Introduction: evidence base

The advent of technology for the delivery of radiofrequency energy via electrode catheters, in the late 1980s, led to the perfection of techniques for the ablation of accessory pathways and classical flutter [1–4]. This has been so successful that these substrates for arrhythmia are rarely seen in the Western world. Two major arrhythmias, however, still remain to be conquered—atrial fibrillation and ventricular tachycardia/fibrillation.

The occurrence of atrial fibrillation (AF) seems to be dependent on a number of factors [5]. In most situations there is some form of underlying atrial substrate, which is usually the presence of intra-atrial conduction delay. In addition, initiating factors for AF are required and the commonest of these appear to be atrial ectopic beats [6]. The major sources of these ectopic beats appear to be the pulmonary veins [7], although extrapulmonary vein sources are being increasingly reported [8,9]. Numerous recent studies suggest that AF may be treated by the techniques based on ablation within or around the pulmonary veins. Initial reports were based on the identification of pulmonary vein ectopic foci and the abolition of these sources [10]. The difficulties of making pulmonary foci fire and thereby identifying the culprit vein [11] led to the approach of attempting to achieve electrical isolation of all four pulmonary veins in the hope of abolishing the initiating triggers [12]. The recent results reported by Haïssaguerre’s group suggest that around 70% of patients with paroxysmal atrial fibrillation in normal hearts, can be made to hold long-term sinus rhythm by means of this technique [12,13].

Pulmonary vein anatomy

Most patients have four pulmonary veins, two on the left and two on the right (Fig. 1). Many patients will have veins on the right or left side merging to a common ostium before entering the left atrium. In other individuals, branches of the veins can open into the left atrium through separate orifices. A muscular sleeve of atrial tissue can extend for several centimetres into each vein [14]. Although the majority of the vein is composed of circular fibres, longitudinal fibres also occur, and these
may constitute the electrical paths through which pulmonary vein foci, deep within the vein, are able to excite the atrial myocardium [15]. The variability of the pulmonary vein anatomy can lead to technical difficulties in the performance of the pulmonary vein ablation and thus recognition of the individual patient’s anatomy is critical to success. It is for this reason that some workers will perform a magnetic resonance imaging (MRI) scan and others a transoesophageal echocardiogram prior to the ablation to achieve accurate elucidation of the anatomy.

Two approaches have been taken to achieve electrical isolation of the PVs. The first is focal ablation to try to identify the longitudinal fibres carrying excitation in and out of the vein, and to ablate these. The second is to achieve complete encirclement of the PV orifice aiming at isolation.

I will attempt to describe the technique for PV isolation as it is used in our laboratory.

**Equipment and staff requirements**

Some basic equipment and personnel are required if PV ablation is to be undertaken.

1. A fully equipped and staffed catheter laboratory with standard equipment for diagnostic electrophysiology and ablation must be available.
2. The operator must be experienced in ablation of the common arrhythmias and be capable of performing transseptal puncture.
3. The technical staff must be able to measure and record pressures and keep lines flushed and free of air.
4. A pericardiocentesis set and echocardiogram must be available if urgently needed.

Patient selection

Although the types of patients with atrial fibrillation to which this technique can be successfully applied are unclear, the sorts of patients who appear to benefit include the following:

1. Patients with symptomatic episodes of AF, where symptoms have not been successfully controlled with antiarrhythmic drugs.
2. Patients with paroxysmal atrial fibrillation. The technique can be attempted on patients with persistent atrial fibrillation, but the success rate is relatively poor, perhaps around 20%.
3. Patients with structurally normal hearts. The technique has low success rates in patients with cardiac disease, particularly if the left atrium is dilated beyond 5 cm.

