The poor success of pharmacologic therapy for atrial fibrillation (AF) has encouraged many investigators to explore alternative strategies (1-9). Recent randomized studies have demonstrated that ablation strategy is superior to antiarrhythmic drug therapy in patients with paroxysmal/persistent AF (10-12) and more recently even in patients with “chronic” AF (13), but whether this superiority translates into morbidity and mortality benefits remains to be demonstrated into future multicenter trials possibly by uniforming ablation techniques. In the last few years the number of AF ablation procedures is growing worldwide with shorter procedure times resulting in a movement towards inclusion of patients with structural heart disease and long-lasting/permanent AF. Because of the excellent success rates reported by the pioneering groups and the attractiveness of a definitive cure for AF, many patients have begun seeking this curative approach as well as electrophysiologists and centers that offer it according to the new guidelines for AF treatment. From 1999 to 2007 we have performed in Milan at the San Raffaele University-Hospital more than 15,000 AF ablation procedures with an overall long-term success > 90% in paroxysmal/persistent AF and 80% in permanent AF with an acceptably low incidence of major complications. Despite the development of newer technologies and tools, mechanisms of AF are multiple and many of them still remain unknown. Three years ago, we first demonstrated the benefit of vagal denervation in patients with paroxysmal AF undergoing AF ablation and these observations remain a cornerstone in the understanding of AF pathophysiology and treatment. However, at present we need to have more information on pathophysiology of permanent AF to tailor or limit ablation targets, since patients with long-lasting or permanent AF require an extensive ablation with repeat procedures. Recent data from our laboratory indicate that progression from first paroxysmal AF to persistent or permanent AF is relatively rapid and can be predicted by clinical variables (14). As a result, identification of subjects at high risk of progression is useful for an optimal ablation timing avoiding a late procedure when AF becomes permanent. Currently, ablation strategies for permanent AF and associated structural heart disease are complex, time consuming, less effective and are associated with higher risk of complications. In the last 2 years pioneering groups have confirmed our previous results even in patients with permanent AF using the stepwise tailored approach, which includes sequential additional ablation targets with repeated procedures to limit or modify the anatomic, electrophysiologic and/or autonomic substrates (15). If substrate elimination is indeed crucial for the outcome, then mapping and navigation systems should be able to exactly visualize the complexity of left atrial anatomy to place lesions accurately avoiding unnecessary and dangerous RF applications to compensate for inaccuracy (Figure 1). The circumferential pulmonary vein ablation or CPVA is the standard procedure as performed in Milan at the San Raffaele University-Hospital. The procedure is performed by manual catheters or remotely by magnetic soft catheters in shorter time as compared with other approaches (16). CPVA consists of large circumferential lesion lines to perform a point-by-point tailored distal disconnection of all PVs, vagal denervation, wide encircled areas with additional standard lesion lines, and non-inducibility of both AF and AT at the end of the procedure. Accumulating data from our laboratory indicate that among patients with paroxysmal/persistent AF without enlarged atria the CPVA alone is associated with an excellent outcome while in patients with longstanding/ persistent or permanent AF and enlarged atria further linear lesions using the least amount of ablation is necessary to achieve non-inducibility. **End Points of CPVA** The goal of catheter ablation is trigger elimination and substrate modification using the least amount of ablation necessary. Restoration of stable sinus rhythm and no inducibility of both AF and/or AT at the end of the procedure is the gold standard of CPVA. However, most patients with longstanding/permanent AF after achieving sinus rhythm at the end of the procedure, are still inducible for sustained AF/AT requiring further linear lesion in the LA to achieve noninducibility. Procedural end points of standard CPVA include PV electrical disconnection, vagal denervation, and posterior lines with the mitral isthmus line,
while further limited linear lesions, including coronary sinus (CS) disconnection, are the last targets. End points are obtained with a single mapping/ablation catheter. At present, we do not use balloon technology as our approach is not limited to PV disconnection alone and the achievement of multiple targets precludes its use. In addition, PVs have largely variable anatomies from patient to patient, with a wide range of diameters and the frequent presence of common ostia in up to 30% of patients making challenging balloon technology.

**PV disconnection.**
Circumferential lines are aimed at atrial tissue outside the ostium of the PVs, an area often termed the antrum (Figure 1). The lesions are designed to encircle the left and right PVs individually or in pairs. Validation of electrical isolation with circular mapping catheter is not performed in our laboratory since we perform a true distal electrical isolation by potential abatement (>90% reduction of electrogram amplitude) even within the encircled areas (electrogram amplitude <0.1 mV). PV disconnection is obtained by optimal catheter stability and wall contact which results in rapid attenuation of atrial electrograms during each RF energy application up to complete elimination for up to 50 seconds, usually within a few seconds depending on the local effect (Figure 2). Partially ablated signals require further RF applications before moving on the next ablation site.

