablation is currently considered less effective than other ablation modalities [25, 26].
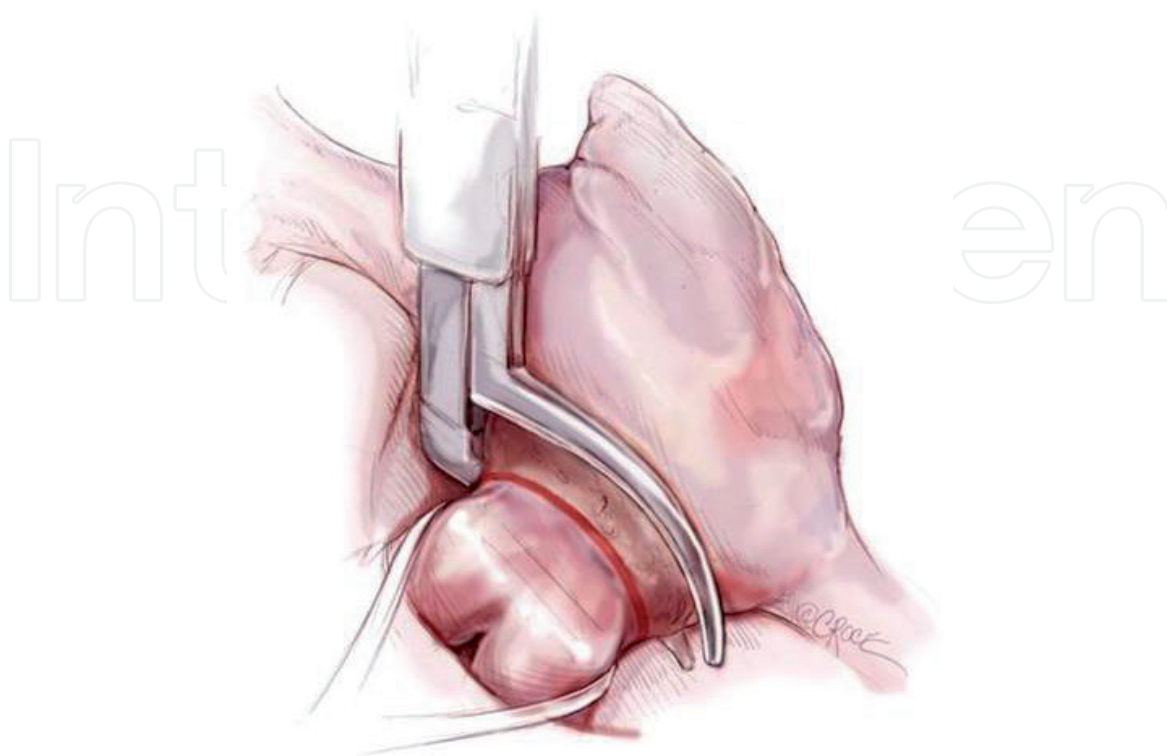

Figure 4.
Radiofrequency surgical ablation clamp (A) and cryoprobe (B) [105].

3.4 Laser and ultrasound

Alternative energy sources being explored in AF ablation are that of laser and ultrasound. Laser ablation uses a monochromatic, phase coherent beam to cause heating and cellular destruction. Laser has shown efficacy in restoration of SR (>70%) in isolated procedures and during concomitant surgery [27]. However, currently, laser ablation has not gained approval for clinical use outside of trials due to limited evidence supporting its efficacy and safety [27]. Ultrasound, utilises high-frequency sound waves (2–20 MHz) emitted by piezoelectric crystals to cause thermal heating and disruption of cell membranes. It creates permanent transmural lesions when applied epicardially and is advantageous in that CPB is unnecessary, and ablation can be executed on a beating heart. Ultrasound lesions can also be delivered via a balloon catheter, allowing isolated PVI [28, 29]. Reasonable conversion rates to SR have been demonstrated in isolated PVI for lone paroxysmal AF. However, due to frequent complications, such as atrio-oesophageal fistula, pericardial effusion and phrenic nerve palsy, use of ultrasound is not currently recommended, and its role in permanent AF is unproven [28, 29].

4. Surgical approaches for ablation

The MAZE IV can be performed either through a sternotomy or through a right mini thoracotomy. A combination of RFA and cryoablation is used to create the lesion set in the majority of cases. After gaining access to the chest both pulmonary veins are bluntly dissected, after initiating normothermic cardiopulmonary bypass (CPB). The patient is then cooled to 34°C and RA lesion set performed on a beating heart. A small purse-string suture at the base of the RA appendage allows one jaw of a RFA clamp to pass and create a lesion along the RA free wall (**Figure 5**). A vertical atriotomy extending from the intra-atrial septum up towards the atrioventricular

Figure 5.
Radiofrequency surgical ablation clamp performing right sided pulmonary vein isolation [106].
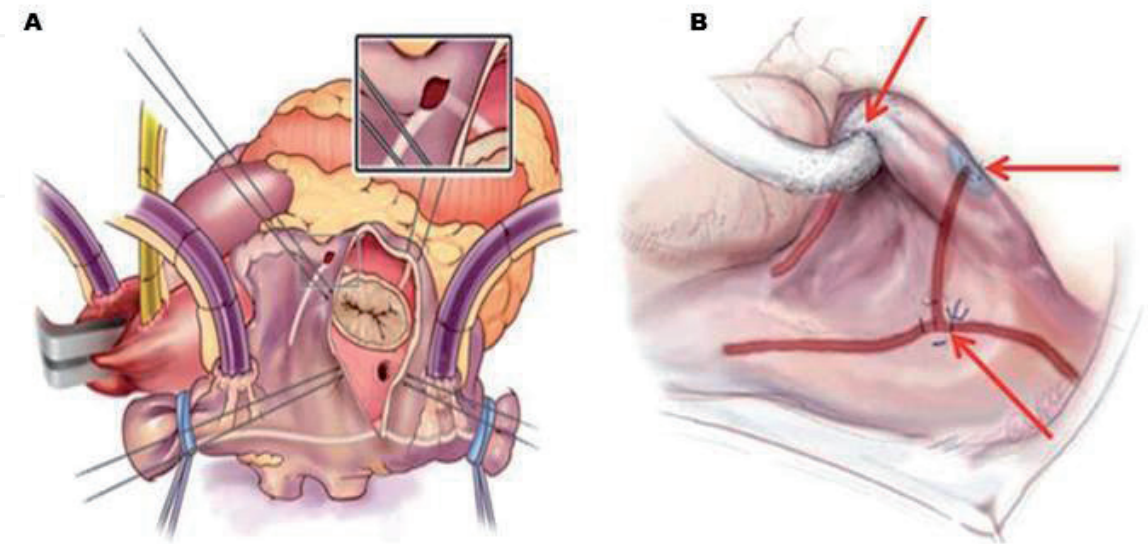
groove near the free margin of the heart is made at least 2 cm from the free wall lesion. From the inferior aspect of the incision, the RFA clamp then creates ablation lesions extending to the SVC and down towards the IVC. A linear cryoprobe is used to create an endocardial ablation on the tricuspid annulus at the two o'clock position. The cryoprobe is placed through the previously placed purse-string suture and an endocardial ablation is performed down to the 10 o'clock position on the tricuspid valve. When using a right mini-thoracotomy, the atriotomy is replaced by two additional purse-strings; one just above the intra-atrial septum midway between the SVC and IVC and one just next to the atrioventricular groove (**Figure 6**).

The LA lesion set is then performed under cardioplegic arrest. The LAA is amputated and the RFA clamp passed through to create a connecting lesion into the left superior pulmonary vein. The coronary sinus is marked with methylene blue at a point between the left and the right coronary arteries. A left atriotomy is performed and the posterior LA isolated using the RFA clamp both inferiorly and superiorly to connect the atriotomy to the previously made left pulmonary vein lesion (**Figure 7**). From the inferior part of the atriotomy an ablation lesion towards the mitral annulus is created. This lesion crosses the coronary sinus between the right coronary artery (RCA) and the circumflex artery. Cryoablation is then used to bridge the 2 cm gap from the end of the RFA lesion to the mitral valve annulus. Completion of the LA lesion set is carried out by cryoablating the coronary sinus in line with the isthmus lesion on the epicardial surface [30].
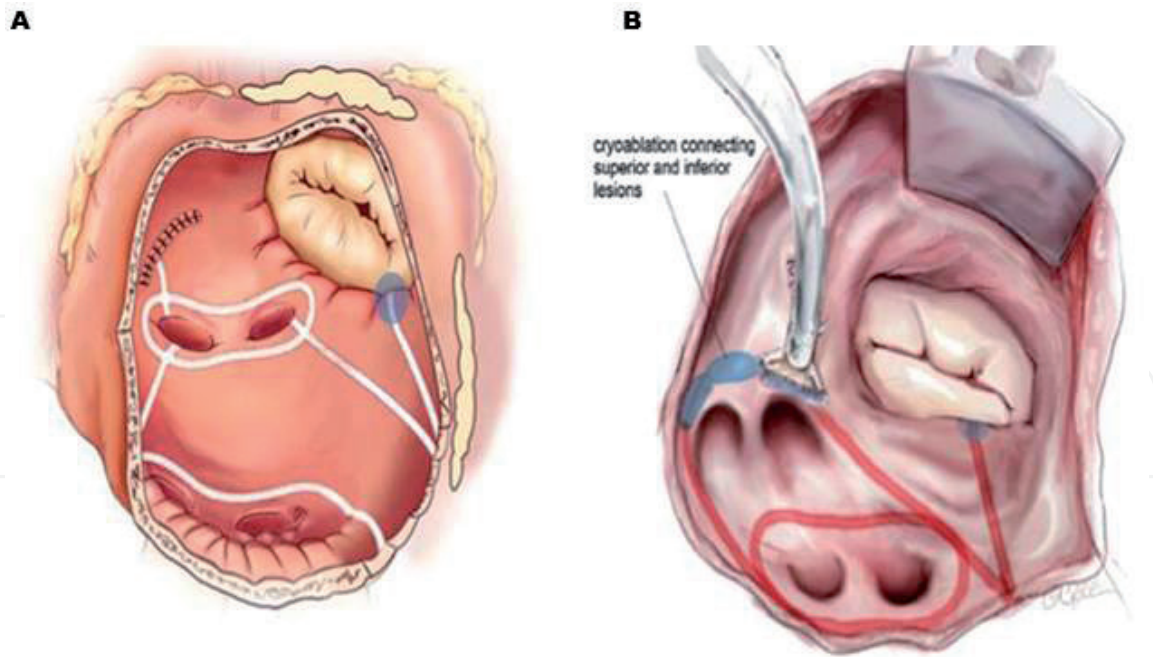
4.1 Thoracoscopic surgery