Preparation of patient

The risks, benefits and achieved results of the procedure should be discussed with the patient before listing for pulmonary vein isolation. Patients should be fully anticoagulated to an international normalized ratio (INR) between 2 and 4 for at least 4 weeks prior to the procedure and this is especially critical in patients with persistent AF who are likely to require cardioversion prior to, and during the ablation. Warfarin should be stopped 48–72 h prior to the procedure to allow the INR to fall between 1.4 and 1.7. The patient is admitted on the day before the ablation and heparin infusion is given to maintain the anticoagulated state until 6 h prior to going to the laboratory. The patient’s consent is obtained, again with the explanation of the risks and possible benefits of the procedure. On arrival at the laboratory, the patient should be connected to an ECG, non-invasive blood pressure and oxygen saturation probe for monitoring throughout the procedure. Venous cannulation is performed to allow administration of drugs and fluids. The patient is given analgesia and conscious sedation using diamorphine and midazolam together with an antiemetic. Venous sheaths are placed in the left groin and subclavian veins and quadripolar electrode catheters are inserted and positioned at the site of the His bundle electrogram and the distal coronary sinus. An arterial sheath is also placed in the left groin and a pigtail catheter is placed in the aortic root. The right groin is used to place two transseptal sheaths, one for the pulmonary mapping catheter and the other for the ablation catheter.

Performance of transseptal puncture

A long sheath and dilator suitable for insertion of the mapping catheter is prepared. It is absolutely critical that these sheaths are prepared with heparinised saline flush and meticulous attention is paid to excluding air. The length of the transseptal needle is compared with that of the sheath such that the possibility of the needle being inadvertently pushed out of the end of the sheath and dilator is minimised. The sheath with dilator is inserted over a guide wire to the superior vena cava. The transseptal needle is inserted into the sheath and positioned such that the tip of the needle is a few millimetres inside the tip of the dilator. The sheath/dilator and the needle are orientated such that the tip points towards the back (the arrow on the transseptal needle pointing towards 5 pm). The sheath/dilator and needle are then withdrawn as a single assembly until the tip is seen to jump forward; this is usually the position of the aortic root. The needle and sheath/dilator are withdrawn further and the tip should jump forward again into the fossa ovalis. At this stage the tip of the sheath should be below and behind the aortic root (marked by the pigtail catheter) and above or at the same level as the His catheter. These catheters act as important anatomic markers for positioning the sheath for transseptal puncture. If the sheath and needle are advanced a little forward at this site, then some resistance should be felt. In this position the radiological view should be changed to the left anterior oblique projection, and the operator should confirm that the needle and sheath are pointing to the back of the patient. The needle can be advanced beyond the tip of the sheath and should enter the left atrium. This should be confirmed by the pressure recording. Once it is certain that the left atrium has been punctured, the sheath and the needle can be pushed forward, with the needle being withdrawn as the sheath goes into the left atrium. Once the sheath tip is definitely in the left atrium, the needle and dilator are completely withdrawn. It is important that the sheath is purged of air and kept on slow constant flush with heparinised saline. A second transseptal puncture is performed in the same manner with a sheath suitable to take the ablation catheter. As soon as the sheaths are in place, the patient should be heparinised to achieve an activated clotting time (ACT) of around 300 s. The author uses sheaths...
with a 55° bend at the tip to allow positioning and manoeuvring of the catheters.

**Placement of catheters within the pulmonary vein**

In many centres an MRI of the heart or a transoesophageal echocardiogram is performed on the day prior to the procedure and there is some understanding of the number and positions of the pulmonary veins. This is not, however, absolutely necessary and with some experience, the four pulmonary veins can easily be located during the procedure. It is usual to begin with the left upper vein. If the sheath for the mapping catheter is gently advanced forward, it usually enters the left upper pulmonary vein and this is indicated by the tip of the sheath passing outside the cardiac outline. Injection of radiological dye via the sheath will confirm the position within the vein. At this point a cineangiogram of the vein should be taken and displayed to give anatomical landmarks. The cineangiogram should be studied carefully to determine the position of the ostium of the vein. The length of the vein before branching should be established and the approximate diameter of the main body of the vein should be determined. This allows appropriate selection of the mapping catheter.