**Autonomic targets with vagal denervation.**
When possible, elimination of vagal reflexes at innervations sites during the procedure represents one of the most important end points since vagal denervation is a strong predictor for the long-term success (Figure 3). We first demonstrated that CPVA induces a long-term but transient vagal denervation, which enhances the efficacy of the procedure in the long-term outcome (8). These results have been confirmed by many other Authors with different AF ablation approaches and now vagal denervation constitutes a new fascinating AF ablation strategy. Our results on modification of HRV parameters after ablation add new insights for the understanding of the mechanisms of AF and its treatment. While performing the standard CPVA lesion set, RF applications evoke vagal reflexes in up to 30% of patients. Vagal reflexes are considered to include sinus bradycardia (< 40 beats per minute), asystole, AV block, and hypotension that occurs within a few seconds after the onset of RF application (Figure 3). If a reflex is elicited, RF energy is delivered until such reflexes are abolished, or for up to 30 seconds. The endpoint of ablation at these sites is termination of the reflex, followed by sinus tachycardia or AF. Failure to reproduce the reflexes with repeated RF applications is considered as confirmation of denervation. Complete local vagal denervation is defined by the abolition of all vagal reflexes. Based on our experience, we always attempt to elicit and then ablate potential sites of reflexes for vagal denervation. We reported a detailed “autonomic map” of the LA as a target for ablation showing that like the left superior pulmonary vein, the septal region is richly innervated (8).

**Posterior and mitral isthmus lines.**
In the standard CPVA additional ablation lines are placed along the back and the roof of LA between the two sets of PVs connecting the superior and inferior PVs and the mitral valve annulus (Figure 1). The mitral isthmus line is deployed to prevent postablation macroreentrant left atrial tachycardias (5,16,17) and to further reduce the substrate (Figure 3). Completeness of the mitral isthmus line is an important electrophysiological end point and it is validated during CS pacing by endocardial and coronary sinus mapping, looking for widely spaced double potentials across the line of block, and confirmed by differential pacing (5). The minimum double-potential interval at the mitral isthmus during CS pacing after block is achieved is 150 ms, depending on the atrial dimensions and the extent of scarring and lesion creation (5).

**Cavotricuspid isthmus line.**
Patients with AF and history of common atrial flutter or patients with permanent AF undergo ablation of the cavotricuspid isthmus line.

**Non-inducibility of AF/AT.**
If all endpoints are reached at the end of the standard CPVA and the patient is in sinus rhythm, non-inducibility of AF/AT is the last end point.

**Additional linear lesions and coronary sinus disconnection.**
If AF/AT inducibility persists even after cardioversion, we accurately revisit lesion lines and encircled areas to check for residual potentials and apply radiofrequency where needed. If necessary, adjunctive linear ablation (usually the roof, septum or the base of LAA) is performed before CS isolation, which is the last target (Figure 4). Conduction block is assessed by the presence of a corridor of double potentials and demonstration of activation moving towards the line of block on both sides. A complete LA roof line may be demonstrated by activation progressing in a caudocranial direction on the posterior wall during LAA pacing. Rapid atrial activity from the musculature of the CS may be a driver for long-lasting or permanent AF. Electrical disconnection of the coronary sinus from the atrium is performed by endocardial or epicardial ablation (or both). Total elimination of coronary sinus activity is the ideal end point but organization of CS activity and/or slowing of local rate with dissociation between CS and LA potential activity is also considered as proof of CS isolation. Endocardial and/or epicardial CS sites are frequent ablation targets in patients with permanent AF and enlarged atria.

**Post-ablation re-mapping.** Once AF/AT noninducibility has been achieved, the LA is remapped, and preablation and postablation activation maps are compared (Figure 1). In patients in sinus rhythm, postablation re-mapping of the LA is done using pre-ablation map for acquisition of new points to compare pre- and post-ablation bipolar voltage maps. In patients in AF, after sinus rhythm restoration, post-ablation re-mapping is performed using the anatomic map acquired during AF for accurate lesion validation. Incomplete block is revealed by impulse propagation across the line and requires further RF applications for completeness of the line despite noninducibility.

