Surgical treatment of atrial fibrillation using radiofrequency ablation

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CHAPTER 3

Considerations regarding energy sources to treat atrial fibrillation as a concomitant surgical procedure; techniques and pitfalls

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Introduction
The treatment of AF is important. Medication, cardioversion and atrioventricular node ablation with pacemaker implantation proves to be of limited success in the treatment of AF. Wood and associates, who conducted a meta-analysis comprising 21 studies including 1181 patients, who had a medically refractory atrial tachyarrhythmia, primarily AF (97%), showed a clinical benefit of AV node ablation with subsequent pacing. However, the calculated 1-year mortality rate remained at 6.3%, which was similar for medical therapy. In addition to that, coumadine could not be stopped in these patients. Two surgical concepts emerged to be successful; first, the “cut and sew” Maze technique, a precisely defined bi-atrial pattern of incisions, which interrupts all multiple wavelet re-entrant circuits, which perpetuate AF (1) and secondly the selective pulmonary vein orifice isolation, striking the so called trigger foci, which are presumed to initiate AF in paroxysmal AF (2). The “cut and sew” technique is an extensive and complex procedure. Therefore, alternative sources of energy, like radiofrequency (RF), microwave (MW), cryoablation (CA), ultrasound and laser emerged to create intra-atrial linear lesions.

Energy sources and techniques
Aim of the alternative source of energy is to create a conduction block without causing any tissue dehiscence. Therefore, the energy application should induce a temperature between 50 and 95 degrees Celsius at a depth of 6-7 mm in the atrial wall. Irreversible cell damage occurs above 50 degrees Celsius, while tissue layer integrity is preserved beneath 95-100 Degrees Celsius.

Radiofrequency
Unipolar radiofrequency
This type of energy uses alternating electrical current of 100 KHz to 1 MHz to heat tissue, while avoiding excitation of muscles and nerves. The unipolar RF drives the current from an active electrode (the ablation catheter) to an indifferent electrode and back to the generator. The current is converted into thermal energy because of molecular agitation (Ohmic heating). Three types of radiofrequency application can be defined; irrigated RF, temperature controlled RF and dry RF (3).

- Irrigated RF creates deeper lesions than temperature RF and dry RF, because more energy can be delivered due to an improved current conductivity from the electrode to the tissue because of the irrigation. The set-up of the irrigated RF constituted of a saline-irrigated, cooled- tip radiofrequency ablation-catheter. The catheter is connected via an infusion pump with a NaCl 0.9% infusion bag. The flow rate is set at 200-320 ml/hour. The catheter is connected to a radiofrequency generator. The energy delivery is set between 20 and 32 Watt. Lesions are created with a hand-held pen catheter, making oscillating movements on the endocardial surface, without pressing the atrial tissue to the adjacent mediastinal structures, till a whit-yellow discoloration and blistering of the endocardial layer appears. The delivered amount of energy is tailored to the presumed atrial wall thickness. “Pops” caused by sudden release of steam from the deep tissue layers may cause small endocardium cracks. Shomoike tested a 25 mm long stainless steel linear irrigated RF probe. Histological examinations demonstrated linear and transmural lesions and electrophysiological examinations revealed conduction block (4). Thomas tested two temperature controlled RF devices epicardium of the left ventricle in mongrel dogs, varying the target temperature form 70-90 degrees Celsius. The Mongrel dogs, which were sacrificed 20 minutes after ablation. RF duration of ablation. The target temperature was not reached before 60 seconds. Depth width and cross sectional are of the lesion increase with increasing temperature but was not statistically significant. The time course of the lesion formation was 63% of the lesion, created with 120 seconds, is formed in 15 seconds. Doubling the ablation from 30 to seconds 60 increases the depth by another 16%, doubling the duration to 120 adds to another 16% (5).
Temperature controlled RF is more effective than dry RF, but still less effective than cooled RF, because the delivered amount of energy is variable and restricted by the pre-determined temperature limit. Increase of the application time will moderately increase the size of the lesion. Temperature RF targets a temperature of 70-80 degrees Celsius. The power output is adjusted concordantly. Application time per lesion is 60 to 90 seconds. Various probes are available. The most used one is a malleable probe with 7 electrodes. The probe is fixed against the atrial wall while ablating. Consistent and secure tissue contact, especially around the left pulmonary vein orifices, can be demanding. In addition to that, overshoot of the set point temperature, as has been described for specific temperature controlled RF probes, might be an important cause of collateral tissue damage (6). Santiago and associates, who conducted a vitro and vivo study showed that in mitral valve patients it was difficult to achieve transmural endocardial lesion due to the composition of the endocardial and myocardium (7). They concluded that the temperature increase is not the sole factor for lesion formation. Epicardial of temperature controlled RF is presumed to be ineffective, especially when epicardial fat tissue is present. Thomas conducted an animal study comparing the lesion geometry of epicardial and endocardial. He found that both endo- and epicardial lesion were unlikely to be transmural if the atrial wall exceeds a 4 mm thickness. Epicardial fat impedes an effective lesion formation, but even in the absence of after epicardial lesion are considered more width than deep due to endocardial cooling. Prolongation of the ablation does not result in an increase of depth (8). Khairy compared the formation of thrombus in temperature controlled RF and cryoenergy. He found that endocardial RF of equal size in equivalent cardiac chambers confers a 5 fold increased risk of thrombus formation compared to cryoenergy. Whereas the extent of RF lesion positively correlated to the thrombus volume cryoenergy does not predict thrombus volume. This probably reflects the histological observation that cryo ablation results in well delineated discrete lesion with preservation of the tissue ultra structure including the endothelial layer. In contrast RF lesions have serrated edges with more extensive endothelium cell destruction (9). RF is significantly more thrombogenic than cryoablation.