The MAZE IV is regarded as the gold standard surgical treatment for AF. However, the surgery although highly effective is quite invasive with related complications. Therefore, the totally thoracoscopic ablation procedure is gaining support as a minimally invasive alternative, and being performed both in a non-hybrid or (staged) hybrid setting. A large variety of thoracoscopic approaches are now established and regarded as safe [31] (**Figure 8**). Totally, thoracoscopic LA 'MAZE' procedures and PVI are described [32]. The procedures can be performed

Figure 6.
Right atrial lesion sets for MAZE IV procedure. (A) Majority of linear lesions are created using bipolar radiofrequency clamps, and blue shades represent cryoablation lesions placed at two points on the tricuspid annulus through direct vision or small purse-string sutures (red arrows). (B) Linear lesions also can be created with cryoablation if required for mini-thoracotomy. Right atrial lesion set consisting of an ablation line along the SVC and IVC, ablation along the RA free wall with line to tricuspid valve annulus [106].
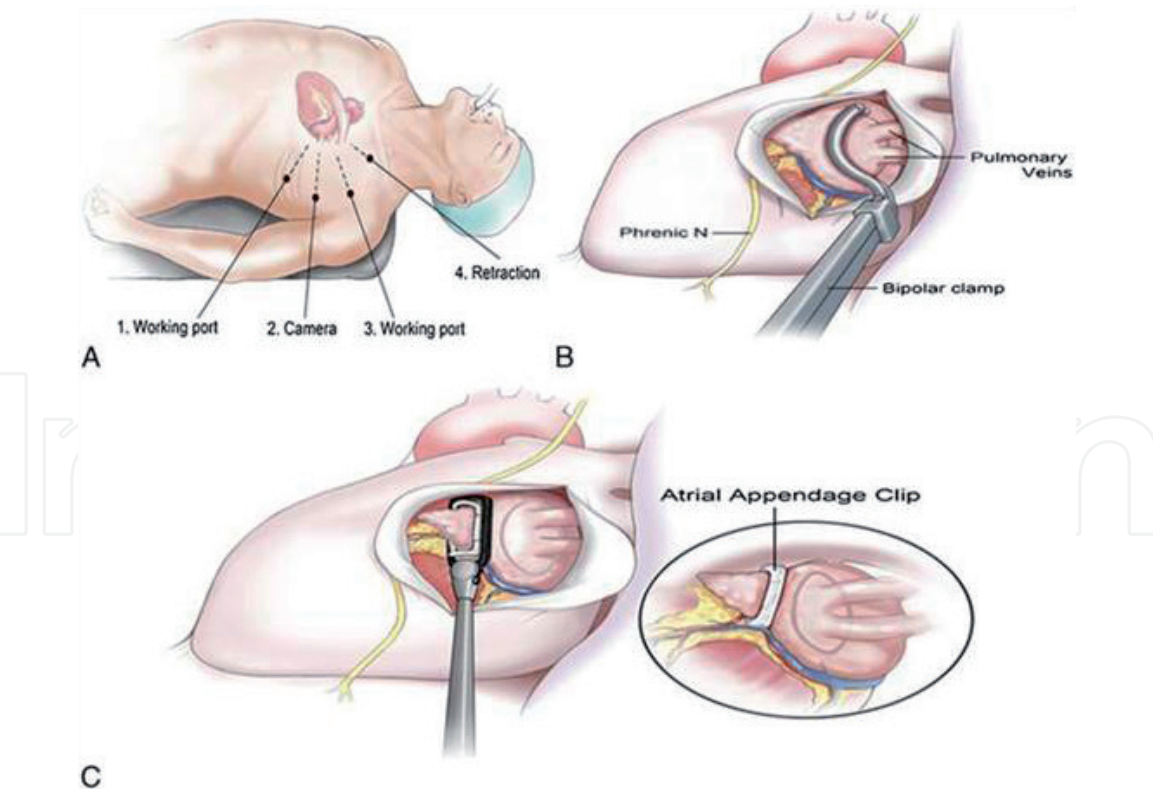
Figure 7.
Left atrial lesion sets for MAZE IV procedure. (A) Majority of linear lesions are created with bipolar radiofrequency clamps. Blue shades represent cryoablation lesions at the mitral isthmus and left pulmonary veins (minimally invasive approach). (B) Linear lesions can also be created with cryoablation if required for mini-thoracotomy. Left atrial lesion set consisting of bilateral PVI, pulmonary vein roof and floor connecting lesions, lesion from LSPV and amputated LAA, and lesion from inferior atriotomy to mitral valve annulus [106].

Figure 8.
Thoracoscopic PVI and LAA occlusion procedure. (A) Patient position and ports on left side. (B) Bipolar ablation clamp being placed around pulmonary vein hilum. (C) Clip being placed at the base of the left atrial appendage [107].

using three ports on both sides. On the right side, the pericardium is opened anterior to the phrenic nerve, followed by exploration of Waterston's groove for subsequent positioning of the ablation device. Prior to PVI, ganglionic plexus location is

performed using a transpolar pen and high frequency pacing. A positive plexus location is ablated for 20 s with the transpolar pen. High-frequency pacing is again performed to confirm successful ganglionic plexus ablation, and repeated if necessary. After isolating the right pulmonary veins, some techniques include making a trigonum line. From the trigonum line, a separate lesion is made to the LAA. Blunt dissection around the PVs is performed using a dissector and PVI achieved by bipolar RFA ablation clamp. A minimum of three overlapping ablation lesions are performed at the antrum of the right PVs. Conduction block is confirmed, by the absence of PV potentials if AF is present; and by pacing if SR is present. Ablation is repeated if necessary. Both a roof line and a floor line are created with a linear pen, making up the box lesion. Left sided procedure is then carried out in a similar fashion; the pericardium is opened posterior to the phrenic nerve and ligament of Marshall divided. The LAAO is amputated/occluded by a verity of techniques [32, 33].

However, review of 14 thoracoscopic studies shows that a wide variety of lesion sets are used, most frequently the trigone line, connecting the roof line with the left fibrous trigone; the LAA line, connecting the superior PVs with the LAA; and the bi-caval line [31]. Most described techniques employ bipolar RFA.

4.2 COBRA Fusion device

There are many suitable types of minimally invasive ablation devices on the market and the box lesion technique is used in most of them. One such novel device is the COBRA Fusion device. For this device the transverse and oblique sinuses are bluntly dissected, along with the layer of fat in the area of the interatrial groove and transverse sinus. A special introducer, with a magnetic tip, is inserted into each sinus to meet behind the heart and form a loop, and the COBRA Fusion 150 (Estech, San Ramon, CA) ablation catheter is then connected to the introducer and pulled around the PVs (**Figure 9**).

Contact between atrial tissue and the catheter is then achieved using a unique suction device, with a target of suction of −500 mm Hg. The catheter uses unipolar and bipolar RFA to create lesions. The RFA is applied in 2 steps using temperature-control using a setting of 70°C for 60 s. Following this first cycle, the catheter is moved circumferentially to complete the box lesion and a second cycle of energy, both mono- and bipolar is applied. The continuity of lesion is checked visually in a reachable area, and a third overlapping ablation lesion performed if the line of the box lesion appears non-continuous. This third ablation is usually needed between the right superior pulmonary vein and the right inferior pulmonary vein mainly in patients with a large LA. In addition to visual inspection of the lesion line, in patients

Figure 9.
COBRA Fusion surgical ablation device. A versatile and flexible design for epicardial ablation [105].

in SR exit block can be routinely tested by pacing the right PVs and the adjacent posterior LA, and another ablation performed if necessary. Of note however, successful box lesion isolation is only achievable in a minority of patients (<50%) [34].

5. Evidence and guidelines supporting surgical ablation

The majority of high-quality RCTs and meta-analyses of surgical ablation are weighted towards, but not confined to concomitant mitral procedures. As compared with patients in SR, those with AF tend to be older and to have worse baseline risk profiles. High baseline risk influences the decision not to perform concomitant ablation, nevertheless, the majority of studies advocate that worse risk profiles are not a contraindication to surgical ablation [35]. It is established that surgical ablation for AF can be performed without additional operative risk of mortality or major morbidity [35, 36]. Indeed, recent US registry data suggests that surgical ablation is associated with reduced mortality in multiple valve populations [37]. Currently, US guidelines recommended concomitant ablation during mitral surgery (Class 1, Level A), AVR, isolated CABG, and AVR + CABG (Class1, Level B) [35].

Surgical ablation for symptomatic AF in the absence of structural heart disease, refractory to medical therapy or catheter-based therapies, receives a class II recommendation as a primary stand-alone procedure (Level B). In addition, surgical ablation for symptomatic persistent or long-standing AF in the absence of structural heart disease is deemed reasonable as a stand-alone procedure, using the MAZE III/IV in comparison to PVI alone (Class IIA, Level B). Current literature shows that few technical restrictions are present opposing surgical ablation at the time of open atrial operations, and most studies agree that AF incidence is approximately halved, with this benefit maintained at 1 year [35, 37].

