During the past decade, radiofrequency ablation (RFA) has revolutionized care for patients with commonly occurring arrhythmias, including atrial fibrillation, atrial flutter, and supraventricular tachycardia. Even complex arrhythmias such as ventricular tachycardia and ventricular fibrillation are now being treated with advanced imaging, mapping, and ablation systems.

Premature ventricular contractions (PVCs), when occurring sporadically, are considered normal. Patients with cardiomyopathy often have more frequent PVCs, and by themselves the PVCs are not thought to confer incremental risk for sudden death beyond that represented by the patient’s depressed ventricular function.

**Which Came First?**

“When PVCs and cardiomyopathy coexist, 2 possibilities need to be considered: first, that the PVCs are a result of the myocardial disease process giving rise to depressed ventricular function, that is, the PVCs result from the cardiomyopathy; or second, that the PVCs, because of their frequency, cause myocardial dysfunction and give rise to the cardiomyopathy (tachycardia-related cardiomyopathy),” says Samuel J. Asirvatham, MD, an invasive electrophysiologist at Mayo Clinic in Rochester. “A recent target for RFA has been the site of origin for frequent PVCs, curing certain patients’ cardiomyopathy.”

**Case History**

A previously active 19-year-old man presented with fatigue and exertional dyspnea. Echocardiography revealed systolic dysfunction and an ejection fraction of 26%. Further investigations were negative for coronary artery disease, coronary anomalies, ventricular dysplasia, or evidence of myocarditis. Frequent PVCs were seen on a routine 12-lead electrocardiogram (Figure 1). A 24-hour Holter monitor recording showed 28,000 PVCs, nearly all of similar QRS morphology. A 9-month trial of β-blockers at increasing doses was ineffective in reducing PVCs, decreasing symptoms, or improving ventricular function. Subsequently, an electrophysiologic study and RFA procedure were performed. A single focus giving rise to the PVCs was mapped to the region of the left coronary cusp of the aortic valve. Radiofrequency energy was delivered at the site and eliminated the PVC. The patient felt much better 3 months after the ablation, and repeated echocardiography showed an improved ejection fraction of 67%. No recurrence of PVCs or ventricular dysfunction was noted at follow-up 1 year after ablation.

**Comment on the Case**

Clinicians encounter a large number of patients who have cardiomyopathy and PVCs noted on Holter monitor. “How does one recognize which of these myriad patients represents an opportunity to effect cure from myocardial dysfunction by ablating their PVCs?” asks Dr Asirvatham.
vatham. Most patients with cardiomyopathy (ischemic and nonischemic) will have relatively infrequent PVCs (fewer than 5,000 per day), and the morphology of these extrasystoles will vary. Often, at least 5 or 6 clearly different morphologies will be noted on careful review of 24- or 48-hour Holter monitor recording. Relatively healthy patients with no clinical evidence of ischemia or myocarditis who had more than 10,000 PVCs in a 24-hour period are more likely to have a reversible cause of cardiomyopathy caused by the PVCs. Importantly, the PVCs appear to be arising from a single focus, as recognized by an identical QRS morphology for each of these beats. Further, often the PVC morphology is of either right or left bundle branch block pattern, with a strong inferior axis (all R-waves) in leads II, III, and aVF (Figure 1). These differences are summarized in the Table.

### Anatomic Substrate for Frequent Ectopy
In the patients where PVC ablation completely reverses myocardial dysfunction, there is no underlying pathology in the ventricular myocardium. What then gives rise to these frequent PVCs? The answer to this question is not completely known, says Dr Asirvatham. However, anatomic dissections have shown myocardial sleeves that extend beyond the semilunar valves of the great arteries (Figure 2). This structure is analogous to the finding of myocardial extension into the pulmonary veins, now thought to be the substrate for most patients with atrial fibrillation. The eventual successful site of ablation and the QRS morphology described in many patients with PVC-induced cardiomyopathy is consistent with arrhythmia that originates at or near the semilunar valves. Other possibilities include embryonic remnants of conduction tissue or autonomic ganglia located near the valves causing the arrhythmia.

### Radiofrequency Ablation
Because the cause for the frequent PVCs is a localized area of myocardium, radiofrequency ablation is highly effective and often curative. Spontaneously occurring PVCs or those induced with adrenaline-like drugs are mapped to find the earliest myocardial site of activation before the onset of the surface QRS complex. This earliest site is then targeted for radiofrequency energy delivery, which then ablates (burns) the source of the PVC.