**Ablation procedure**

**Patient selection.**

Patients with clear contraindication to anticoagulation (heparin or warfarin) therapy are not considered potential candidates for CPVA, which can also be performed in elderly patients up to 80 years of age who have permanent AF and/or aortic or mitral metallic prosthetic valves. The procedure is indicated in symptomatic patients with AF refractory to antiarrhythmic drug therapy or who wish an opportunity to have a long-term cure of AF avoiding lifelong anticoagulation. Drug treatment for nonarrhythmic indications is generally continued. Although there is no consensus with regard to discontinuing antiarrhythmic drugs, to avoid confounding ablation effects, antiarrhythmic drugs except amiodarone and digoxin are discontinued for more than 5 half-lives. If symptomatic arrhythmias demand, effective antiarrhythmic drugs may be continued. A low left ventricular ejection fraction does not represent an absolute contraindication to CPVA.

**Pre-procedure preparation.** One month before ablation, transesophageal echocardiography (TEE) is the modality of choice to exclude LA or left atrial appendage thrombi, which are considered an absolute contraindication to the procedure which is postponed until cardiac thrombi is excluded by a repeat TTE during anticoagulation therapy. In patients with permanent AF an adequate and effective preablation anticoagulation therapy is necessary and at least 3 consecutive INR values ranging between 2.5 and 3.5 are required before the procedure. In addition, a 24-hour Holter monitoring, and daily transtelephonic random or symptom-triggered recordings are usually scheduled. A chest radiograph and laboratory tests are also required to exclude diseases that preclude anticoagulant therapy. At admission, we perform a routine TTE. Three days before the procedure, patients taking anticoagulants stop oral anticoagulant therapy. The night before ablation, we start heparin infusion to achieve ACT values between 200 and 250 seconds, which is stopped just 2 hours before the procedure to safely perform the transseptal puncture. We also use a weight-adjusted infusion of an intravenous narcotic such as remifentanil (0.025 to 0.05 mcg/Kg/minute). Cardiac surgery should be promptly accessible to perform emergency surgical procedures as needed. Urgent bedside echocardiography in the EP laboratory should be available primarily for diagnosing pericardial tamponade. The medical personnel, nursing, and technical support staff must be appropriately trained with adequate experience before starting AF ablation.
Procedure. Usually, before transseptal puncture, a catheter is placed into the coronary sinus to map for left atrial activity, and a multipolar catheter is placed inside the right atrium to map for right atrial activity. CPVA requires a single transseptal puncture for the mapping/ablation catheter. After transseptal access a single bolus of intravenous heparin is administered and 2 blood samples are taken every 15 minutes to monitor the activated clotting time which needs to be > 250 s or more if necessary.

Identification of ablation targets. Accurate target identification and ablation in a relatively short period of time to avoid major complications is essential to successfully achieve all end points and an excellent longterm outcome. Currently, this is facilitated using 3-D navigation and mapping systems which provide an accurate anatomical and electrophysiologic guidance. CPVA is being performed within 1 hour but it may be longer (up to 3 hours) in patients with permanent AF and enlarged atria to achieve all end points including CS disconnection and AF/AT non-inducibility. We do not use routinely intracardiac echocardiography and Lasso catheter.