**Selection of the mapping catheter**

The author’s favoured mapping catheter is the 31 mm basket catheter (Constellation™, Boston Scientific, Natick, MA). The advantage of this catheter is that one size fits most veins; it adapts to the size and anatomical form of the vein. It also allows recording of the electrograms from the ostium of the vein and also from deep within it (Fig. 2). The catheter should be positioned such that the proximal poles of the catheter are at the ostium of the vein and the recording system is set up such that the rings of the basket catheter are displayed together (rather than the splines). This allows conduction into the vein, and its path to be seen. The basket catheter is not suitable for short veins since it will not sit in a stable position and will be continually displaced. In these circumstances a ring mapping catheter such as a Lasso™ (Biosense-Webster, Diamond Bar, CA) or Spiral (St. Jude, Minitonka, MN) is more appropriate (Fig. 3). The size of the latter mapping catheters will have to be selected to fit the vein and the chosen catheter is then positioned just within the ostium of the vein (Fig. 3). The mapping catheter should supply electrocardiograms from within the pulmonary vein and these are displayed and timed for the operator. The second sheath is used to introduce the ablation catheter, which is initially placed deep within the vein and gradually withdrawn to the ostium, proximal to the mapping catheter. Mapping and ablation can now begin and the patient’s heparinisation is maintained at an ACT of around 300 s. The pigtail catheter is now withdrawn and the sheath is used to monitor arterial pressure.

**Pulmonary vein mapping**

The current understanding of pulmonary vein electrophysiology is that most of the fibres in the vein

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**Figure 2**  Examples of the Constellation basket catheter and an 8 mm tip ablation catheter positioned in (A) the left upper pulmonary vein, (B) the left lower pulmonary vein and (C) the right upper pulmonary vein. The proximal poles of the mapping catheter are at the ostium of the pulmonary vein.
are circular and do not carry conduction into the vein. The electrical links of the vein are longitudinal fibres, which run from the atrium into the vein and can carry electrical activity from the vein to the atrium and from the atrium into the vein. Pulmonary vein isolation is achieved by ablation of these connecting fibres. For the left-sided veins, pacing of the distal coronary sinus tends to increase the separation of the atrial signal and the pulmonary vein potential making these more visible. The signals from within the vein are studied carefully. Each individual signal consists of a far field atrial signal, which is generally of low amplitude, and a sharp local pulmonary vein spike. The earliest pulmonary vein spike represents the site of the connection of the pulmonary vein and atrium. If the pulmonary vein spike and the atrial potential are examined, on some of the poles of the ablating catheter, these electrograms are widely separated, at other sites there will be a fusion potential of the atrial and PV signal (Figs. 4 and 5). The latter indicate the sites of the longitudinal fibres and the potential sites for ablation. The ablating catheter is moved just proximal to the poles of the mapping catheter where an atrial/PV fusion potential is present using fluoroscopy, and radiofrequency energy is applied. With the basket catheter, specialised navigation software will allow appropriate positioning of the ablating catheter which considerably simplifies this process. It is critical that the ablating catheter is placed proximal to the mapping catheter and as close to the ostium of the vein as possible.

Radiofrequency ablation

When applying energy to the vein it is important that the energy is limited to 30 W and the temperature is set to 50 °C. Most of the data which are available suggest that PV stenosis is much more likely if high-energy applications are used and temperatures above 50 °C are achieved [16]. The application is maintained for a minimum of 30 s and up to 1 min. At some sites, applications of 2 min may be necessary. With good applications a diminution of the PV signal amplitude is seen and there may be a greater splitting of the atrial/PV potential, with a change in activation sequence suggesting ablation of one connection between the atrium and the PV and unmasking of another link. Ablation is then moved to the next fusion potential and this continues until the vein is ablated.