5.1 Safety and efficacy of surgical ablation

Clear direct demonstration of survival benefit following surgical ablation is not straight forward, due to heterogeneous study groups, follow-up periods and limited sample sizes. However, a clear link between restoration of SR and survival is verified in the literature. Regardless of survival benefit, long-term quality of life improvement following surgical ablation has been demonstrated by many, but not all studies [38, 39]. Surgical ablation does not abolish stroke risk, but has been associated with reduction in long-term stroke risk.

Surgically untreated AF correlates with increased morbidity and mortality following AVR [40], and freedom from AF is greater after concomitant surgical AF ablation [35]. Reluctance to open the atria during AVR and or CABG discourages full MAZE procedures, and less extensive/invasive epicardial ablative methods are often favoured. Therefore, the potential consequences of non-adherence to the strict MAZE principles outlined earlier, on outcomes must be appreciated. As such, SR recovery appears to be greater with bi-atrial MAZE procedures compared to PVI alone during CABG and or AVR [41, 42]. As with mitral surgery, performing the MAZE procedure during AVR and/or CABG surgery is also established to be safe [43]. SR restoration rates greater than 95% at 5 years have been reported following MAZE procedure and CABG, and concomitant PVI with CABG improves restoration of SR in paroxysmal AF, with SR rates greater than 85% at 18 months [41, 44]. The efficacy of surgical ablation following AVR and or CABG has been shown to be at least equivalent to, if not superior to that following mitral surgery [35, 45].

The European guidelines also advocate concomitant AF ablation during cardiac surgery and agree its safety [46, 47]. A variety of Class II recommendations are

made [46]: (A) MAZE surgery, preferably bi-atrial, is recommended in symptomatic patients undergoing cardiac surgery to improve symptoms attributable to AF, balancing the added risk of the procedure and the benefit of rhythm control therapy. (B) Concomitant bi-atrial MAZE or PVI may be considered in asymptomatic AF patients undergoing cardiac surgery [48].

In stand-alone surgery, MAZE procedure via mini-thoracotomy or thoracoscopic PVI have shown success rates ranging from 60 to 85% at 1 year, and success following failed catheter ablation [49, 50]. European guidelines are positive, expressing that isolated epicardial PVI via minimally invasive surgery, OR MAZE surgery potentially using a minimally invasive approach should be considered, in patients with symptomatic refractory AF and failed catheter ablation.

Thoracoscopic ablation may be more effective in restoring SR than catheter ablation in selected patients, although rate of complications is higher in the surgically group [51, 52]. With ever improving ablation technology and surgical instrumentation, the ability to perform larger lesion sets via a minimally invasive approach is likely to increase; and lead to expansion in the use of stand-alone AF surgery, and hybrid surgical-electrophysiological ablation. Data relating to hybrid procedures is encouraging, with success rates greater than 80% at 1 year [53, 54]. Long procedure times currently impede greater use, and more evidence is required to define optimal patient selection and long-term efficacy.

5.2 Limitations of evidence

The data discussed thus far is encouraging for surgical AF ablation. However, it is impossible to draw firm conclusions from the large amount of data relating to surgical AF ablation, with relation to survival, and definitive conclusions relating to efficacy, are hampered by the multi-level heterogeneity, with respect to lesion set performed, nature/duration of AF, patient population, follow up duration and definition/assessment of rhythm outcomes. Satisfactorily sized randomised trials, with standardised lesion sets, energy devices, uniform follow-up and rhythm assessment are needed to provide high level evidence; and are in progress.

A recent Cochrane review of 22 published trials concluded for patients with AF undergoing cardiac surgery, that concomitant AF surgery doubles the rate of freedom from AF/atrial arrhythmias while increasing the risk of permanent pacemaker (PPM) implantation. However, the authors described the available evidence as only moderate quality, and concluded that effects on mortality were uncertain. Significant heterogeneity was encountered amongst studies, but safety, stroke risk, and health-related quality of life were not affected by concomitant surgical AF ablation. No benefit of one type of AF ablation over another was demonstrated [47]. All included studies were rated as being at a high risk of bias in at least one assessed domain. The recently published AMAZE randomised trial from Papworth, re-established that surgical ablation increases the proportion of patients in SR at 12 months and 24 months: 61.5% versus 46.9% and 58.5% versus 36.4%, respectively. The trialists concluded that surgical ablation was safe, but it did not improve quality of life or survival at 2 years, a relatively early time point. There was no significant difference in stroke-free survival, in serious adverse events, operative or overall survival, cardioversion or PPM implantation [55]. A major limitation of this study is that lesion sets were *not* standardised between surgeons. The longer-term results are awaited.

5.3 Pulmonary vein isolation versus MAZE procedure

The majority of surgical ablation studies in stand-alone AF have employed minimally invasive approaches; most frequently thoracoscopic off-pump RF PVI

plus LAA amputation. Overall rates of freedom from AF of approximately 70–85% are reported at 12 months. Most studies, but not all, show conversion rates to be higher in paroxysmal AF than persistent AF when using PVI [56–58]. It is generally accepted that PVI is a reasonable treatment for paroxysmal AF with freedom rates of 70% reported at 5 years [59]. Direct randomised comparison between PVI and MAZE procedures is hard to find, with studies displaying marked heterogeneity.

In non-paroxysmal AF, PVI alone does not seem to be sufficient for maintenance of SR. In permanent AF patients with LA dilatation and valvular disease, additional lesions seem necessary. Systematic review of multiple studies shows that isolated PVI, has inferior efficacy to on-pump endocardial MAZE procedures, in patients with stand-alone AF, with a clear advantage of performing additional atrial lesions [60]. These effects are echoed in non-stand-alone AF. In a recent study of 260 patients undergoing mitral valve surgery, with pre-dominantly non-paroxysmal AF, patients underwent surgical ablation with either PVI or biatrial MAZE, or mitral valve surgery alone. At, 12 months post-surgery, both ablation groups showed lower rates of AF than those undergoing mitral valve surgeries alone. A higher rate of AF was seen in the PVI group compared to biatrial MAZE (36% versus 23%). The aim of this study was primarily to assess a novel rhythm monitoring strategy post-surgery, and not lesion set comparison. The trial was not powered to detect a difference between the PVI and biatrial MAZE, but re-enforced other studies findings that a more complete lesion set may be superior in restoring SR, in patients undergoing mitral valve surgery [61]. In patients undergoing aortic or mitral valve surgery with permanent AF, PVI alone has been shown to be significantly inferior to PVI + additional LA lesions in restoration of SR; 25% versus 86% at 2 years [62]. This study along with others has demonstrated via electrophysiological mapping that complete continuous isolation of the pulmonary veins is often not achieved during surgical ablation. In a combined population of paroxysmal and persistent AF patients undergoing the Cox-Maze IV procedure, superior freedom from AF was obtained when patients received complete posterior LA isolation via a box-lesion, compared to a line between the inferior PVs only. Patients received a variety of concomitant procedures in this study including; CABG, mitral valve repair, tricuspid valve replacement, closure of patent foramen and aortic valve replacement [63]. Gillinov et al. showed in a randomised mitral valve surgical population with persistent or long-standing persistent AF that surgical ablation significantly improved freedom from AF at 1 year [64]. In a sub-set analysis they showed that PVI alone in comparison to biatrial lesion set creation appeared to show equivalent results; approximately 60% freedom from AF at 1 year. The authors have commented that the study was not adequately powered to show a difference between the two ablation sets, and emphasised the need for larger randomised studies to explore this question. This study has also received criticism for the relatively low percentage use of bipolar RFA in the PVI group (43%), relatively low success rate of freedom from AF at 1 year (60%), and the creation of biatrial lesion sets that did not strictly adhere to the true MAZE concept. The latter criticism, coupled to the factor that adequacy of PVI was confirmed electrophyisologically intra-operatively, may have led to the enhanced efficacy of PVI seen in this study, in this population.

5.4 Post-operative and peri-operative drug therapy

5.4.1 Anticoagulation

Following surgical AF ablation, full anticoagulation is common and reasonable until durable restoration of SR is proven, as long as safety criteria for anticoagulation are met. Anticoagulation is usually continued until stable SR is documented by

the very least 24-h Holter monitoring. The time point at which monitoring should be conducted is debated, but is commonly at the 6 month follow up point, but many advocate rhythm monitoring at 1 year or beyond, and at multiple time points to capture late recurrence [35]. Sensible practice also recommends an echocardiogram before discontinuing anticoagulation to confirm adequate LA emptying.

5.4.2 Anti-arrhythmic therapy

There are currently no guideline recommendations for specific anti-arrhythmic drug therapy following surgical ablation. Randomised, controlled, prospective data relating to this question is lacking and is desirable. As discussed earlier there is marked heterogeneity between surgical ablation studies, and this extends to definition of AF recurrence, rhythm assessment protocols and also anti-arrhythmic therapy. Forming firm conclusions based on these studies relating to optimal drug therapy regimens, would be non-scientific and inappropriate. For example, in the recently performed AMAZE trial, amiodarone use in the post-operative period was standardised; however, beta blocker use was left up to the discretion of treating teams [55].

Overall, anti-arrhythmic drug therapy is commonly given for 8–12 weeks after catheter or surgical ablation to reduce early AF recurrence. In addition, a 3 month immediate 'blanking period', in which rhythm assessment is not performed, is usually employed. A recent controlled trial in a catheter ablation population showed that amiodarone halved early AF recurrences compared with placebo [65].