Dry RF is not used intraoperatively.

Bipolar radiofrequency
The bipolar RF systems have electrodes in the jaws of an atraumatic clamp. The RF is delivered to a tissue sheet between the jaws of the clamp. Tissue conductance is monitored and will show a sudden drop, once a transmural lesion is formed. As with unipolar bipolar is available with (e.g. Atricure) and without irrigation (Medtronic). Prasad conducted a histological study in sheep creating 20 ablation lines using the Atricure ablation device. Radiofrequency was delivered at 750 mA. The sheep survived for 30 day. The mean ablation time was 9.3 +/- 4.0 seconds with a mean peak temperature of 48.4 +/- 6.4 degrees Celsius (10).

Bonanomi used an irrigated bipolar system (Medtronic Bipolar), in 12 pigs. Maze-like ablation lines conducted by directly applying to the left epicardium on the beating heart. All ablation lesions demonstrated a conduction block along their entire course. Transmural was achieved without any charring barotrauma (11).

Microwave
This energy type is a high frequency electromagnetic radiation causing oscillation of water molecules within the tissue. Electromagnetic energy is converted into kinetic energy (heat). Application is performed with an antenna mounted on a malleable shaft. As with RF, the size and depth of the produced atrial lesion is determined by the application time and output power. Although energy distribution along the
antenna probe is unequal, an effective lesion along the entire antenna can be created in approximately 25 seconds. Longer ablation time will not increase the depth of the lesion, because a static state is reached where lesion growth essentially plateaus. The microwave system consists of a 25 mm long ablation probe, which has a reflector to direct the electromagnetic energy through a defined window. The probe is connected to a coaxial cable to a microwave generator, which delivers 2.45 GHz with a power output of 35 to 75 Watt. However 40% of the power is lost due to the coaxial cable. Usual settings are 40 to 60 Watt and an application time of 25 seconds per lesion (12). Mazzitelli describe his technique using a flexible microwave antenna with a 40 mm tip perform an off pump epicardial ablation. His energy setting was 65 Watt and the application time was 90 seconds per lesion (13). Manasse, reported in 15 patients in whom the right auricle was epicardially ablated using a Microwave Ablation system Flex 4 probe. In all tissue samples regions containing necrotic cells were extensive and transmural. Several tissue samples however showed viable looking cells within heavily damaged tissue (14).

