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Arrhythmia (D Spragg, Section Editor)

How to Approach Difficult Cases of AVNRT

Darpan S. Kumar, MD
Thomas A. Dewland, MD
Seshadri Balaji, MBBS
*Charles A. Henrikson, MD**

Address
*Knight Cardiovascular Institute, Oregon Health & Science University,
3181 SW Sam Jackson Park Road, UHN62, Portland, OR, 97239, USA
Email: henrikso@ohsu.edu

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Opinion statement

Our approach to the ablation of atrioventricular nodal reciprocating tachycardia (AVNRT), the most common supraventricular tachycardia, is as follows: We first attempt ablation in the right atrial posteroseptum anterior to the coronary sinus ostium with a 4-mm non-irrigated tip catheter. If ablation within the triangle of Koch is unsuccessful with radiofrequency (RF), we switch to cryoablation and target a more superior (mid septal) region. We also utilize cryoablation if RF ablation produces transient VA block (absence of retrograde conduction during junctional rhythm) or a fast junctional rhythm (<350 msec). If cryoablation were to fail, or is not available, we would then suggest ablation within the coronary sinus targeting the roof (2–4 cm from the os) using a 3.5-mm irrigated tip catheter. If tachycardia were still inducible despite these measures, we would then proceed with transseptal puncture (given our greater experience with this over a retrograde aortic approach) and perform RF ablation along the posteroseptal left atrium and inferoseptal mitral annulus utilizing an irrigated tip catheter. In our experience, cryoablation reliably results in elimination of the slow pathway. The only left atrial ablation for AVNRT at our institution in the past year was performed because a patent foramen ovale allowed for rapid left atrial access, facilitating left atrial ablation of the slow pathway.

Introduction

Atrioventricular nodal reciprocating tachycardia (AVNRT), first described in the 1950s [1], is the most common of the supraventricular tachycardias (SVTs). With advancements in interventional electrophysiology, proceeding directly to catheter ablation of this arrhythmia has become the standard of care given the high procedural success rate, infrequent recurrence, and rare complications [2••]. The purpose of this article is to provide insight into the techniques of catheter ablation of this arrhythmia.

Preparation for ablation/setup

Patients with symptomatic SVT who either prefer catheter ablation over medical therapy or who have failed medical treatment are appropriate candidates for invasive electrophysiology study (EPS) and ablation [2••]. In anticoagulated patients on warfarin, we continue the drug, but our preference is to have the international normalized ratio (INR) <3.5. For patients on a novel oral anticoagulant, we hold the morning dose (dabigatran and apixaban; rivaroxaban is continued the night prior to procedure).

The procedure is performed under light sedation to maximize the ability of clinical arrhythmia induction. In adults, we utilize bilateral femoral venous access and insert three 7-Fr sheaths for our diagnostic catheters and an 8-Fr sheath for the ablation catheter. The sheaths are 1-Fr size smaller in older pediatric patients (>25 kg in weight) and individualized in smaller children. The sheaths are attached to continuous infusion heparinized saline drips to minimize the risk of thrombus formation. Systemic heparin is not routinely administered unless left atrial access is obtained. Multielectrode delectable catheters are placed in the high right atrium (HRA), the right ventricle (RV), the coronary sinus (CS), and along the His bundle. A comprehensive EPS is performed to document the clinical arrhythmia and to definitively establish the diagnosis of AVNRT. Isoproterenol is often infused to assist with arrhythmia induction; inducible AVNRT is frequently encountered during isoproterenol "washout" (after continuous infusion is stopped but while drug effect is still evident). We proceed with ablation of AVNRT (Fig. 1) when (1) the clinical arrhythmia is induced and diagnostic maneuvers are consistent with AVNRT or (2) when the clinical arrhythmia is not inducible but the clinical presentation is consistent with AVNRT, dual AV node physiology is present, and there is no evidence of an accessory pathway or atrial tachycardia.