The ESC guidelines on the management of AF raise the concern that prospective studies are lacking with relation to anti-arrhythmic therapy post-catheter ablation, and available evidence is weak [46]. They conclude that better AF prevention is afforded after catheter ablation with anti-arrhythmic therapy, and this represents reasonable practice. Review of the literature relating to surgical ablation reveals that this sensible practice is employed almost universally. AF conversion is generally measured by the percent of patients off class I or III antiarrhythmic drugs and free of atrial tachyarrhythmia at 3, 6, 9, 12, and 24 months postoperatively. Recurrence is generally defined as any atrial tachyarrhythmia lasting longer than 30 s on a 24-h Holter monitor recording 6 months after surgical ablation. Amiodarone is the most commonly used drug for enhancing rhythm control post-surgical ablation, although routine use is not universal. Concomitant use of beta-blockade is common, although, not always routine. A multitude of data exists relating to the likely benefits of statins, amiodarone and various other drug regimens in the prevention of post-operative AF during routine cardiac surgery. To extrapolate this data to the surgical AF ablation population is reasonable. However, detailed, controlled studies are needed to define the precise short and long-term impact of drug therapy following surgical ablation procedures. Specific delineation of differences between different populations, e.g. CABG versus valvular disease groups, and differing drug regimens is necessary, but maybe challenging. The lack of definite evidence relating to drug therapy is reflected by the STS recommendation for multidisciplinary heart team assessment and long-term follow up to optimise outcomes of surgical ablation for AF [35].

5.5 Animal studies

Safety and feasibility of surgical ablation technology and techniques was first explored in animal studies. The animal studies described here, stem from the efforts made to firstly (A) transition away from the traditional, technically demanding cut and sew MAZE procedure, as well as to (B) develop quicker, less invasive, +/− beating heart, surgical ablation techniques.

The limitations of animal studies with relation to extrapolation of efficacy to humans must be borne in mind. There are known differences in atrial tissue and epicardial fat thickness, between the various used animal species and humans. Atrial thickness in the domestic pig is similar to that of the human, but levels of epicardial fat in the human are significantly greater, and so too is the thickness of diseased human atria [66]. In addition, electrophysiological differences with relation to impulse generation and AF pathophysiology, varies between animal species and humans. As with human studies, a multitude of devices and lesion sets have been employed, utilising both normal and chronically fibrillating hearts, precluding direct meaningful study comparison. As such, specific animal studies clearly demonstrating efficacy of the MAZE procedure in restoration of SR are lacking. Overall, animal studies are best regarded as the preliminary studies that proved concept, safety and feasibility of surgical ablation in humans. They crucially provided the anatomical basis, technological characteristics/limitations, mechanistic insights and electrophysiological knowledge, which allowed informed ablation use in humans.

An early sheep study clearly established RFA to produce equally effective lesions to the cut and sew surgical technique. The RFA technique was shown to be significantly faster than incision technique with equivalent safety. In this 18 sheep, on-CPB endocardial ablation study, adequate lesion transmurality was demonstrated using pacing at both acute and chronic (1 month) time points. The lesion set performed was similar but not identical to the classical MAZE procedure, and this study amongst others established RFA to be a simple, time saving alternative to surgical incisions during open heart MAZE procedures [67].

Examination of a variety of ablation technology devices, in various porcine beating heart ablation models, highlighted large variation in their ability to achieve transmurality [66]. The majority of devices failed to achieve full thickness lesions, a factor along with lesion continuity that has proven critical in preventing AF recurrence. Overall, the most consistently reliable devices for creating transmural lesions were demonstrated to be bipolar RFA clamps [68]. Although, highly reliable when performing PVI, use in creating intra-cardiac lesions during beating heart surgery is restricted to the right side, due to potential catastrophic effects of air embolism on the left. As such, the majority of beating heart animal studies study epicardial devices. Porcine studies amongst others, helped delineate the challenges facing surgical epicardial ablation. These included variability of atrial wall muscle thickness and epicardial fat distribution, enhanced heat insulation by fat, and circulating intra-cavitary blood action as a potential heat sink [66]. These studies also identified the anatomical variation in reliability of transmurality achievement. Zones of difficulty, over Bachmann's bundle, crista terminalis and at the mitral or tricuspid annuli, LAA and RAA were identified, along with zones of higher success around the pulmonary veins [69].

Acute and chronic studies using bipolar RF epicardial lesions have established that they do not significantly change pulmonary vein flow, nor cause significant acute or chronic pulmonary vein stenosis [68, 70]. In addition, pacing and epicardial mapping have both confirmed consistent, successful bidirectional isolation, with the real-time tissue conductance assessment, being able to reliably predict short and long term transmurality. Histologic examination re-enforced safety, showing safe discrete lesions without evidence of stricture, or aneurysm formation [70].

6. Complications of atrial fibrillation surgery

A disputed aspect surrounding surgical AF ablation is that of the relationship to PPM insertion. The rate of PPM insertion following surgical AF ablation varies

between 6% and 19%. The relationship is unclear, large meta-analyses comparing PPM insertion rates have demonstrated no significant increase in post-operative PPM requirement during concomitant AF ablation [48], yet a Cochrane review has demonstrated an increased requirement [47]. There is a presumed association between RA lesions and PPM implantation, and indeed a recent meta-analysis demonstrated that bi-atrial AF ablation surgery was associated with increased PPM insertion compared to isolated LA ablation [71]. Although not universal, most clinical studies show the increased need for PPM after AF ablation surgery to be driven mainly by sick sinus syndrome [9]. A proposed possible explanation is that of unmasking preoperative sinus node dysfunction. However, due to a multitude of confounding variables and lack of accurate reporting of preoperative data, it is not possible to precisely establish a causal mechanism.

As discussed earlier, despite increased CPB time and hospital length of stay, in the modern era, concomitant surgical AF ablation is regarded as safe, with no increase in mortality demonstrated [47, 72]. In addition, most studies demonstrate no increase in peri-operative stroke [47, 72]. Overall, the frequency of cardiac tamponade, pericardial effusion, myocardial infarction and re-operative bleeding does not appear to increase following concomitant surgical AF ablation [47, 72]. With relation to minimally invasive MAZE procedures and surgical AF ablation for stand-alone AF, safety is also acceptable. Minimally invasive epicardial surgical ablation is perceived to be safer than the endocardial MAZE procedure, because the former requires smaller incisions and does not require CPB. However, no statistically significant difference in mortality has been demonstrated [73]. Mortality rates of less than 0.5% are reported [60]. Results vary and are technique dependent, with some analyses showing lower re-operative bleeding rates and conversion to sternotomy with minimally invasive endocardial MAZE procedure [60], and others favouring minimally invasive epicardial surgical ablation without the use of CPB [73]. Similar conflicting results are noted with respect to the incidence of renal failure and hospital length of stay. As mentioned earlier, controlled studies are required to precisely delineate relationships between efficacy and safety of various minimally invasive techniques.

6.1 Predictors of AF recurrence following surgical ablation

Great efforts have been directed towards identifying predictors of AF recurrence, but have been hampered by the heterogeneity of studies with relation to ablation set, AF characteristics, rhythm assessment and pharmacological regimens, amongst other variables. Risk factors for recurrence are broadly classified into pre-operative variables and intra-operative variables. Preoperative variables associated with AF recurrence include increasing LA diameter [15, 74, 75], age [76], and prolonged pre-operative duration of AF [75, 76]. In an excellent 280 patient prospective study, Damiano et al. showed in patients with both paroxysmal AF and persistent AF three risk factors for AF recurrence following the MAZE IV procedure: increasing LA size, early post-operative AF and failure to anatomically isolate the entire posterior LA [15]. LA size of over 8 cm being has been shown by the same group to correlate with a >50% chance of AF recurrence. Gillinov et al. also showed in approximately 260 patients undergoing the cut and sew MAZE III procedure and mitral valve surgery, in a cohort of predominantly permanent AF patients, that risk factors for AF recurrence included longer duration of AF, larger LA diameter, older age, and higher left ventricular mass index [76]. *In a systematic review involving 5200 patients from 19 studies the authors showed that AF recurrence after surgical ablation was again most often predicted by LA size, duration of AF and age [75]. They also concluded that the* innate heterogeneity of published data precluded a meta-analysis

for predictors of surgical ablation success, and highlighted the need for consistent and reliable outcome predictors, and a standardised system of measurement for clinical parameters.

Impact of intra-operative variables such as energy source and lesion set are a contested area. Again, heterogeneity of studies hinders comparison. Overall it is difficult to demonstrate that use of various energy sources affects AF recurrence rates. Similar long-term success rates have been observed with either uni- or bipolar RFA and cryoablation [77], yet both superiority of either bipolar RFA [78] or monopolar [79] has been shown in different studies. Although not certain, the bi-atrial lesion set appears to display superiority to isolated LA lesion set in prevention of AF recurrence [78, 80]. In addition, modifiable risk factors such as hypertension, diabetes and smoking are implicated in surgical ablation failure [81].

7. Surgical versus catheter ablation

Catheter ablation is highly effective for the treatment of symptomatic, drug refractory AF. The reported efficacy for catheter ablation varies widely, although freedom from AF of up to 70% is reported, with worldwide registry data showing a procedural major adverse event rate of ~ 4.5%. Catheter ablation for the treatment of AF is currently recommended by guidelines as a second-line therapy in patients with paroxysmal and persistent AF after treatment with ≥1 antiarrhythmic drug has failed (Class I recommendation for paroxysmal AF, Class IIa for persistent AF, and Class IIb for long-stranding persistent). Most randomised controlled trials (RCTs) of drug therapy versus catheter ablation have studied patients with pre-served left ventricular function [82]. Recently, RCTs have also shown the benefit of rhythm control with catheter ablation over medical therapy for AF associated with heart failure [83]. A recent meta-analysis examining six RCTs confirmed these findings demonstrating catheter ablation to be superior to medical therapy for AF in patients with HF, resulting in greater improvement in LVEF, quality of life and functional status, with a definite survival benefit [84]. Results from the recent CABANA trial also echo these positive catheter ablation effects in HF patients [85]. Although variable, a pooled freedom from AF of 71% was seen in this analysis.