Current electroanatomic mapping systems. Advantages and disadvantages. Generally, in evaluating the relative advantages of electroanatomic positioning systems, one must consider the need for accuracy, reproducibility, compatibility with ablation and mapping catheters, and cost issues when considering a specific system for a given patient (16). One of the disadvantages of all catheter tracking systems is that they are operator dependent since primarily require catheter movement to create the virtual geometry. Incomplete or inaccurate electroanatomic maps may result in deformed anatomy, difficult catheter navigation of planned ablation targets or in residual high voltage occurrence in the lesion set. If a greater force is applied, the resulting virtual map appears to be deformed leading to surface and volume overestimation. Better 3-D spatial resolution results in safer catheter navigation, more detailed maps, and ultimately facilitation of ablation targets at the desired endocardial sites (Figure 1). The possibility to catalog points of interest allows the operator to revisit sites of interest at any time to make contiguous and complete lesion lines. We routinely use the CARTO (Biosense-Webster, Diamond Bar, CA, USA) or the EnSite-NavX (St. Jude Medical, St. Paul, MN, USA) systems for positioning of catheters in virtual 3-D space, which significantly shorten fluoroscopy time enhancing safety (Figure 1). The early adoption by our group of the CARTO system many years ago allowed the first accurate reconstruction of the complex left atrial anatomy resulting in its eventual widespread acceptance by the electrophysiologic community performing catheter ablation of AF (2). The CARTO system localizes continuous catheter position using three ultra-low magnetic fields, while NavX system is based on electrical fields generated by three pairs orthogonal skin patches in X, Y, and Z axes. (Figure 1). Unlike CARTO, the recent NavX technology allows to obtain a 3-D reconstruction of both the tip and the shaft of the catheter, which is particularly useful in challenging areas such as PVs ostia, the ridge, the mitral valve annulus, and the septal area. Monitoring of the ablation catheter by NavX is obtained by a proximity indicator that, based on the intensity of the color of the tip allows the operator to monitor the optimal tissue contact of the ablation catheter, which when associated to the atrial potential abatement indicates the achievement of endpoints (Figure 1). During RF applications cardiac motion, pain and respiration all affect the stability of catheter positioning., but NavX software allows to minimize the extent of moving targets as well as respiratory artifacts. When ablating the posterior wall, which is a vulnerable area at greater risk of cardiac perforation, the occurrence of pain may cause the patient to change his respiratory frequency and a new respiratory compensation by NavX is useful for catheter stability. Also, NavX technology is able to create separately any desired anatomy for each ablation target which results in more accurate ablation of challenging targets particularly PVs ostia, their antrum, the posterior wall, and CS (Figures 4 and 5). Although the Ensite NavX system allows to collect rapidly and sequentially many points, in difficult areas we prefer to acquire points manually like the CARTO system. Another
important advantage of the NavX system as compared with CARTO is that patient movements during the procedure don’t affect the reconstruction of the map since the reference catheter moves equally to the patches attached to the patient’s body. As with the CARTO system, after ablation a voltage map is shown as color gradients to verify complete abatement on the lesion lines and within them (Figure 1). Currently, with both electroanatomic systems in a few minutes we are able to reconstruct the LA anatomy with ablation targets. Reconstruction of PVs and their ostia represents the first step and is confirmed by simultaneous use of fluoroscopy, electrograms, and impedance gradients. Characteristically and simultaneously, once the catheter enters the PV, the tip is seen outside cardiac shadow on fluoroscopy, the impedance values significantly rise (>4 Ohms above left atrial impedance), and the atrial electrograms disappear. Once PVs are displayed, a sequential detailed reconstruction of the left atrium including the posterior and anterior walls, LAA, the roof, the septum, and the mitral annulus with its isthmus, is performed. The septum and the channel between LAA and the LSPV often require acquisition of many more points than other areas. The LAA, which is identified and confirmed by the presence of not fractionated and high amplitude atrial electrograms and large ventricular electrograms with organized electrical activity in AF, represents one of the latest areas to be mapped. The channel between LAA and LSPV shows potentials that characteristically are smaller than those of the LAA but higher and more fractionated than the rest of the left atrium. If this channel is not accurately reconstructed, the left-sided circumferential lesion may be deployed unsafely too close to the LAA or within the PV ostium which may result in poor efficacy and major complications such as LAA perforation or PV stenosis. Although reconstruction of the roof is easier requiring less points to be acquired, incorrect interpolation should be avoided when using the CARTO system.

**Ablation of desired targets.**
Once the main PVs and LA have been adequately reconstructed, RF energy, which in our laboratory is the modality most frequently used for ablation, is delivered to the endocardial ablation targets to complete the lesion set while achieving the above mentioned anatomical and electrophysiological endpoints (Figure 1). In the last 3 years we are using open-irrigation tip catheters instead of 8-mm non irrigated tip RF catheters which have many limitations, including coagulum formation and insufficient power delivery in areas of low blood flow (12). Irrigated ablation allows to deliver adequate power to obtain larger lesion size and volume compared with traditional RF catheters minimizing the risk of embolic events. In our approach, efficacy of RF application is and remains important but we tailor RF applications since safety is crucial particularly in challenging areas. Usually, at constantly lower power settings (30-50W) we use a baseline irrigation rate of 2 ml/min (during mapping) and up to 50 ml/min depending on the location of ablation targets. RF applications are delivered at a distance greater than or equal to 1 cm from the ostia (wider than > 5mm as previously used) to create circumferential lesions while reducing the risk of PV stenosis (Figure 1). If there is an impedance rise (≥10 Ohms) or burning pain, RF applications is stopped immediately. When ablation starts, the irrigation rate is raised from 2 to 17 ml/min and impedance and tip temperature values are continuously monitored. Energy output is limited to 50W and 48°C throughout the entire ablation procedure but lower values are used in the posterior wall and into the coronary sinus to reduce the risk of injury to the surrounding structures. Usually, circumferential lesion lines are performed, starting at the lateral mitral annulus and withdrawing posteriorly, then anterior to the leftsided PV, passing on the ridge between LSPV and LAA before completing the circumferential line on the posterior wall. The right PVs are isolated in a similar fashion, and then two posterior lines connecting the 2 circumferential lines are deployed. Circumferential lines are tailored according to the individual PV-LA junction anatomy. A single large circumferential line around 2 ipsilateral PVs is performed in the presence of ostia less than 20 mm apart from each other, a common ostium with early branching, or separately branching PV. If anatomically possible (4 separate PV ostia), we also perform a lesion line between the 2 PVs ostia to further reduce the electrophysiologic and anatomic substrate
Characteristically, in patients with permanent AF and enlarged atria, often while delivering RF energy within the coronary sinus and before conversion of AF to sinus rhythm, we observe a gradual prolongation and stabilization of AF cycle length resembling an organized AT with uniform P-wave morphology (Figure 6). With our approach there is a conversion to SR in almost all patients with permanent AF. Permanent AF converts either directly to SR or via the ablation of intermediate AT. The procedure is considered successfully completed only when all acute endpoints are fully met.