Markers of pulmonary vein isolation

When all the links between the atrium and the vein have been abolished, there is electrical silence within the vein, with only the far field atrial signal being recorded (Fig. 4). Occasionally spikes of electrical activity are seen within the pulmonary vein with no conduction to the rest of the atrium; these clearly demonstrate electrical discontinuity of the vein from the rest of the atrial myocardium. It is notable that by pacing the coronary sinus and recording electrical activation within the vein, we are able to study conduction into the vein and the
presence or absence of entry block. Attempts to pace within the vein and examine whether this conducts to the atrium are generally not successful because such high energies are required to achieve capture within the pulmonary vein, that electrotonic capture of the atrium is usually effected, and therefore exit block is usually difficult to confirm. However, most data suggest that if entry block into the vein is achieved then exit block is invariably also achieved. Unidirectional block has not been reported. The presence of pulmonary vein spikes in the absence of atrial capture is a convincing evidence of pulmonary vein exit block.

Once ablation of the left upper pulmonary vein has been achieved, the ablating catheter is drawn back and the mapping catheter is withdrawn while simultaneously the guide sheath is advanced over this into the vein. The sheath is purged of air and a cineangiogram of the vein is taken to confirm that no damage has occurred, in particular that no stenosis is present. Presence of damage and stenosis acutely is invariably associated with stenosis long-term [17,18].

Attention is then turned to the left lower pulmonary vein. The left lower pulmonary vein is situated below the left upper PV and usually withdrawal of the mapping sheath and advancement into a lower position will often result in engagement of the vein ostium. Occasionally manipulation of the sheath may be necessary because the origin of the vein is more posterior and use of the steerable ablating catheter may help in engaging the ostium. In difficult cases it may be necessary to change the guide sheath to one with a 90° bend, especially if the transseptal puncture has taken place in the high atrial septum. Following this a cineangiogram of the vein is made and the mapping catheter is advanced and positioned within the vein. Again pacing of the coronary sinus can be used to enhance splitting of the atrial/PV electrograms. Ablations are performed on the ostial margin of the vein until complete isolation is achieved as described above. A vein cineangiogram is again performed, after the mapping and ablating catheters are withdrawn, to establish that no damage has been done.

The right upper vein is usually easily located from the left veins. The guide sheath is withdrawn and rotated in a clockwise direction until it points to the right lateral wall of the atrium. Usually advancement of the catheter in this position will enable it to enter the right upper PV. The vein is first imaged and the mapping and ablating catheters are positioned within the vein. Ablation is performed to isolate this vein as described, except

**Figure 4** (A) Electrograms recorded from the left upper pulmonary vein with coronary sinus pacing prior to ablation. The pulmonary vein potential can be clearly seen following the pacing artifact. The earliest point of activation seen on poles 7 and 8 suggests the site for ablation. (B) Following isolation of the vein, only the far field atrial electrogram is seen with no obvious pulmonary vein potential, demonstrating entry block into the pulmonary vein.
that pacing is generally not necessary to enhance signal splitting.

There is some controversy as to whether the right lower pulmonary vein needs ablation. Most of the available data comes from Haïssaguerre’s group [12,13,15], where isolation of all four pulmonary veins is routinely performed. Morady achieved similar results to those of the French group by ablating just three veins [19]. Nevertheless if ablation of the right lower pulmonary vein is to be performed, it is sometimes possible to withdraw the guide sheath from the right upper pulmonary vein, point the tip down and enter the right lower pulmonary vein. Often, however, this manoeuvre proves extremely difficult to accomplish and it is necessary to change the guide sheath to one with a 90° or 120° curve. This vein can be imaged and ablated in the same way as the other veins.

Following ablation of three or four veins, the two transseptal sheaths are withdrawn into the right atrium unless linear radiofrequency applications are to be placed in the left atrium. The techniques for these are outside the scope of this article. It is critical that the ACT is maintained at around 300 s using heparin throughout the procedure. Furthermore it is critical that the sheaths are purged of air every time a manoeuvre is performed to avoid complications.

**Post-ablation care of the patient**

The anticoagulation is allowed to reduce until the ACT is below 160 s, when the sheaths can be safely removed. Four hours later the patient is reheparinised and this is maintained until warfarin therapy is re-established with an adequate INR. It is important that the patient has an echocardiogram following the ablation, since tamponade can occur in a significant number even when the procedure has been carried out without difficulty. The patient should be discharged with full anticoagulation and the antiarrhythmic drugs are maintained and later weaned off. This is because it is not uncommon for atrial ectopic beats and atrial fibrillation to increase over the first few weeks after the ablation before finally settling. Occasionally the patient may need cardioversion to re-establish sinus rhythm during this period.