There is not much direct comparison of surgical ablation versus catheter ablation in the literature. The FAST study included 124 patients with drug–refractory AF, LA dilatation and hypertension or failed prior catheter ablation. Patients were randomised to either catheter ablation or thoracoscopic surgical ablation. Catheter ablation consisted of linear antral PVI and optional additional lines. Surgical ablation consisted of bipolar RF PVI, ganglionated plexi ablation, and LAA excision with optional additional lines. Freedom from AF was superior for surgical ablation at 12 months (36.5% versus 65.6%), but this was at the expense of greater rate of complications, driven mainly by pneumothorax, major bleeding, and the need for PPM [52]. A meta-analysis of eight studies showed that thoracoscopic surgical ablation showed significantly greater freedom from AF at 12-months compared to catheter ablation (78.4 versus 53%), with a reduced requirement for repeat ablation [86]. This superiority was maintained in paroxysmal and persistent AF subgroups. However, again, complications were shown to be considerably higher in the surgical group, driven mainly by pleural effusion and pneumothorax. Limitations of the data were the retrospective nature of some of the included studies and the heterogeneity of patients involved.

The superior efficacy demonstrated by surgical intervention is postulated to be due to several factors [86]. The ablation lesion set employed with surgery is generally much more extensive including PVI, but also targeted epicardial ganglionic plexi, LAA excision and additional LA lines. The importance of ganglionic plexi

and the LAA in perpetuating AF re-entrant circuits is well recognised [87, 88]. In catheter ablation relative inadequate treatment may be occurring, as additional ablation lines are often not performed, with endocardial lesions consisting of PVI using wide-area antrum ablation alone. In addition, a better ability of surgical technology to create adequate transmural lesions may underlie its superior efficacy.

Debate continues regarding the optimal lesion set for stand-alone surgical abla-tion. Specifically, the comparative efficacy of strategies of PVI versus extended LA lesion sets, or MAZE IV approach remains unknown, and requires further study. Further controlled studies are also needed to delineate the apparent supremacy of surgical ablation over catheter ablation. However, concerns relating to the higher rate of complications and prolonged length of stay of the more invasive surgical approach currently impede adoption of its use on a broader scale. The majority of these complications are non-severe and managed conservatively, and whether such this level of apprehension is justified is unclear. Surgical ablation is increasingly performed as a stand-alone procedure and with improving technology and surgical skill its use is likely to expand with time, either on its own or as part of a hybrid electrophysiological approach.

7.1 Electrophysiological mapping

Unfortunately electrophysiological evaluation after bipolar RF PV isolation has been scarcely performed. Only a small minority of surgical ablation studies have per-formed detailed intra-operative or peri-operative validation of ablation sets [64]. It is clear that confirmation of adequacy of ablation transmurality and continuity impacts upon surgical ablation efficacy and subsequent AF recurrence rate [89, 90]. Several factors oppose routine electrophysiological validation of ablation including; (A) technically challenging to adequately pace in between instead of on the performed ablation lines, (B) time consuming to perform correctly; with epicardial lesions, at least 20 min between PV isolation and endocardial validation is needed and (C) pre-cise delineation of the border between conducting and non-conducting tissue at the distal sleeve of the PV is sometimes difficult to perform without complex mapping techniques. In its simplest form following PVI, entrance block is defined as failure to capture the PVs during pacing from the LA, and exit block can be defined by failure to capture the LA, when pacing from the PVs distal to the RF lesions.

Following minimally invasive PVI, recurrence rates as high as 40% have been seen despite intra-operative electrophysiological validation. Repeat electrophysi-ological investigation shows the vast majority are due to PV reconnection. In mini-MAZE [90] and total thoracoscopic procedures [91] intra-operative electro-physiological validation has been associated with higher success rates of 84% and 93% at 24 and 12 months respectively, in mixed AF populations. Sophisticated 3D electrophysiological mapping again showed recurrence was secondary to PV gaps in 50% of patients, with ectopic foci in LAA, peri-mitral LA roof flutter in the remain-der. Post-operative recurrence is generally amenable to catheter ablation, with good intermediate-term success [92]. These findings re-enforce the growing belief that the hybrid ablation approach, either immediate or staged will produce the best long term ablation outcomes. Augmented success rates with a combined staged hybrid approach have been achieved, with a required catheter-based 'touch up' rate of approximately 20% following surgical intervention [93].

The predominant factor in AF recurrence post-ablation is PV reconnection or incomplete isolation. Several reasons for the gaps around the PVI ring are impli-cated: (A) clamp application failure over the roof of the superior PVs, (B) incom-plete clamping at the bottom of inferior PV, (C) clamp application failure at the antral side of the PV due to the long distance between the superior and inferior PVs,

or accessory PVs and (D) increasing LA size. Multiple reasons for improper clamp application and diminished RFA effect are also cited including (A) angulation of clamps rather than perpendicular placement; (B) blood within the PVs limiting tissue involution between the clamps on beating hearts; (C) clamp movement during beating heart ablation; (D) the cooling effect of circulating blood and (E) anatomic factors such as atrial folds, ridges and variable myocardial thickness.

Improving the quality of the lesion set, will undoubtedly improve durability and success of surgical ablation; and better intra-operative electrophysiological mapping strategies represents a good target to focus upon. It is clear that simple entrance and exit block confirmation has a false negative rate, most likely related to tissue oedema, trauma and ischaemia, and the optimum universal mapping technique and strategy is not established. Randomised controlled studies with detailed electrophysiological interrogation follow up, are needed to identify this technique and strategy and then standardise their application, and improve surgical lesion set creation.

8. Left atrial appendage intervention

LAA exclusion or occlusion LAAO can be safely performed. Growing interest in LAA intervention has been driven by the observation that 90% of thrombi in non-valvular AF (NVAF) and 60% of those in valvular AF develop in the LAA. LAAO by surgical excision or device occlusion is postulated to reduce the risk of stroke, peripheral thromboemboli, and necessity for oral anticoagulants. Surgical techniques available to isolate the LAA include LAA excision with amputation, or occlusion which can be performed endocardially or epicardially. LAAO can be performed using an implantable device or without. Non-device approaches include surgical two-layer closure with running or mattress sutures, stapling and excision, and placement of surgical purse-strings or clips around the LAA base. Success is dependent on total LAA excision or isolation. Any residual stump of the LAA >1 cm in length, or gap with associated blood flow is thrombogenic [94]. LAA exclusion however has been inconsistent in terms of techniques, rates of complete exclusion, and thus adoption. Studies comparing internal ligation, external staple excision and surgical excision show that complete LAA elimination should not be assumed. Initial stump-free elimination can deteriorate with time, and a residual stump can be immediately present, emphasising the importance of immediate and late echocardiographic interrogation of LAA intervention [95].

8.1 Left atrial appendage devices

A variety of devices exist. The most widely used endocardial device is the Watchman device, which is a percutaneously delivered polyester fabric on a nitinol frame (**Figure 10**). The Lariat device utilises a combined percutaneous and epicardial approach to deliver a lasso around the appendage guided by an intraluminal magnet tip. The AtriClip is made of two polyester-covered parallel tubes with nitinol springs (**Figure 11**). The AtriClip is a self-closing clamp placed epicardially at the base of the LAA to exclude blood flow. In general, endocardial devices remain in contact with intracardiac blood, and therefore anticoagulation for 2 months is recommended following implantation, making them less attractive for patients with contraindications to anticoagulation. Endocardial devices also fail to lie properly in LAAs with unfavourable morphologies.

The strongest evidence supporting reduction of stroke risk and potentially the elimination of anticoagulation with LAAO comes from the large, multi-centre RCT, PROTECT AF. This study used the percutaneous Watchman LAA device. After

Figure 10.
The watchman left atrial appendage occlusion device. A percutaneously delivered polyester fabric device on a nitinol frame [108].

Figure 11.
Left atrial appendage occlusion AtriClip device. Parallel titanium crossbars apply adequate pressure without crushing or damaging tissue [105].

3.8 years of follow-up in patients with NVAF at elevated risk for stroke, percutaneous LAA closure met criteria for both non-inferiority and superiority, compared with warfarin, for preventing the combined outcome of stroke, systemic embolism, and cardiovascular death, as well as superiority for cardiovascular and all-cause mortality [96].

In a large meta-analysis reviewing over 2400 patients, the efficacy of LAA closure compared to warfarin in 2 RCTS, PREVENT AF and the PREVAIL trial was analysed. At a mean follow up of 2.7 years in patients with NVAF at increased risk for stroke or bleeding, LAA intervention improved rates of haemorrhagic stroke, cardiovascular/unexplained death, and non-procedural bleeding. These positive effects were offset by an increase in ischemic strokes, mainly peri-procedural. All-cause stroke or systemic embolism was similar between both strategies. This analysis emphasised a non-inferiority of LAAO to warfarin use; with LAA intervention beneficial effects seeming to be underpinned by the circumvention of anticoagulation-related morbidity and mortality, as opposed to prevention of thromboembolism [97]. However, these positive results could not be automatically extrapolated to surgical LAA intervention.

8.2 Left atrial appendage intervention during cardiac surgery

Retrospective analysis of over 10,000 patients undergoing surgical AF ablation with and without concomitant surgical LAAO, showed only 37% underwent LAAO. Concomitant LAAO significantly reduced readmission for

thromboembolism and all-cause mortality. The additional procedure was demonstrated to be safe, but the important differentiation between technique of LAAO, nature of AF and echocardiographic parameters between groups was not made [98]. In an updated meta-analysis examining over 3600 patients from 7 studies a significant reduction in stroke, and all-cause mortality was demonstrated in patients with AF undergoing LAAO during cardiac surgery, compared to those not undergoing LAAO. Techniques of suture ligation and stapling were utilised, and a variety of post-operative anticoagulation regimens and follow up periods [99].