**Challenging ablation targets.**

Achievement of all end points is crucial but it may be challenging in specific areas (16). Usually, repeat RF applications of short duration, greater power, and higher irrigation rates are necessary around the LSPV where atrial electrogram potentials may be difficult to eliminate. Complete abatement of atrial potentials in the ridge between the LSPV and LAA also requires repeat and longer RF applications with higher-power delivery settings. If the ridge is too narrow, the ablation line is performed at the base of LAA. The right-sided PV area and the mitral isthmus also represent 2 difficult sites for both mapping and ablation requiring continuous adjustment of delivery settings and irrigation rates to achieve the desired end point. Incomplete lesion lines particularly the mitral isthmus line may result in residual gaps and postablation incessant left AT. In patients with mitral and/or aortic metallic prosthetic valves mapping and ablation in the mitral area may be challenging but no case of catheter entrapment in the mitral valve even occurred. The mitral isthmus line requires validation of disconnection with pacing maneuvers and, in a large minority of patients further RF applications within CS are required. Ablation of connection sites between CS and atrial musculature require strict attention by lower energy settings and lower irrigation rates to avoid perforation and cardiac tamponade. Usually we deliver two short low energy sequential RF applications (usually between 15 and 30 W) by dragging the catheter in a distal to proximal direction, instead of performing a single application, in order to keep the temperature down and avoid potential complications (Figure 6). The posterior wall also represents a vulnerable area for possible complications such as cardiac perforation and esophageal injury with tip-irrigated catheters. It is well known that posterior wall not only is the thinnest area of the LA, but it lies in close proximity to the esophagus as well. While applying RF energy on this region, we use lower-energy delivery settings, shorter RF applications, and lower irrigation rates whenever ablation is performed.

**Clinical outcomes**

Post-procedure management and complications. At the end of the procedure, usually we use intravenous protamine to permit removal of sheaths. Afterward, the management consists of continuing and maintaining anticoagulation by heparin and then oral anticoagulation. The possibility to tailor RF applications, energy settings, irrigation rates in vulnerable areas contributes to minimize major complications. Pericardial tamponade must be excluded in patients with postprocedural hypotension but in our experience this complication is very rare if one uses a careful titration of RF power and duration delivery particularly in challenging areas thus reducing tissue boiling and endocardial rupture. Only a few patients have required pericardiocentesis for cardiac tamponade and a case of nonfatal esophageal fistula has occurred. The late occurrence (6-10 days postablation) of a febrile state with or without neurological symptoms should prompt suspicion of an atrio-esophageal fistula which should be excluded by contrast-enhanced spiral CT. In our extensive experience on more than 15,000 procedures, no case of death or other major complications such as significant PV stenosis, phrenic nerve injury, acute coronary artery occlusion have occurred after CPVA. Minor complications may occur rarely while small, nonhemodynamically significant pericardial effusion may develop in up to 4% of patients (16). Pericarditic discomfort may occur during the first days and aspirin is an adequate treatment.

**Rhythm outcome.**

The absence of symptoms may not correspond to stable restoration of sinus rhythm and the accuracy of evaluating postablation recurrences depends mostly on the duration of ECG recording. Usually, after ablation we
schedule 24-48-hour Holter recordings at 1, 3, 6 and 12 months and daily transtelephonic ECG monitoring, supplemented by ECG transmission, up to one year after the index procedure to assess the asymptomatic recurrences burden (12,13,16).

**Efficacy.** Early recurrences of AF after the index procedure usually occur within the first 2 months (5), but in half of cases they are a transient phenomenon not requiring a redo procedure. Long-term efficacy of CPVA is > 90% for patients with paroxysmal AF and about 85 % for permanent AF once AF/AT non-inducibility has been achieved at the end of the procedure. In patients with paroxysmal AF and local vagal denervation, the long-term success rate is higher. If recurrence of persistent AF or monthly episodes of symptomatic paroxysmal AF occur beyond the first month after ablation or incessant highly symptomatic left or right atrial flutter is present, then a second procedure is scheduled at 6 months after the index procedure. A maximum of three ablation procedures per patient are allowed.