### Technological Advances That Aid Ablation
Several difficulties arise when attempting to ablate frequent ectopy. Various new technologies have been developed to specifically address the commonly encountered sources of difficulty.

The ventricular outflow tract and the fascicular system represent among the most complex anatomic structures encountered by ablationists (Figure 3). To aid accurate mapping and identification of the exact site of origin of an abnormal electrical signal and to catalog activation times in the 3-dimensional complex geometric milieu, electroanatomic mapping (cataloging activation point in 3 dimensions) and intracardiac ultrasound have been developed. Use of these advanced technologies has greatly facilitated the treatment of these difficult arrhythmias.

PVCs may be very infrequent or may be associated with significant hemodynamic consequences (ventricular tachycardia) such that detailed point-to-point mapping is precluded. In these situations, an intracavitary balloon catheter that does not make contact with the myocardial wall can be very helpful. This system (noncontact mapping) theoretically allows the exact definition of the site of origin to origin of ventricular tachycardia, even from a single beat of arrhythmia (Figures 4 and 5).

### Table. PVCs and Cardiomyopathy

<table>
<thead>
<tr>
<th></th>
<th>PVCs associated with cardiomyopathy</th>
<th>PVCs causing cardiomyopathy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patient characteristics</strong></td>
<td>Older patients with known cardiovascular disease</td>
<td>Otherwise healthy individuals</td>
</tr>
<tr>
<td><strong>Comorbid conditions</strong></td>
<td>Hypertension, ischemic heart disease, myocarditis, family history of myocardial disease</td>
<td>Often no prior cardiac or major medical or family history</td>
</tr>
<tr>
<td><strong>Ejection fraction</strong></td>
<td>Depressed</td>
<td>Depressed</td>
</tr>
<tr>
<td><strong>Frequency of PVCs</strong></td>
<td>&lt;5,000/24 hours</td>
<td>&gt;10,000/24 hours, often &gt;20,000/24 hours</td>
</tr>
<tr>
<td><strong>Pattern of PVCs</strong></td>
<td>Multiple morphologies</td>
<td>Monomorphic</td>
</tr>
<tr>
<td><strong>QRS morphology</strong></td>
<td>Nonspecific</td>
<td>Outflow tract morphology (right or left bundle branch block pattern with inferior axis)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fascicular morphology (typical right bundle branch block pattern with superior axis)</td>
</tr>
<tr>
<td><strong>Response to radiofrequency ablation</strong></td>
<td>Only required if associated with ventricular tachycardia that has been triggering frequent ICD shocks No effect on the ventricular function</td>
<td>Normalization of ventricular function frequently seen</td>
</tr>
</tbody>
</table>

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**Figure 2.** Noncontact map that identifies the origin of PVCs, in this instance arising from above the pulmonary valve. Myocardial extension above the semilunar valves may give rise to ventricular tachycardia or frequent ectopy and can be targeted for radiofrequency ablation.
The risks associated with radiofrequency ablation for PVCs depend in part on the ventricular chamber in which radiofrequency energy is delivered. While bleeding, infection, and cardiac perforation may occur with any ablation procedure, thromboembolic stroke is specific to ablation in the left-sided circulation. Another potential hazard for bleeding in the left-sided circulation is injuring the coronary arteries when ablating above the semilunar valve. Using intracardiac ultrasound, coronary angiography, or both can mitigate this risk.

Role for Medical Therapy and Device Implantation

In some patients with frequent PVCs, despite using the criteria mentioned (Table), it can be difficult to counsel patients on the likelihood that ablating their PVCs will improve ventricular function. Here, the electrophysiologist must also decide whether ablation is not to be performed, then because of the decreased ventricular function, debrillator implantation for the primary prevention of sudden cardiac death may be required. A useful maneuver in that instance is to use antiarrhythmic therapy to ameliorate PVCs and see if there is a response in ventricular function. In general, antiarrhythmics are not particularly effective in suppressing frequent PVCs. An exception to this rule is the drug amiodarone. While amiodarone successfully decreases PVC frequency, its adverse effect profile precludes long-term use, particularly in young patients. Thus, when doubt exists as to whether PVCs in a given patient are causing cardiomyopathy, a brief trial of amiodarone (3 to 6 months) can be instituted. “If, when PVCs subside, cardiac function improves, then amiodarone can be discontinued and the PVC focus targeted for ablation using one of the advanced imaging/mapping systems,” says Dr. Asirvatham. “On the other hand, if there was no discernible benefit to getting rid of PVCs on ventricular function recovery, then the risks involved with ablation are not warranted unless the PVCs themselves are symptomatic.”