The best clinical evidence for LAAO devices exists for the AtriClip device (AtriCure). It is the most commonly used surgical device with over 100,000 recorded implants worldwide. It is applied with concomitant cardiac operations as well as in isolated thoracoscopic procedures safety and efficacy of the AtriClip device was evaluated in the EXCLUDE trial. In 70 patients undergoing primary cardiac operations AtriClip, demonstrated 95% successful exclusion with 98% complete LAA exclusion on CT at 3 months [100]. Success was defined as occlusion with no residual neck >1 cm and no leaks or migration. The upcoming results of the large (n = 4700) multicentre, randomised LAAOS III trial will aid in clarifying the long-term outcomes of LAAO in AF patients undergoing cardiac surgery [101].

The practice of prophylactic LAA closure in patients without AF undergoing cardiac surgery does not appear to be effective. A recent large scale, propensity-matched analysis of prophylactic LAA closure, showed that this was associated with early increase in post-operative AF and no decrease in stroke risk or mortality [102]. The ATLAS trial is now randomising patients without documented AF, at high risk for the developing post-operative AF undergoing elective cardiac surgery; to LAA exclusion with the AtriClip or no concomitant AtriClip placement. The LAAOS III and ATLAS trials are the largest trials investigating efficacy of LAA occlusion for stroke prevention at the time of cardiac surgery; and their results are eagerly awaited.

Currently, the US and the European guidelines state that it is reasonable to, or consideration should be given to, performing LAA intervention in conjunction with surgical AF ablation and during cardiac surgery, for longitudinal thromboembolic morbidity prevention (Class II, Level C/B). European guidelines also say it is reasonable to perform isolated LAA intervention in patients in AF with contraindication to anticoagulation.

8.3 Left atrial appendage intervention and anticoagulation

There is large variability in anticoagulation strategies post LAAO and surgical ablation alone with mixed-use of warfarin, NOACs and single and dual antiplatelet agents. The optimal anticoagulation therapy is still a matter of debate. Decisions regarding anticoagulation and imaging should be made and tailored to patient and procedural characteristics. The decision is often straight forward, in patients with a contraindication to anticoagulation referred for LAA exclusion. However, for patients without contraindications to anticoagulation, the decision is less simple. The Zurich group has shown in 36 patients receiving AtriClip, with a mean CHA2DS2-VASc score of 3.7, that only one transient ischemic attack (TIA) occurred after >1200 day follow up, with no strokes [98]. Three patients received anticoagulation. They have also shown a reduction in stroke risk in 291 patients with a mean CHA2DS2-VASc score of 3.1, receiving AtriClip during concomitant surgery cardiac surgery [103]. Patients that did not receive anticoagulation after LAA exclusion had a relative risk reduction of 87.5% in stroke, with an observed ischaemic stroke-rate of 0.5/100 patient-years compared with an expected rate in a group of patients with similar CHA2DS2-VASc scores of 4.0/100 patient-years. No evidence of reperfusion or residual stump was observed [104].

Evidence regarding anticoagulation management post-operatively is not robust, and further well-powered long-term evidence is needed to confidently guide anticoagulation management in patients receiving the AtriClip but have no contraindications to anticoagulation. Currently, the European guidelines recommend that patients undergoing LAA intervention remain on anticoagulation (Class 1). However, the view that anticoagulation is not needed after AtriClip application is also held by many, with single anti-platelet agent thought to be sufficient.

9. Summary and conclusions

Surgical AF ablation has evolved over the past few decades and is now safe, and associated with minimal morbidity. The gold standard lesion set remains that of the MAZE IV, yet 'lesser' lesion sets, are gaining favour within the minimally invasive, hybrid and non-hybrid treatment setting, for treatment of NVAF. It is clear that surgical ablation displays beneficial effects, but the supportive evidence is not of the highest quality, and high quality RCTS with standardised ablation sets, AF criteria and defined rhythm assessment outcomes are needed. New studies need to precisely define and quantify the role of surgical ablation on rhythm, survival, symptoms, thromboembolic risk, and the exact relationship with specific target AF populations. Similarly, high level evidence is needed to quantify the impact of LAA intervention on thromboembolic risk in AF. Identification of the optimal LAA intervention, together with clear guidance on anticoagulation is necessary.

Author details

Manoraj Navaratnarajah*, Suvitesh Luthra and Sunil Ohri
Department of Cardiac Surgery, University Hospital Southampton,
Southampton, Hampshire, United Kingdom

*Address all correspondence to: manoraj.navaratnarajah@doctors.org.uk

IntechOpen

References

[1] Xu J, Luc JG, Phan K. Atrial fibrillation: Review of current treatment strategies. Journal of Thoracic Disease. 2016;**8**(9):E886-E900

[2] Menezes AR, Lavie CJ, DiNicolantonio JJ, et al. Atrial fibrillation in the 21st century: A current understanding of risk factors and primary prevention strategies. Mayo Clinic Proceedings. 2013;**88**:394-409

[3] Svennberg E, Engdahl J, Al-Khalili F, et al. Mass screening for untreated atrial fibrillation: The STROKESTOP study. Circulation. 2015;**131**:2176-2184

[4] Heeringa J, van der Kuip DA, Hofman A, et al. Prevalence, incidence and lifetime risk of atrial fibrillation: The Rotterdam study. European Heart Journal. 2006;**27**:949-953

[5] Eguchi K, Ohtaki E, Matsumura T, et al. Pre-operative atrial fibrillation as the key determinant of outcome of mitral valve repair for degenerative mitral regurgitation. European Heart Journal. 2005;**26**:1866-1872

[6] Lim E, Barlow CW, Hosseinpour AR, et al. Influence of atrial fibrillation on outcome following mitral valve repair. Circulation. 2001;**104**:I59-I63

[7] Maan A, Heist EK, Passeri J, et al. Impact of atrial fibrillation on outcomes in patients who underwent transcatheter aortic valve replacement. The American Journal of Cardiology. 2015;**115**:220-226

[8] Geidel S, Lass M, Boczor S, et al. Monopolar and bipolar radiofrequency ablation surgery: 3-Year experience in 90 patients with permanent atrial fibrillation. The Heart Surgery Forum. 2004;7:E398-E402

[9] Gammie JS, Haddad M, Milford-Beland S, et al. Atrial fibrillation correction surgery: Lessons from the Society of Thoracic Surgeons National Cardiac Database. The Annals of Thoracic Surgery. 2008;**85**:909-914

[10] Ad N, Suri RM, Gammie JS, et al. Surgical ablation of atrial fibrillation trends and outcomes in North America. The Journal of Thoracic and Cardiovascular Surgery. 2012;**144**:1051-1060

[11] Cox JL. Atrial fibrillation II: Rationale for surgical treatment. The Journal of Thoracic and Cardiovascular Surgery. 2003;**126**(6):1693-1699

[12] Cox JL. The surgical management of cardiac arrhythmias. Cardiovascular Clinics. 1987;**17**:381-413

[13] Cox JL, Churyla A, Malaisrie SC, Kruse J, et al. When is a MAZE procedure a MAZE procedure? The Canadian Journal of Cardiology. 2018;**34**(11):1482-1491

[14] Cox JL, Jaquiss RD, Schuessler RB, et al. Modification of the Maze procedure for atrial flutter and atrial fibrillation: II. Surgical technique of the Maze III procedure. Journal of Thoracic and Cardiovascular Surger. 1995;**110**(2):485-495

[15] Damiano RJ Jr, Schwartz FH, Bailey MS, et al. The Cox Maze IV procedure: Predictors of late recurrence. The Journal of Thoracic and Cardio-vascular Surgery. 2011;**141**:113-121

[16] Johansson B, Houltz B, Berglin E, et al. Shortterm sinus rhythm predicts longterm sinus rhythm and clinical improvement after intraoperative ablation of atrial fibrillation. Europace. 2008;**10**:610-617

[17] Khargi K, Lemke B, Deneke T. Concomitant antiarrhythmic procedures to treat permanent atrial fibrillation in

CABG and AVR patients are as effective as in mitral valve patients. European Journal of Cardio-Thoracic Surgery. 2005;**27**:841-846

[18] Beukema WP, Sie HT, Misier AR, et al. Intermediate to longterm results of radiofrequency modified Maze procedure as an adjunct to openheart surgery. The Annals of Thoracic Surgery. 2008;**86**:1409-1414

[19] Chiappini B, Di Bartolomeo R, Marinelli G. Radiofrequency ablation for atrial fibrillation: Different approaches. Asian Cardiovascular & Thoracic Annals. 2004;**12**:272-277

[20] von Oppell UO, Masani N, O'Callaghan P, et al. Mitral valve surgery plus concomitant atrial fibrillation ablation is superior to mitral valve surgery alone with an intensive rhythm control strategy. European Journal of Cardio-Thoracic Surgery. 2009;**35**:641-650

[21] Basu S, Nagendran M, Maruthappu M. How effective is bipolar radiofrequency ablation for atrial fibrillation during concomitant cardiac surgery? Interactive Cardiovascular and Thoracic Surgery. 2012;**15**:741-748

[22] Camm CF, Nagendran M, Xiu PY, et al. How effective is cryoablation for atrial fibrillation during concomitant cardiac surgery? Interactive Cardiovascular and Thoracic Surgery. 2011;**13**:410-414

[23] Blomström-Lundqvist C, Johansson B, Berglin E, et al. A randomized doubleblind study of epicardial left atrial cryoablation for permanent atrial fibrillation in patients undergoing mitral valve surgery: The SWEDish Multicentre Atrial Fibrillation Study (SWEDMAF). European Heart Journal. 2007;**28**:2902-2908

[24] MacDonald DR, Maruthappu M, Nagendran M. How effective is microwave ablation for atrial fibrillation

during concomitant cardiac surgery? Interactive Cardiovascular and Thoracic Surgery. 2012;**15**:122-127

[25] Lin Z, Shan ZG, Liao CX, et al. The effect of microwave and bipolar radiofrequency ablation in the surgical treatment of permanent atrial fibrillation during valve surgery. The Thoracic and Cardiovascular Surgeon. 2011;**59**:460-464