Cryoablation
In contrast to RF an MW, cryoablation is a hypothermic type of energy. The tip of the cryoprobe is rapidly cooled to -50 up to -90°degrees Celsius by the release and expansion of compressed nitrogen or argon gas. The tip of the probe freezes to tissue during application. Cell death occurs at -40 to -60°C. Application time per lesion is 2 to 5 minutes. Multiple applications, however, are sometimes necessary to increase the depth of the ablation lesion. Therefore this technique can be time consuming. The rigidity of the probes is a disadvantage, but more malleable probes are being developed. Cryothermal tissue injury preserves the tissue architecture and causes minimal thrombus formation. The chronic scar is made of dense fibrotic tissue that has no tendency to rupture or dilate (15). The mechanism of cryoenergy tissue injury is highly complex and involves freeze/thaw effects, hemorrhage, inflammation and replacement fibrosis. The net result is tissue destruction with sharply delineated lesion that preserves underlying tissue and extra cellular matrix architecture.

Ultrasound
This type of energy is delivered with an ultrasonic coagulator, causing mechanical disruption of the molecular bonds. However no published clinical data are available.

Laser
This is a hyperthermic type of energy, which still is experimental.

Pitfalls
Safety and effectiveness are two important criteria to evaluate the various techniques. Two potential causes, which could increase postoperative morbidity and mortality will be considered, first the prolongation of the total operative procedure and secondly the operative technique including the ablation device and the lesion pattern. The additional mean aortic cross clamp time, to perform the anti-arrhythmic procedure varies between 10 and 17 minutes in mitral valve patients (16, 17). In CABG and AVR patients, the additional aortic cross clamp time doubles because it is technically more demanding to get into the left atrium to perform the various ablation lines, since the left atrium is smaller, mean 50.0 mm versus 59.8 mm. In addition to that, the additional mean extra-corporeal circulation time in the bi-atrial procedure, is 26 minutes compared with the left atrial procedure.

Morbidity
In our series of 124 patients, treated with irrigated RF, the incidence of postoperative complications including a bleeding, a pulmonary infection or atelectasis, a pneumothorax or a transient ischemic neurological attack were within the expected range. A transient low cardiac output, defined, as the need
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for intravenous inotropic support exceeding the first 48 postoperative hours, is related to an impaired preoperative left ventricular function and a prolonged operative procedure. The postoperative bleedings were never related to a radiofrequency ablation line. No atrial wall ruptures, late tamponades, atrial wall aneurysm or pseudoaneurysm were noticed. All complications were treated successfully. During follow-up not a single patient showed signs or symptoms, which is associated with an esophageal- or circumflex artery- or pulmonary vein orifice injury.

Mohr and associates surgically treated atrial fibrillation in 234 patients using a 10 mm T-shaped ablation probe (Osypka GmbH, Grenzach, Wyhlen, Germany) targeting a temperature of 60 degrees for 20 seconds (18). A minimal invasive surgical approach through a right lateral minithoracotomy was performed in 133 out of 234 patients. The postoperative complications in their series were bleeding 7.7% (18/234), a circulatory or pulmonary artificial support 3.0% (7/234), reoperation 0.9% (2/234) due to a mitral valve dysfunction, a mediastinitis 0.9% (2/234), a cerebral stroke or infarction 1.7% (4/234), an inguinal infection 0.4% (1/234). An atrio-esophageal fistula occurred in 1.3% (3/234) and a circumflex artery stenosis in 0.4% (1/234).

Gillinov and colleagues reported a fatal esophageal injury in a cachectic female patient, following a radiofrequency ablation procedure using the Cobra RF system (Boston Scientific, Boston, Mass) targeting 80 degrees Celsius for 60 seconds (19). Oval lesions were made around the left and right pulmonary orifices separately and then interconnected. In addition to that, radiofrequency lesions around the left atrial appendage, from the left pulmonary vein to left appendage and to mitral valve annulus were created. This patient revealed an esophageal perforation on the 10th postoperative day with two linear perforations on the anterior wall, behind the carina.