Physicians should be aware that certain patients who are otherwise healthy but present with myocardial dysfunction and have documented frequent monomorphic PVCs can benefit and sometimes be cured of their cardiomyopathy with radiofrequency ablation of the PVC focus.
STEMI Protocol at Mayo Clinic Rochester Reduces Time to Treatment in Acute Myocardial Infarction

In patients with ST-elevation myocardial infarction (STEMI), the prompt restoration of coronary blood flow reduces infarct size and improves survival. Delays in patient presentation to the emergency department, diagnostic difficulties, transport times, and impediments to rapid administration of fibrinolytic therapy or mobilization of the cardiac catheterization team can prolong the time to treatment for these patients. Mayo Clinic in Rochester has implemented an evidence-based protocol to improve time to treatment for patients presenting with STEMI to its Rochester hospitals and a regional network of 28 hospitals located within a 150-mile radius of Rochester, Minnesota. This quality improvement project has been led by Henry H. Ting, MD, an interventional cardiologist at Mayo Clinic in Rochester.

“Fibrinolytic agents are most effective when administered within 2 to 3 hours from symptom onset when primary percutaneous coronary intervention (PCI) cannot be performed rapidly,” says Dr Ting. “The ACC/AHA Guidelines recommend a door-to-balloon time of less than 90 minutes for all patients with STEMI, including those who present directly to or are transferred to a PCI center, to maximize myocardial salvage and survival.” Less than 25% of acute care facilities in the United States have 24/7 on-site PCI capabilities, so there is additional interest in reducing time to treatment for these patients who require transfer to a PCI-capable hospital.

Dr Ting continues: “There is an important gap in current understanding of how to implement processes and systems of care for timely reperfusion to a regional population and regional network of hospitals. We designed an evidence-based protocol and implemented this in real-world practice to improve time to treatment and outcomes in patients presenting with STEMI to both Mayo Clinic in Rochester and regional hospitals, with and without on-site PCI capability.”

The protocol includes emergency department activation of the cardiac catheterization laboratory without review or approval by cardiology, a single call system to activate the entire catheterization team, and a commitment from the catheterization lab to be fully operational within 30 minutes after activation. Specific process changes have been implemented:

• Prioritizing electrocardiography in all patients presenting with chest pain within 5 minutes.
• Empowering the emergency department physician to directly activate the cardiac catheterization laboratory team without requiring a cardiovascular medicine consultation.
• Parallel-display paging process to activate the cardiac catheterization team.
• Web-based, prospective data acquisition for continuous quality improvement.

These changes have resulted in a reduction in the median door-to-balloon time from 98 minutes in May 2003 to 67 minutes in May 2008 (31.6% decrease).

Patients who present to regional hospitals are treated with a fibrinolytic agent, followed by early invasive PCI (within 3 hours after onset of symptoms) or transferred for primary PCI (if onset of symptoms occurred more than 3 hours previously). The 28 regional hospitals located within 150 miles of Rochester have an estimated time of less than 120 minutes from first hospital door to primary PCI at Saint Marys Hospital in Rochester. Patients undergo early rescue PCI for suspected failure to reperfuse after fibrinolytic administration and undergo routine elective catheterization within 24 to 48 hours if reperfusion has been achieved. Inclement weather prohibits helicopter and ground transport up to 5% of the time. Patients who are at high clinical risk (such as cardiogenic shock or persistent ventricular arrhythmias), have contraindications to fibrinolytic therapy, or have an uncertain diagnosis, including equivocal electrocardiographic findings, are transferred for primary PCI.

Specific elements of the transfer protocol include the following:
• Standardized protocol for selecting fibrinolysis or primary PCI as the reperfusion strategy.
Mayo Clinic in Jacksonville Opens New Hospital

Mayo Clinic’s new hospital opened in Jacksonville on April 12, representing a long-awaited dream of creating a fully integrated medical campus with inpatient and outpatient services “under one roof.” The new hospital serves Jacksonville residents as well as regional, national, and international patients. The new 650,000-square-foot hospital combines the best of high technology and safety with the highest level of patient care and attention. Modern equipment and advanced technologies are used in a nurturing, friendly environment, merging the art of healing with the science of medicine.