[26] Kim JB, Cho WC, Jung SH, et al. Alternative energy sources for surgical treatment of atrial fibrillation in patients undergoing mitral valve surgery: Microwave ablation vs cryoablation. Journal of Korean Medical Science. 2010;**25**:1467-1472

[27] Kyprianou K, Pericleous A, Stavrou A, et al. Surgical perspectives in the management of atrial fibrillation. World Journal of Cardiology. 2016;**8**(1):41-56

[28] Klinkenberg TJ, Ahmed S, Ten Hagen A, et al. Feasibility and outcome of epicardial pulmonary vein isolation for lone atrial fibrillation using minimal invasive surgery and high intensity focused ultrasound. Europace. 2009;**11**:1624-1631

[29] Schmidt B, Chun KR, Metzner A, et al. Pulmonary vein isolation with highintensity focused ultrasound: Results from the HIFU 12F study. Europace. 2009;**11**:1281-1288

[30] Lawrance CP, Henn MC, Damiano RJ Jr. Surgical ablation for atrial fibrillation: Techniques, indications, and results. Current Opinion in Cardiology. 2015 Jan;**30**(1):58-64

[31] van Laar C, Kelder J, van Putte BP. The totally thoracoscopic maze procedure for the treatment of atrial fibrillation. Interactive Cardiovascular and Thoracic Surgery. 2017 Jan;**24**(1):102-111

[32] Yilmaz A, Geuzebroek GS, Van Putte BP, et al. Completely

thoracoscopic pulmonary vein isolation with ganglionic plexus ablation and left atrial appendage amputation for treatment of atrial fibrillation. European Journal of Cardio-Thoracic Surgery. 2010;**38**(3):356-360

[33] Vos LM, Bentala M, Geuzebroek GS, et al. Long-term outcome after totally thoracoscopic ablation for atrial fibrillation. Journal of Cardiovascular Electrophysiology. Jan 2020;**31**(1):40-45

[34] Osmancik P, Budera P, Zdarska J, et al. Electrophysiological findings after surgical thoracoscopic atrial fibrillation ablation. Heart Rhythm. 2016;**13**(6):1246-1252

[35] Badhwar V, Rankin JS, Damiano RJ Jr, et al. The Society of Thoracic Surgeons 2017 clinical practice guidelines for the surgical treatment of atrial fibrillation. The Annals of Thoracic Surgery. 2017;**103**(1):329-341

[36] Saint L, Damiano RJ, Cuculich PS, et al. Incremental risk of the Cox-maze IV procedure for patients with atrial fibrillation undergoing mitral valve surgery. The Journal of Thoracic and Cardiovascular Surgery. 2013;**146**:1072-1077

[37] Rankin JS, He X, O'Brien SM, et al. The Society of Thoracic Surgeons risk model for operative mortality after multiple valve surgery. The Annals of Thoracic Surgery. 2013;**95**:1484-1490

[38] Lee R, McCarthy PM, Wang EC, et al. Midterm survival inpatients treated for atrial fibrillation: A propensity-matched comparison to patients without a history of atrial fibrillation. The Journal of Thoracic and Cardiovascular Surgery. 2012;**143**:1341-1351

[39] Attaran S, Saleh HZ, Shaw M, et al. Does the outcome improve after radiofrequency ablation for atrial fibrillation in patients undergoing cardiac surgery? A propensity-matched comparison. European Journal of Cardio-Thoracic Surgery. 2012;**41**:806-811

[40] Saxena A, Dinh DT, Reid CM, et al. Does preoperative atrial fibrillation portend a poorer prognosis in patients undergoing isolated aortic valve replacement? A multicentre Australian study. The Canadian Journal of Cardiology. 2013;**29**:697-703

[41] Damiano RJ, Gaynor SL, Bailey M, et al. The long-term outcome of patients with coronary disease and atrial fibrillation undergoing the Cox maze procedure. The Journal of Thoracic and Cardiovascular Surgery. 2003;**126**:2016-2021

[42] Ad N, Henry L, Hunt S, et al. Do we increase the operative risk by adding the Cox maze III procedure to aortic valve replacement and coronary artery bypass surgery? The Journal of Thoracic and Cardiovascular Surgery. 2012;**143**:936-944

[43] Malaisrie SC, Lee R, Kruse J, et al. Atrial fibrillation ablation in patients undergoing aortic valve replacement. The Journal of Heart Valve Disease. 2012;**21**:350-357

[44] Pokushalov E, Romanov A, Corbucci G, et al. Benefit of ablation of first diagnosed paroxysmalatrial fibrillation during coronary artery bypass grafting: A pilot study. European Journal of Cardio-Thoracic Surgery. 2012;**41**:556-560

[45] Khargi K, Hutten BA, Lemke B, et al. Surgical treatment of atrial fibrillation; a systematic review. European Journal of Cardio-Thoracic Surgery. 2005;**27**:258-265

[46] Kirchhof P, Benussi S, Kotecha D, et al. ESC guidelines for the management of atrial fibrillation developed in collaboration with EACTS. European Heart Journal. 2016;**37**(38):2893-2962

[47] Huffman MD, Karmali KN, Berendsen MA, et al. Concomitant atrial fibrillation surgery for people undergoing cardiac surgery. Cochrane Database of Systematic Reviews. 2016;**8**:CD011814

[48] Cheng DC, Ad N, Martin J, et al. Surgical ablation for atrial fibrillation in cardiac surgery: A meta-analysis and systematic review. Innovations (Phila). 2010;**5**:84-96

[49] McClelland JH, Duke D, Reddy R. Preliminary results of a limited thoracotomy: New approach to treat atrial fibrillation. Journal of Cardiovascular Electrophysiology. 2007;**18**:1289-1295

[50] Castella M, Pereda D, Mestres CA, et al. Thoracoscopic pulmonary vein isolation in patients with atrial fibrillation and failed percutaneous ablation. The Journal of Thoracic and Cardiovascular Surgery. 2010;**140**:633-638

[51] Wang S, Liu L, Zou C. Comparative study of video-assisted thoracoscopic surgery ablation and radiofrequency catheter ablation on treating paroxysmal atrial fibrillation: A randomized, controlled short-term trial. Chinese Medical Journal. 2014;**127**:2567-2570

[52] Boersma LV, Castella M, van Boven W, et al. Atrial fibrillation catheter ablation versus surgical ablation treatment (FAST): A 2-center randomized clinical trial. Circulation. 2012;**125**:23-30

[53] Krul SP, Driessen AH, van Boven WJ, et al. Thoracoscopic video-assisted pulmonary vein antrum isolation, ganglionated plexus ablation, and periprocedural confirmation of ablation lesions: First results of a hybrid surgical electrophysiological approach for atrial fibrillation. Circulation. Arrhythmia and Electrophysiology. 2011;**4**:262-270

[54] La Meir M, Gelsomino S, Luca F, et al. Minimally invasive surgical treatment of lone atrial fibrillation: Early results of hybrid versus standard minimally invasive approach employing radiofrequency sources. International Journal of Cardiology. 2013;**167**:1469-1475

[55] Nashef SAM, Fynn S, Abu-Omar Y, et al. Amaze: A randomized controlled trial of adjunct surgery for atrial fibrillation. European Journal of Cardio-Thoracic Surgery. 1 Oct 2018;**54**(4):729-737

[56] Edgerton JR, McClelland JH, Duke D, et al. Minimally invasive surgical ablation of atrial fibrillation: Six-month results. The Journal of Thoracic and Cardiovascular Surgery. 2009;**138**:109-114

[57] Edgerton JR, Brinkman WT, Weaver T, et al. Pulmonary vein isolation and autonomic denervation for the management of paroxysmal atrial fibrillation by a minimally invasive surgical approach. The Journal of Thoracic and Cardiovascular Surgery. 2010;**140**:823-828

[58] Kasirajan V, Spradlin EA, Mormando TE, et al. Minimally invasive surgery using bipolar radiofrequency energy is effective treatment for refractory atrial fibrillation. The Annals of Thoracic Surgery. 2012;**93**:1456-1461

[59] De Maat Gijs E, Pozzoli A, et al. Long-term results of surgical minimally invasive pulmonary vein isolation for paroxysmal lone atrial fibrillation. Europace. 2015;**17**(5):747-752

[60] Je HG, Shuman DJ, Ad N. A systematic review of minimally invasive surgical treatment for atrial fibrillation: A comparison of the Cox-maze procedure, beating-heart epicardial ablation, and the hybrid procedure on safety and efficacy. European Journal of Cardio-Thoracic Surgery. 2015;**48**:531-541

[61] Blackstone EH, Chang HL, Rajeswaran J, et al. Biatrial maze procedure versus pulmonary vein isolation for atrial fibrillation during mitral valve surgery: New analytical approaches and end points. Journal of

Thoracic and Cardiovascular Surgery. 2019;**157**(1):234-243

[62] Gaita F, Riccardi R, Caponi D, et al. Linear cryoablation of the left atrium versus pulmonary vein cryoisolation in patients with permanent atrial fibrillation and valvular heart disease: Correlation of electroanatomic mapping and long-term clinical results. Circulation. 2005;**111**(2):136-142

[63] Voeller RK, Bailey MS, Zierer A, et al. Isolating the entire posterior left atrium improves surgical outcomes after the Cox maze procedure. The Journal of Thoracic and Cardiovascular Surgery. 2008;**135**(4):870-877

[64] Gillinov AM, Gelijns AC, Parides, et al. Surgical ablation of atrial fibrillation during mitral-valve surgery. The New England Journal of Medicine. 2015;**372**(15):1399-1409

[65] Darkner S, Chen X, Hansen J, et al. Recurrence of arrhythmia following short-term oral AMIOdarone after CATheter ablation for atrial fibrillation: A double-blind, randomized, placebo-controlled study (AMIO-CAT trial). European Heart Journal. 2014;**35**:3356-3364