A clear explanation for the discrepancy in observation of esophageal- and circumflex injuries in our series and that from Mohr, Gillinov and colleagues cannot be provided. Nevertheless important differences in operative techniques, ablation devices and lesion patterns can be distinguished. Mohr performed 133 patients through a right lateral minithoracotomy, whereas all our patients had a standard sternotomy. We dissected the left atrium free from its adjacent structures before the ablation is started. The left atrial roof is freed from the right pulmonary artery and the superior caval vein. The transverse- and oblique sinuses were opened. Therefore the heart is fully mobilized within its pericardial sac. Mohr used a 10 mm T-shaped, temperature-controlled, non-irrigated radiofrequency ablation probe (Osypka GmbH, Grenzach, Wyhlen, Germany) targeting a temperature of 60 degrees Celsius for 20 seconds for each lesion without taking the variability of the local atrial wall thickness into account. The probe is fixed and pressed against the atrial wall during application. Gillinov used an even higher temperature (80 degrees Celsius) and a longer application time (60 seconds) in a cachetic patients (29 kg and 146 cm). The anatomical relationship of esophagus and left atrium in this patient was apparently unfavorable.

We used an irrigated catheter which is a hand-held, flexible, pen-catheter, which enables the surgeon to match the delivered amount of radiofrequency energy to the estimated atrial wall thickness, creating a conduction block without any tissue dehiscence. Formation of yellow-white blistering endocard lesions, induced by oscillating catheter movements, were considered sufficient. Stable catheter-tissue contact is preserved, without pressing the atrial wall against adjacent mediastinal structures. Mohr made linear ablations from the inferior aspect of the mitral annulus to the left lower pulmonary vein ensuing to the left upper pulmonary vein traversing to the right upper pulmonary vein going to the right lower vein. Additional lesions were created at the roof to the surgical incision. The left appendage is not excised or ligated. We performed circumferential lesions around each pulmonary vein orifice, without ever entering any of these orifices. The left auricle is always resected or closed from inside.

Williams and colleagues also used temperature-controlled radiofrequency ablation to treat atrial fibrillation in 48 patients, but a standard sternotomy was always chosen (20). In contrast to Mohr and associates, Williams used a flexible ablation probe, which had seven consecutive electrodes (Cobra Boston Scientific-EP Technologies), each independently regulated by the generator. Williams targeted a
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higher temperature, 70-80 degrees Celsius, and they used longer application times, 1 minute per lesion, than Mohr and associates did. Energy delivery is flexible, but still up to 150 Watt. Ablation lesions were either made as separate ovals around the left and right orifices or as a complete one circumferential island around all four pulmonary orifices. Nevertheless, Williams did not report any esophageal- or circumflex injuries, nor did Benussi and Melo and colleagues who also used temperature-controlled radiofrequency in a combined cohort of 105 patients (21, 22). Both used an epicardial ablation of the pulmonary vein orifices with a subsequent endocardial interconnecting ablation line. Benussi suggested to adapt the left atrial ablation lines, especially the lines to the mitral valve annulus, in accordance with the specific coronary anatomy (23).

Sie and co-workers used hand held cooled tip probe with generator (HAT 200S, Sulzer-OsyankaGmbH, grenzach-Wyhlen, Germany) (24). In their series morbidity included bleeding 9% (11/122), IABP 5.7% (7/122), right ventricular perforation 1.6% (2/122), endocarditis 0.8% (1/122), sternal wound infection 0.8% (1/122), dual chamber pacemaker 3.3% (4/122), stroke 0.8% (1/122). No esophageal- or circumflex artery injuries were reported (24). Knaut used MW in 228 patients without any signs of esophageal or circumflex artery injury (25).

Epicardial radiofrequency coagulation may be a very effective way of converting patients with atrial fibrillation into sinus rhythm. Forty patients without mitral valve underwent epicardial radiofrequency coagulation on both atria. Twenty eight patients were in chronic AF, 9 patients in paroxysmal AF and 3 patients had an atrial flutter. The procedure were CABG (n=19), AVR (n=9), CABG with AVR (n=0), others (n=4). The increase in aortic cross clamp time is 10 minutes. SR recovery occurred in 15/16 (93.7%) at 6 months and 8/8 in 100% in 12 months (26).