Currently, the hospital has 214 beds; long-range plans allow for further expansion up to 16 floors and 500 beds to meet future market needs. The surgical suite includes 16 oversized operating rooms, and the intensive care/critical care unit has 30 beds. Computerized systems and Mayo’s electronic medical record help expedite the flow of decision-making information to physicians. The Emergency Department, open to all, has a special chest pain observation unit, a comprehensive stroke center, and a helicopter landing pad for air ambulance service.
Minimally Invasive Robotic and Thoracoscopic Cardiac Surgery

The use of high-definition imaging systems and robotic technology now allows complex cardiac surgery to be carried out via small incisions with the complete avoidance of sternotomy. The putative benefits of such an approach include a decreased length of ventilator support, decreased blood transfusion, shorter hospital stay, decreased postoperative functional limitation, and quicker return to normal activity. The current role of minimally invasive and robotic surgery in the cardiovascular surgery practice at Mayo Clinic in Rochester includes mitral valve repair, tricuspid valve repair, atrial fibrillation surgery, and congenital surgery.

“Although cardiac surgery performed via a median sternotomy provides excellent exposure to the heart and great vessels, the necessary limitation in upper extremity mobility while sternal union occurs often precludes early return to functional activity,” according to Rakesh M. Suri, MD, DPhil, a cardiovascular surgeon at Mayo Clinic in Rochester.

From an anatomic perspective, surgical access to the mitral and tricuspid valves along with the atria and the interatrial septum can be obtained easily via an incision in the right chest. “A small right anterolateral thoracotomy permits direct visualization of the atrial aspects of the atrioventricular valves,” says Harold M. Burkhart, MD, a cardiovascular surgeon at Mayo Clinic in Rochester. “It is this convenient alignment that potentiates the ability to perform intracardiac procedures through a small, well-tolerated incision in the right chest wall.”

Facilitating Technology

Whenever the heart is opened, even though the incisions are considered “minimally invasive,” cardiopulmonary bypass is necessary to ensure a still, bloodless field during surgical manipulation of intracardiac structures. Traditional aortoatrial cannulation performed via median sternotomy has evolved into a small 1.5- to 2-cm groin incision for near-percutaneous femoral arterial/vein cannulation, permitting full cardiopulmonary bypass support. Cardiac arrest is achieved by using a trans-thoracic cross-clamp and direct cardioplegia instilled into the aortic root.

The distance to the atrioventricular valves makes the right mini-thoracotomy approach using only the naked eye more challenging than conventional open surgery. The technically simplest option to facilitate surgical visualization is a thoracoscopic approach using a high-definition video thoracoscope and long, shafted instruments. “The appeal of this approach is that it is simple, requires minimal equipment, and may be quickly set up and dispersed,” says Dr Suri. “The limitations of thoracoscopic surgery include suboptimal exposure in certain situations and the relative difficulty of performing fine technical manipulations at the valve/subvalvar level.” Despite this, mitral and tricuspid valve procedures along with congenital, atrial septal, and arrhythmia surgery can all be performed using a purely thoracoscopic approach.

The next tier of technical sophistication in minimally invasive valve surgery involves use of a robotically assisted platform (da Vinci Surgical System; Intuitive Surgical, Sunnyvale, California). The robotic system has a central computer processor that allows the surgeon to manipulate multiple instruments simultaneously (Figure 1). The high-definition robotic system currently in use at Mayo Clinic allows 3 instruments to be used concurrently in addition to the camera, permitting the surgeon to shift quickly between control of the dynamic atrial retractor and robotic arms to expose, visualize, and manipulate cardiac tissue. The robotic arms are designed to mimic the movements of a surgeon’s hands. The surgeon operates from a console, surrounded by a 3-dimensional view of the operative field. “The computer processor reproduces hand movements of the surgeon in a scaled manner, translating them into real-time movement of instruments mounted on robotic arms through chest wall ports,” says Dr Burkhart. The robotic instruments are not only shafted (long conventional instruments with a shaft but no articulation) but also “wristed,” thereby permitting more natural manipulation of suture and tissue. Robotic technology allows the surgeon to approach and, in some instances, exceed the level of technical precision possible with a traditional open-chest approach.
Robotic Mitral Valve Repair