[66] Schuessler RB, Lee AM, Melby SJ, et al. Animal studies of epicardial atrial ablation. Heart Rhythm. 2009;**6**(12 Suppl):S41-S45

[67] Caccitolo JA, Stulak JM, Schaff HV, et al. Open-heart endocardial radiofrequency ablation: An alternative to incisions in maze surgery. The Journal of Surgical Research. 2001;**97**(1):27-33

[68] Prasad SM, Maniar HS, Schuessler RB, et al. Chronic transmural atrial ablation by using bipolar radiofrequency energy on the beating heart. Journal of Thoracic & Cardiovascular Surgery. 2002;**124**(4):708-713

[69] Doll N, Kornherr P, Aupperle H, et al. Epicardial treatment of atrial fibrillation using cryoablation in an acute off-pump sheep model. The Thoracic and Cardiovascular Surgeon. 2003;**51**(5):267-273

[70] Prasad SM, Maniar HS, Diodata MD, et al. Physiological consequences of bipolar radiofrequency energy on the atria and pulmonary veins: A chronic animal study. Annals of Thoracic Surgery. 2003;**76**(3):836-841; discussion 841-2

[71] McClure GR, Belley-Cote EP, Jaffer IH, et al. Surgical ablation of atrial fibrillation: A systematic review and meta-analysis of randomized controlled trials. Europace. 2018;**20**(9):1442-1450

[72] Phan K, Xie A, Tian DH, Shaikhrezai K, Yan TD. Systematic review and meta-analysis of surgical ablation for atrial fibrillation during mitral valve surgery. Annals of Cardiothoracic Surgery. 2014;**3**(1):3-14

[73] Ad N, Suri RM, Gammie JS, Sheng S, O'Brien SM, Henry L. Surgical ablation of atrial fibrillation trends and outcomes in North America. The Journal of Thoracic and Cardiovascular Surgery. Nov 2012;**144**(5):1051-1060

[74] Kamata J, Kawazoe K, Izumoto H, et al. Predictors of sinus rhythm restoration after Cox maze procedure concomitant with other cardiac operations. The Annals of Thoracic Surgery. 1997;**64**(2):394-398

[75] Ad N, Holmes SD, Patel J, et al. The need for consistent predictors of success for surgical ablation of atrial fibrillation: A call to action. Innovations (Phila). 2017;**12**(6):421-429

[76] Gillinov AM, Sirak J, Blackstone EH, et al. The Cox maze procedure in mitral valve disease: Predictors of recurrent atrial fibrillation. The Journal of Thoracic and Cardiovascular Surgery. 2005;**130**:1653-1660

[77] Pecha S, Ghandili S, Hakmi S, et al. Predictors of long-term success

after concomitant surgical ablation for atrial fibrillation. Seminars in Thoracic and Cardiovascular Surgery. 2017;**29**(3):294-298

[78] Gelsomino S, La Meir M, Van Breugel HN, et al. Surgical ablation in patients undergoing mitral valve surgery: Impact of lesion set and surgical techniques on long-term success. Europace. 2015;**18**:1528-1537

[79] Loardi C, Alamanni F, Veglia F, et al. Modified Maze procedure for atrial fibrillation as an adjunct to elective cardiac surgery: Predictors of mid-term recurrence and echocardiographic follow-up. Texas Heart Institute Journal. 2015;**42**(4):341-347

[80] Ad N, Holmes SD, Stone LE, et al. Rhythm course over 5 years following surgical ablation for atrial fibrillation. European Journal of Cardio-Thoracic Surgery. 2015;**47**:52-58

[81] Gu W, Guo H, Lu C, et al. Surgical ablation for persistent atrial fibrillation in concomitant cardiac surgery: Mid-long-term result. European Journal of Cardio-Thoracic Surgery. 2017;**52**(5):888-894

[82] Jais P, Cauchemez B, Macle L, et al. Catheter ablation versus antiarrhythmic drugs for atrial fibrillation: The A4 study. Circulation. 2008;**118**:2498-2505

[83] DiBiase L, Mohanty P, Mohanty S, et al. Ablation versus Amiodarone for treatment of persistent atrial fibrillation in patients with congestive heart failure and an implanted device: Results from the AATAC Multicenter randomised trial. Circulation. 2016;**133**:1637-1644

[84] Virk SA, Bennett RG, Chow C, et al. Catheter ablation versus medical therapy for atrial fibrillation in patients with heart failure: A meta-analysis of randomised controlled trials. Heart, Lung & Circulation. 2019;**28**(5):707-718

[85] Packer DL, Mark DB, Robb RA, et al. Catheter ablation versus antiarrhythmic drug therapy for atrial fibrillation (CABANA) trial: Study rationale and design. American Heart Journal. 2018;**199**:192-199

[86] Phan K, Phan S, Thiagalingam A, et al. Thoracoscopic surgical ablation versus catheter ablation for atrial fibrillation. European Journal of Cardio-Thoracic Surgery. 2016;**49**(4):1044-1051

[87] Scanavacca M, Pisani CF, Hachul D, et al. Selective atrial vagal denervation guided by evoked vagal reflex to treat patients with paroxysmal atrial fibrillation. Circulation. 2006;**114**:876-885

[88] Di Biase L, Burkhardt JD, Mohanty P, et al. Left atrial appendage: An underrecognized trigger site of atrial fibrillation. Circulation. 2010;**122**:109-118

[89] Maesen B, Van-Loo I, Pison L, La-Meir M. Surgical ablation of atrial fibrillation: Is electrical isolation of the pulmonary veins a must? Journal of Atrial Fibrillation. 2016;**9**(1):1426

[90] Zeng Y, Cui Y, Li Y, Liu X, Xu C, Han J, et al. Recurrent atrial arrhythmia after minimally invasive pulmonary vein isolation for atrial fibrillation. The Annals of Thoracic Surgery. 2010;**90**(2):510-515

[91] On YK, Park KM, Jeong DS, et al. Electrophysiologic results after thoracoscopic ablation for chronic atrial fibrillation. Annals of Thoracic Surgery. 2015;**100**(5):1595-1602; discussion 1602-3

[92] Kron J, Kasirajan V, Wood MA, et al. Management of recurrent atrial arrhythmias after minimally invasive surgical pulmonary vein isolation and ganglionic plexi ablation for atrial fibrillation. Heart Rhythm. 2010;7(4):445-451

[93] Pison L, La Meir M, van Opstal J, et al. Hybrid thoracoscopic surgical and

transvenous catheter ablation of atrial fibrillation. Journal of the American College of Cardiology. 2012;**60**(1):54-61

[94] Gillinov M, Soltesz E. Surgical treatment of atrial fibrillation: Today's questions and answers. Seminars in Thoracic and Cardiovascular Surgery. 2013;**25**(3):197205

[95] Lee R, Vassallo P, Kruse J, et al. A randomized, prospective pilot comparison of 3 atrial appendage elimination techniques: Internal ligation, stapled excision, and surgical excision. The Journal of Thoracic and Cardiovascular Surgery. 2016;**152**(4):1075-1080

[96] Reddy VY, Sievert H, Halperin J, et al. Percutaneous left atrial appendage closure vs warfarin for atrial fibrillation: A randomized clinical trial. Journal of the American Medical Association. 2014;**312**(19):1988-1998

[97] Holmes DR Jr, Doshi SK, Kar S, et al. Left atrial appendage closure as an alternative to warfarin for stroke prevention in atrial fibrillation: A patient-level meta-analysis. Journal of the American College of Cardiology. 2015;**65**(24):2614-2623

[98] Friedman DJ, Piccini JP, Wang T, et al. Association between left atrial appendage occlusion and readmission for thromboembolism among patients with atrial fibrillation undergoing concomitant cardiac surgery. Journal of the American Medical Association. 2018;**319**(4):365-374

[99] Tsai YC, Phan K, Munkholm-Larsen S, et al. Surgical left atrial appendage occlusion during cardiac surgery for patients with atrial fibrillation: A meta-analysis. European Journal of Cardio-Thoracic Surgery. 2015;**47**(5):847-854

[100] Ailawadi G, Gerdisch MW, Harvey RL, et al. Exclusion of the left atrial appendage with a novel device: Early results of a multicenter trial. The Journal of Thoracic and Cardiovascular Surgery. 2011;**142**(5):1002-1009

[101] Whitlock R, Healey J, Vincent J, et al. Rationale and design of the left atrial appendage occlusion study (LAAOS) III. Annals of Cardiothoracic Surgery. 2014;**3**:45-54

[102] Melduni RM, Schaff H, Lee HC, et al. Impact of left atrial appendage closure during cardiac surgery on the occurrence of early postoperative atrial fibrillation, stroke, and mortality: A propensity score-matched analysis of 10,633 patients. Circulation. 2017;**135**(4):366-378

[103] Emmert MY, Puippe G, Baumüller S, et al. Safe, effective and durable epicardial left atrial appendage clip occlusion in patients with atrial fibrillation undergoing cardiac surgery: First long-term results from a prospective device trial. European Journal of Cardio-Thoracic Surgery. 2014;**45**(1):126-131

[104] Caliskan E, Sahin A, Yilmaz M, et al. Epicardial left atrial appendage AtriClip occlusion. Reduces the incidence of stroke in patients with atrial fibrillation undergoing cardiac surgery. Europace. 1 Jul 2018;**20**(7):e105-e114

[105] Available from: www.atricure.com

[106] Robertson JO, Saint LL, Leidenfrost JE, Damiano RJ Jr. Illustrated techniques for performing the Cox-Maze IV procedure through a right minithoracotomy. Annals of Cardiothoracic Surgery. 2014;**3**:105-116

[107] Beaver TM, Hedna VS, Khanna AY, Miles WM, et al. Thoracoscopic ablation with appendage ligation versus medical therapy for stroke prevention: A proof of concept randomised trial. Innovations (Phila). 2016 Mar-Apr;**11**(2):99-105

[108] Available from: www. bostonscientific.com