Mortality

Thirty day-mortality in our series of 124 patients was 4.8% (6/124; euroscore 17, 11, 8, 8, 6, 5). The cause of death was a cerebral stroke, an atrial-ventricular dehiscence, a cardiac failure and low cardiac output (n=3). Autopsies did not reveal any esophageal-, pulmonary orifice-, or circumflex artery injuries. No ablation related bleeding was observed. Mohr reported an in-hospital and 30-day mortality of 6.4% (15/234). The cause of the in-hospital deaths were an adult respiratory syndrome (n=2), pulmonary embolism (n=1), sepsis (n=3), low cardiac output (1), stroke (n=1) and unknown (n=1). Benussi reported a 2.5% (1/40) hospital mortality; one fatal pneumonia. Williams reported 12.5% (6/48) hospital mortality; right ventricular failure (n=1), multi organ failure (n=4) with associated perforated colon, pneumonia, and acute lung injury. Sie reported an in-hospital mortality of 4.1% (5/122); mitral annulus rupture, late tamponade, low cardiac output (n=2), multi organ failure. Knaut reported an operative mortality of 1.7% (3/181) due to low cardiac output, right ventricular failure and multi organ failure.

Since the occurrence of 2 sudden cardiac deaths during follow up our postoperative medication is changed from sotalol to metoprolol. We felt that brady- arrhythmias, induced by sotalol, could be the cause of death, although no clear documented evidence is available. But, up till now none of the metoprolol patients experienced any sudden cardiac death.

Sinus rhythm

In our series, the cumulative postoperative SR rate at 6 and 12 months is 60% and 70%. The gradual increase of the SR conversion rate starting from 32% immediate postoperatively to 70% after 12 months is consistent with our previous observations. The increase of the SR rate occurs due to spontaneous SR conversions over time. A potential explanation of the spontaneous cardioversion is that the temporarily shortening of the refractory time of the atrial tissue, in the immediate postoperative period, disappears during follow-up. This shortening of the refractory time is caused by the surgical trauma causing edema and inflammation, and by the elevated catecholamine levels. Therefore multiple
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Wavelet reentrant circuits can still persist during the early postoperative period. When the refractory time lengthens than the reentrant circuits will extinguish themselves. Another explanation is the reinnervation of the autonomous nervous system, which contributes to the sinus node vitality.

Mohr and colleagues reported a SR rate of 77.8% (42/54) at 6 months and 70% (30/43) at 12 months in a series of 95 mitral valve procedures. An atypical flutter is observed in of 5.6% (3/54) at six months and 7.0% (3/43) at 12 months. In a different subset of patients (n=65), who had a non-mitral valve concomitant procedure Mohr observed a SR rate of 66.7% (20/30) at six months and 61.9% (13/21) at 12 months. The atypical flutter rate is 3.3% (1/30) at six months and 4.8% (1/21) at 12 months. Benussi and co-workers reported a 77% (30/39) SR rate at a mean follow-up of 11.6 months (21). Williams and colleagues published a SR rate of 81% (34/42) at a mean follow up of 138 days. Sie observed a SR rate of 72% (77/102) in his series. Gueden and associates described a 92 to 95 SR rate for the bi-atrial (n=39) or a left atrial lesion pattern (n=23) lesion pattern (27). Knaut reported a SR rate after 1 year between 60% and 85%, depending on the type of surgery.

Failures

The actual failure rate in our series is 32% (36/113); a flutter in 3.5% (4/113) and atrial fibrillation in 28% (32/113). Two potential causes of these failures should be considered; first a non-transmural intraatrial lesion due to an inadequate ablation line, secondly an inadequate lesion pattern. The atrial flutter may have 2 important origins; the isthmus in the right atrium or a preserved conduction line between the left and right atrium through the coronary sinus. Three patients needed a percutaneous arrhythmia corrective reintervention because of a right atrial flutter (n=2) and a left atrial flutter (n=1). The right atrial flutters could be ablated successfully, while the left atrial flutter was treated with AV node ablation and DDD pacemaker implantation.

Summary

A concomitant anti-arrhythmic surgical procedure obviously extends the operative procedure, however without causing any disproportionate morbidity of mortality. Irrigated RF and microwave prove to be safe and effective. Cryoablation is promising. The indication for a concomitant anti-arrhythmic procedure especially in low risk patients is warranted. In high-risk patients the indication should be individualized since an increase postoperative morbidity and mortality can be anticipated. On the other hand, high-risk patients will theoretically have an “out-of-proportionally-high” benefit if a SR with atrial contraction can be restored.
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