**Atrial remodeling.**

The assessment of potential consequences of RF ablation on the LA contractility is important for a potential relationship to thromboembolic risk. After ablation, we evaluate carefully the left atrial transport function before and after the procedure and serially during the long-term follow-up. In our experience, after ablation the LA diameters decrease and LA contractile function is improved but the magnitude of this benefit mainly depends on the atrial dimensions before ablation (12,13). In patients without recurrences and with improved atrial transport and function (reverse atrial remodeling) we discontinue chronic anticoagulation therapy.

**Postablation AT.**

If end points are successfully achieved in the index procedure, postablation ATs may develop in less than 5% of patients (5), and usually are macro or microreentrant gap-related rather than focal tachycardias (Figure 7). In our extensive experience, these ATs should initially be treated conservatively, with medical therapy and cardioversion. Only incessant ATs in symptomatic patients require a repeated procedure to optimize ablation therapy which will lead to a cure in most cases (5,16,17). Ablation should be tailored to the arrhythmia mechanism rather than performing empiric lesion lines. Close inspection of the 12-lead ECG with P-wave morphology and axis evaluation should be done initially since continuous activation suggests a macroreentrant mechanism, whereas a clear isoelectric baseline between P waves suggests a focal mechanism. We routinely perform both activation and voltage maps combined with entrainment pacing maneuvers to optimize the ablation therapy. Usually, the activation map reveals earliest and latest activations in different colors relative to the reference site within a time window equal to the tachycardia cycle length. The commonest postablation AT is macroreentrant (> 80% of the cycle length) mitral annular tachycardia. Entrainment with post-pacing intervals (PPI) ≈ tachycardia cycle length (TCL) from ≥ 3 sites around the superior and inferior mitral annulus, with an activation time around the mitral annulus ≈ to the AT cycle length strongly suggests a mitral annular AT. Like the right atrial isthmus dependent flutter, the narrowest area of the circuit is between the LIPV and the mitral annulus and the most appropriate approach is to perform reablation of the mitral isthmus looking for residual gaps. For focal microreentrant ATs (<80% of the cycle length) originating from reconnected PV ostia, ablation of sites with earliest activation that demonstrate concealed entrainment will usually be successful. Frequently, voltage maps show areas of preserved voltage at the site of earliest activation suggesting areas not previously targeted or incompletely ablated during the index procedure (Figures 3 and 4). Reentry around left or right PVs can be demonstrated by proximal and distal coronary sinus, left atrial roof and septal pacing. Their management requires the use of 3-D activation maps for delineating the tachycardia course, and for deploying a lesion line connecting anatomic obstacles to interrupt AT circuits (Figure 7). RF applications are delivered after critical isthmuses have been identified by detailed electroanatomic maps and concealed entrainment (5). Usually, few RF applications on the critical isthmus are sufficient to eliminate such tachycardias and their inducibility, but in some cases a further ablation line is required (5, 14-16). Successful ablation is defined as termination of
tachycardia during ablation and non-inducibility of the same tachycardia morphology with burst pacing and/or programmed pacing.

**Anticoagulation concerns**

Stroke is a potential and feared complication of AF ablation particularly if one considers the possibility of asymptomatic ischemic events. To prevent stroke or thromboembolic events in patients not already receiving chronic anticoagulation, TEE is performed with short-term anticoagulation therapy instead of a 3-week course.

**Preablation anticoagulation issues.**

Like patients with permanent AF, patients at risk (patients with persistent AF or those with paroxysmal AF and/or with associated risk factors) require oral anticoagulation therapy with at least 3 weeks of documented INRs values, and should undergo bridging with intravenous heparin or subcutaneous low molecular weight heparin before ablation. We also recommend TEE for any patient presenting in AF who has not undergone oral anticoagulation therapy with bridging before ablation.