The patient should be reviewed at 1 month and then at 2–3 month intervals. The antiarrhythmic medications can be weaned off if the patient is well and in sinus rhythm at 3 months. Continuation of warfarin for a period of 6 months or more is recommended. Anticoagulation policy has yet to be the subject of guidelines in this context. Patients should be followed for symptoms and arrhythmia control assessed by Holter monitoring.
Results achieved with pulmonary vein isolation

The larger-scale studies by the major groups suggest that around 70% of patients are in long-term sinus rhythm following the procedure but many of these patients have undergone multiple procedures. Many workers find it difficult to achieve these figures. Our own results suggest that approximately 30% of this select group are in sinus rhythm long-term (up to 1 year). Around 30% are improved in terms of symptoms, but continue to get atrial fibrillation. Around 30–40% do not demonstrate any change in arrhythmic status. Thus around two thirds of the patients are improved, but one third show no response. There is an improved success rate with repeat pulmonary vein isolation in patients who have recurrences since there is considerable evidence that this is due to reconnection of the vein to the atrium [20].

Difficulties and complications

The transseptal puncture can prove to be difficult. This is generally because the attempt is being made to puncture the muscular portion of the septum rather than the membranous. Repositioning of the catheter will generally make this easier. The pulmonary veins can be difficult to find. In these circumstances injection of radiological dye into the left atrium will help in identification of the ostia. Sometimes the left atrial appendage can mimic the ostium of a PV, but if the sheath is advanced beyond what appears to be the ostium and radiological contrast is injected, the characteristic appearance of the appendage becomes obvious. Withdrawal of the catheter tip and rotation posteriorly will generally engage one of the left pulmonary veins. The mapping catheter may be unstable within the pulmonary vein and the whole assembly may tend to fall back into the atrium. The mapping catheter may then require changing either to a different size or to a different type to enhance stability. Sometimes the PV potential may prove extremely difficult to eliminate, especially in the left upper PV. In these circumstances a catheter should be placed in the atrial appendage and the timing of the PV potential should be compared with the atrial appendage during CS pacing. If these are simultaneous, then the probability is that the atrial appendage potential is being recorded in the PV due to their close proximity and further ablation should be unnecessary. Abolition of the PV potential may require a large number of applications in large pulmonary veins.

Potential complications of the procedure include tamponade. This occurs in up to 5% of cases and the operator should be prepared to perform pericardiocentesis. Having removed the pericardial effusion, anticoagulation should be reversed and the problem should be treated conservatively. Almost all of these will settle without further intervention being necessary. Acute stroke is rarely seen but is a recognised risk of the procedure and should be treated in the normal manner. Pulmonary vein stenosis can occur acutely and if so, chronic stenosis is always seen. If affecting one vein, the patient is usually asymptomatic and this rarely causes any problems. If two or more veins are affected then symptoms are more common. Treatment of this is extremely difficult and though angioplasty and stenting have been attempted these do not carry great long-term success. This complication is best avoided by restricting the ablation to the ostium and using low ablation temperatures.

Newer methods of PV isolation

A new ablation catheter utilising cryotherapy has recently become available and results of its efficacy are awaited. Also a novel linear ablation catheter using radiofrequency energy is in trials (Fig. 5). This would allow ablation of the pulmonary vein with applications achieving a circumferential lesion. These trials, if successful, would allow rapid and complete isolation of the vein, with the necessity for only one transseptal puncture. Developments in this area are keenly awaited.

Conclusions

Ablative techniques for the treatment of atrial fibrillation are rapidly improving. Currently, limited success can be obtained by the technique of pulmonary vein isolation. The methods for this are now well established and operator experience in this technique is growing rapidly. The use of this technique together with other methods, such as linear application of lesions in the left and right atrium, may offer the solution to the treatment of atrial fibrillation.

References

How to perform pulmonary vein isolation