Mitral valve repair bestows a survival benefit in those with severe mitral valve regurgitation due to leaflet prolapse in the absence of symptoms—even when ventricular function is normal. The availability of reproducible valve repair techniques as a safe and durable alternative to prosthetic replacement has dramatically influenced the indications for surgical intervention in patients with mitral regurgitation due to leaflet prolapse. With successful valve repair, patients who maintain sinus rhythm resume full activities without the need for chronic anticoagulation. The evolution in operative techniques has led to predictable and durable results after mitral valve repair. “In our practice at Mayo Clinic in Rochester, more than 95% of patients with pure mitral valve regurgitation due to degenerative disease undergo valve repair rather than prosthetic replacement,” says Dr Suri.

The “Mayo mitral repair” differs from techniques used at other institutions and is based on the premise that eliminating only the redundant prolapsing leaflet edge from the coaptation margin using a simple triangular resection (Figure 2) followed by suture reconstruction (Figure 3) is sufficient, expedient, and durable. All repairs are protected with a 63-mm posterior annuloplasty band anchored between right and left fibrous trigones (Figure 4). Anterior leaflet pathology is routinely corrected by resuspension of the leading edge using artificial neochordae. Bileaflet disease is addressed using a combination of these techniques. With simplified methods of leaflet repair and annuloplasty reinforcement, the rate of reoperation after correction of posterior leaflet prolapse at Mayo Clinic is approximately 0.5% per year, and rates of reintervention after repair of anterior or bileaflet prolapse are similarly low (1.6% and 0.9% per year, respectively). Indeed, the durability of mitral repair for all leaflet prolapse subsets in the current era is similar to that seen after mitral valve replacement (re-repair rate of 0.74% per year overall).

Despite the proven advantages, the psychological barrier associated with the referral of an otherwise healthy, asymptomatic patient for cardiac surgery has in some instances prevented the widespread acceptance of early mitral valve repair for leaflet prolapse in some areas, even to centers where the incidence of repair (rather than replacement) is higher than 95%. Mayo mitral valve repair techniques are perfectly suited to the robotic platform. Robotically assisted mitral valve repair of middle scallop posterior leaflet prolapse at Mayo Clinic currently involves a traditional posterior resection precisely performed using the 3-dimensional 10 magnification with the high-definition robotic camera. The leaflet is then reconstructed robotically with a 2-layer polypropylene suture closure. A standard-length 63-mm posterior annuloplasty band is then anchored into the posterior mitral anulus between right and left fibrous trigones using interrupted sutures placed by robotic instruments; the annuloplasty band both reduces the posterior mitral anular circumference and protects the leaflet closure. The placement of artificial neochordae is similarly done using the robotic platform. Visualization of the subvalvar apparatus (composed of the papillary muscles and chordae tendineae) is sometimes difficult via median sternotomy, leading to the labeling of anterior/bileaflet prolapse as “complex” valve disease. In contrast, using robotic assistance, the surgeon’s view of the mitral valve is often direct and uncompromised. The surgeon is able to precisely determine which leaflet segments are unsupported and resuspend them to the appropriate lengths with artificial neochordae. Robotic instruments are suited to tailoring neochordae by referring to the lengths of more normal adjacent cords. “The robotic platform allows us to perform the same mitral repair as we would via an open-chest sternotomy through small ports in the right chest wall,” says Dr Burkhart.

Robotic Atrial Septal Defect Repair

Surgical techniques have also evolved in the repair of atrial septal defects, including the patent foramen ovale. Currently, when surgical closure is required for atrial septal defects, the procedure can be performed by accessing the heart through the right chest with small port incisions and robotic assistance. Cardio-pulmonary bypass techniques are similar to those of the robotically assisted mitral valve repair. The defect may be closed primarily or with a pericardial patch harvested with the aid of the robotic instruments.

Conclusion

Mayo Clinic patients now benefit from less invasive robotic and thoracoscopic methods of performing traditional cardiac surgical procedures. Complex valve repairs and congenital procedures along with arrhythmia surgery are routinely and successfully carried out, with the same excellent results achieved by conventional techniques.
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