**Anticoagulation therapy during the ablation procedure.**

Anticoagulation should be established after transseptal puncture and in some cases ACT can be tailored up to >300 seconds if necessary to reduce sheath thrombus risk, any direction and steered by the magnetic field. Because magnetic fields vectors are capable of tip orientation, at present its movements can be guaranteed by a mechanical device (Cardiodrive, Stereotaxis). Magnetic field vectors for each target navigation and ablation can be stored and reapplied while the magnetic catheter is navigated automatically for auto-ablation (Figure 8). An accurate electroanatomical map can be performed using an automated mapping function present in the Navigant software specifically designed for mapping of the LA. Additional points can be taken manually in areas of interest accounting for clustering of points in specific areas. Sequential acquisition of many points all around the left atrium by a stable wall contact of the catheter tip allows to create accurately cardiac geometries particularly in challenging areas, with impressive levels of detail, incredible speed and efficiency. In our experience, remote mapping and ablation can be safely achieved in all patients undergoing AF ablation. Initially, the procedure times were a little longer than manual cases, due to the learning curve which at the beginning requires frequent adjustments of the tip’s orientation. Ablation time to complete the lesion lines around challenging areas like right-sided PVs is shorter remotely, which indicates that there are no difficult sites as with standard CPVA, thus avoiding unnecessary RF energy applications which may be associated with residual gaps and risk of major complications. Based on our experience, the remote mapping and ablation system has many advantages but there are some limitations which can be overcome in the next future.

**Advantages of the remote system.**

Since its orientation is guided entirely by a magnetic field and no deflection wires are required, the RMT catheter is far softer than the traditional deflectable catheters along its distal segment. If the catheter does not reach the programmed location because of anatomic obstacles the operator simply withdraws the catheter from the obstacle, and then re-advances it to the desired location with additional manipulations of the magnetic field. This results in reduced endocardial trauma and the risk of cardiac perforation is even lower. Consistent with this notion, no cardiac perforation has been reported during mapping of the thin-walled left atrium. The “softer touch” of the RMT catheter causes less deformation of cardiac chambers compared with manual mapping which results in a more accurate reconstruction with a minimal amount of fluoroscopy. There will be further reductions in radiation exposure for both patients and operators once MNS-compatible, irrigated tip catheters become available for clinical use.

**Limitations of remote technology.**

There are limitations to this system which can be overcome rapidly by advancing technology. The size and position of the floor magnets on either side of the patient, may partially limit the fluoroscopic visual field during the procedures. However, in our experience it is possible to

**Postablation anticoagulation strategy.**

The best anticoagulation protocol after ablation according to the clinical characteristics and thromboembolic risk has not yet established. Due to the risk of embolic
events in the early postprocedural period, maintenance of oral anticoagulation is done in all patients during the first 3.4 months after CPVA. In selected patients without evidence of recurrent AF at 4-6 months after ablation we discontinue warfarin and start aspirin (75-325 mg/day). However, patients at high risk of stroke according to guidelines may continue warfarin despite no AF recurrence while those with moderate risk factors are advised to take aspirin or nothing.

**Remote mapping and ablation with Stereotaxis**

Currently, most catheter ablation procedures in patients with AF are performed with manual catheters which requires advanced operator skills and experience with catheter manipulation and ablation. In a modern electrophysiology laboratory, the addition of remote magnetic navigation can eliminate hand motion as a variable and provide more precision thus enhancing reproducibility of results. The feasibility of the remote system, which is not operator-dependent, may represent an attractive alternative approach in many laboratories worldwide to reproduce the success rates of the pioneering groups while minimizing risks (16,19-21). The recent availability of remote tip irrigated magnetic catheters will enhance the benefits of the remote system making deeper lesions as with manual catheters regardless of the operator’s experience. We have demonstrated that remote navigation technology may facilitate both mapping and ablation in patients with AF independent of operator dexterity (19). The Magnetic Navigation System (MNS) uses soft catheters equipped with 3 small magnets embedded in the tip for accurate catheter orientation in the magnetic field generated by using two large magnets positioned on either side of the procedure table. This system consists of two independent but communicating components: the Niobe® Stereotaxis MNS (Stereotaxis, Inc., St. Louis, MO) and an electroanatomic mapping system (CARTO-RMT, Biosense Webster, Inc., Diamond Bar, CA). The Niobe includes a computer interface system (Navigant), which is controlled by a keyboard and joystick which in turn change the two magnets’ orientation modifying the magnetic field and thus the catheter tip orientation and location. The operator stays in a separate room, virtually at any distance from the X-ray beam and the patient’s body. This system is combined with the CARTO mapping system, which has been modified to be able to function in this magnetic environment. A 4-8mm tip magnetic catheter (NaviStar-RMT, Biosense Webster, Inc.) can be connected with CARTO-RMT but tip irrigated catheters are available now in Europe. The three magnets in the distal portion of the catheter can be deflected in any direction and steered by the magnetic field. Because magnetic fields vectors are capable of tip orientation, at present its movements can be guaranteed by a mechanical device (Cardiodrive, Stereotaxis). Magnetic field vectors for each target navigation and ablation can be stored and reapplied while the magnetic catheter is navigated automatically for auto-ablation (Figure 8). An accurate electroanatomical map can be performed using an automated mapping function present in the Navigant software specifically designed for mapping of the LA. Additional points can be taken manually in areas of interest accounting for clustering of points in specific areas. Sequential acquisition of many points all around the left atrium by a stable wall contact of the catheter tip allows to create accurately cardiac geometries particularly in challenging areas, with impressive levels of detail, incredible speed and efficiency. In our experience, remote mapping and ablation can be safely achieved in all patients undergoing AF ablation. Initially, the procedure times were a little longer than manual cases, due to the learning curve which at the beginning requires frequent adjustments of the tip’s orientation. Ablation time to complete the lesion lines around challenging areas like right-sided PVs is shorter remotely, which indicates that there are no difficult sites as with standard CPVA, thus avoiding unnecessary RF energy applications which may be associated with residual gaps and risk of major complications. Based on our experience, the remote mapping and ablation system has many advantages but there are some limitations which can be overcome in the next future.

**Advantages of the remote system.**

Since its orientation is guided entirely by a magnetic field and no deflection wires are required, the RMT catheter is far softer than the traditional deflectable catheters along its distal segment. If the catheter does not reach
the programmed location because of anatomic obstacles the operator simply withdraws the catheter from the obstacle, and then re-advances it to the desired location with additional manipulations of the magnetic field. This results in reduced endocardial trauma and the risk of cardiac perforation is even lower. Consistent with this notion, no cardiac perforation has been reported during mapping of the thin-walled left atrium. The “softer touch” of the RMT catheter causes less deformation of cardiac chambers compared with manual mapping which results in a more accurate reconstruction with a minimal amount of fluoroscopy. There will be further reductions in radiation exposure for both patients and operators once MNS-compatible, irrigated tip catheters become available for clinical use.

**Limitations of remote technology.**

There are limitations to this system which can be overcome rapidly by advancing technology. The size and position of the floor magnets on either side of the patient, may partially limit the fluoroscopic visual field during the procedures. However, in our experience it is possible to fluoroscopically visualize the entire atrial cavity, even in patients with dilated atrial chambers which may require a larger field of visualization. Nonetheless, this does not represent a major limitation since the need for fluoroscopy is greatly minimized by electroanatomical mapping. The current availability of irrigated-tip catheters certainly represents an important tool, particularly in patients with permanent AF who require more extensive ablation. In the next future as irrigated catheters can be compatible with the remote system it will be possible to conduct randomized studies comparing standard and remote AF ablation.
Fig. 1 Pre-and post-ablation color-coded voltage maps of the left atrium by CARTO (Panel A) and NavX (Panel B) systems with typical circumferential lesions as performed by CPVA are shown in the postero-anterior anatomic view. Note that inside encircled areas no voltage gradients are evident (red color).
Fig 2 During RF applications local atrial potentials on the lesion lines and within encircled areas become wider and lower (black), completely disappearing (light blue) within 20-50 seconds.
Fig. 3 At beginning of RF applications around the left superior PV (ablation site on the pre-ablation voltage map) a vagal reflex is elicited (RF1), attenuated (RF2), and then abolished (RF3). Of note, the ablation site at which the vagal reflex was evoked is included in the standard lesion set (post-ablation voltage map). As shown, the reflex resulted in hypotension and high degree AV block.
Fig. 4 Anatomical map reconstructed by NavX guidance in a patient with permanent AF. After completing the standard CPVA lesion set, atrial fibrillation becomes more organized and slower resembling an AT (cycle length 540 ms) which after coronary sinus disconnection promptly converts to sinus rhythm (cycle length 660 ms). On the map CS geometry is depicted in red and RF applications are tagged in green. CS disconnection is performed under electroanatomic
Fig. 5 Post-ablation anatomic maps under NavX guidance of the left atrium with simultaneous intracardiac recordings. The coronary sinus geometry is represented in red. Note the shape of 2 catheters, of which one is inside the coronary sinus (yellow) as reference catheter and the other around the right PV ostium (white with green tip) for mapping and ablation. After ablation local atrial potentials around the right superior PV are dissociated from LA or completely absent indicating PV disconnection (Panels A and B).
Fig. 6 Post-ablation anatomic maps under NavX guidance with simultaneous intracardiac recordings in a patient with permanent AF. The coronary sinus shape catheter is represented in yellow and the tip irrigated ablation catheter in green. After completing the lesion set, atrial fibrillation still persists but becomes slower and more organized. An additional ablation line to further reduce the substrate results in a further increase of the cycle length before conversion to sinus rhythm.