Radiofrequency catheter ablation of AVNRT

The use of energy delivered through an electrode catheter was first performed in the form of DC shocks positioned adjacent to the His bundle in the early 1980s resulting not only in freedom from arrhythmia but also in complete AV block [3, 4]. In 1989, selective modification of the AV node was first described with radiofrequency current application using a 6-F catheter in an attempt to eliminate AVNRT [5]. The anatomical boundaries of the fast and slow pathways were eventually elucidated and found to be contained within the triangle of Koch (Fig. 2). The fast and slow pathways were felt to breakthrough at the anterior septum near the His and posterior septum near the CS os, respectively [6]. Initial attempts at mapping the earliest retrograde atrial breakthrough during typical AVNRT lead to fast pathway modification near the His and a high incidence of irreversible AV block. Work in the early 1990s then showed

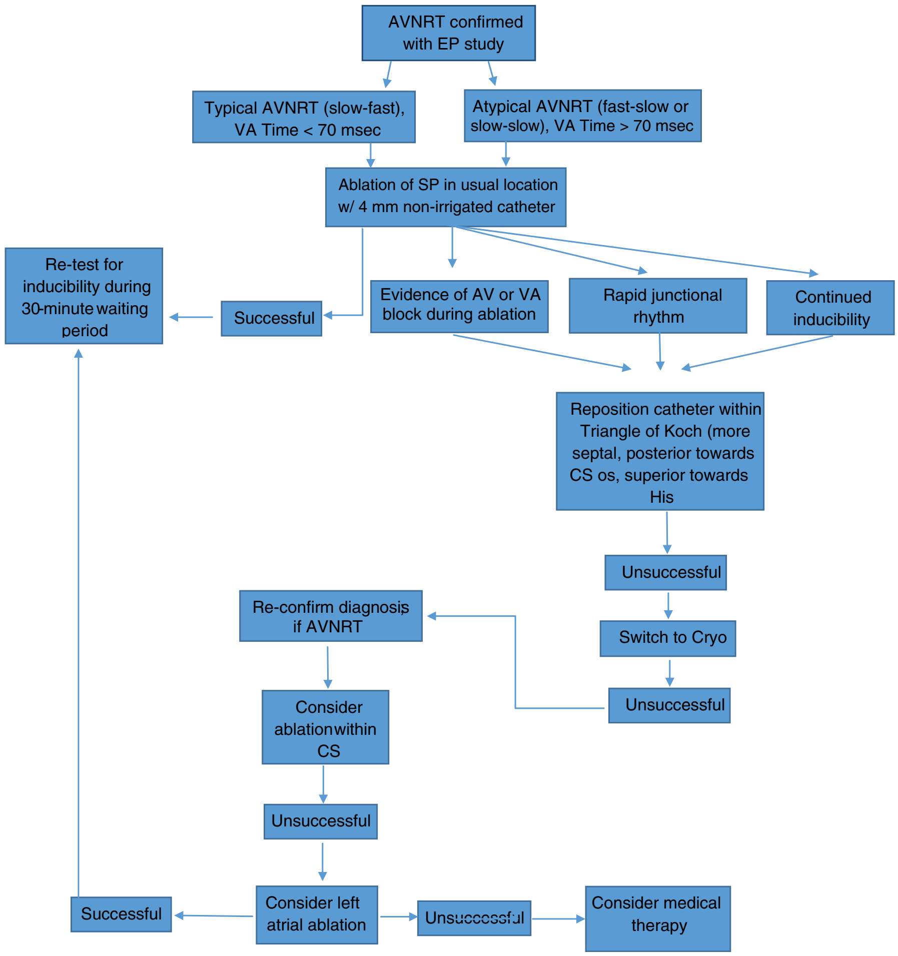

Fig. 1. Step-wise approach to ablation of AVNRT.

that slow pathway modification was a much safer method in eliminating AVNRT with low risk of recurrence and very little risk of AV block and thus has become the standard approach for ablation [6].

Our approach to slow pathway modification is to use a bi-directional 4-mm non-irrigated tip catheter (Biosense Webster, Diamond Bar, CA) for ablation. We use 3-D electroanatomic mapping (EnSite NavX, St. Jude, St. Paul, MN) in order to reduce procedure time, significantly reduce fluoroscopy exposure for both the patient and lab staff, and additionally provide anatomic visualization of structures otherwise not appreciated fluoroscopically [7, 8]. We have achieved significant reductions in fluoroscopy exposure using 3-D mapping for catheter manipulation through venous structures in addition to their placement in the heart, which can usually be performed without fluoroscopic guidance. This can be especially useful in children and adolescents in whom experience with fluoroless AVNRT ablation has shown promise [9]. The boundaries of the His are first annotated on the map, and a catheter with a reliable His signal is positioned for the duration of ablation. We use both anatomic and electrogram guidance for localization of the slow pathway. The ablation catheter is initially inserted into the RV with slight deflection keeping the tip of the

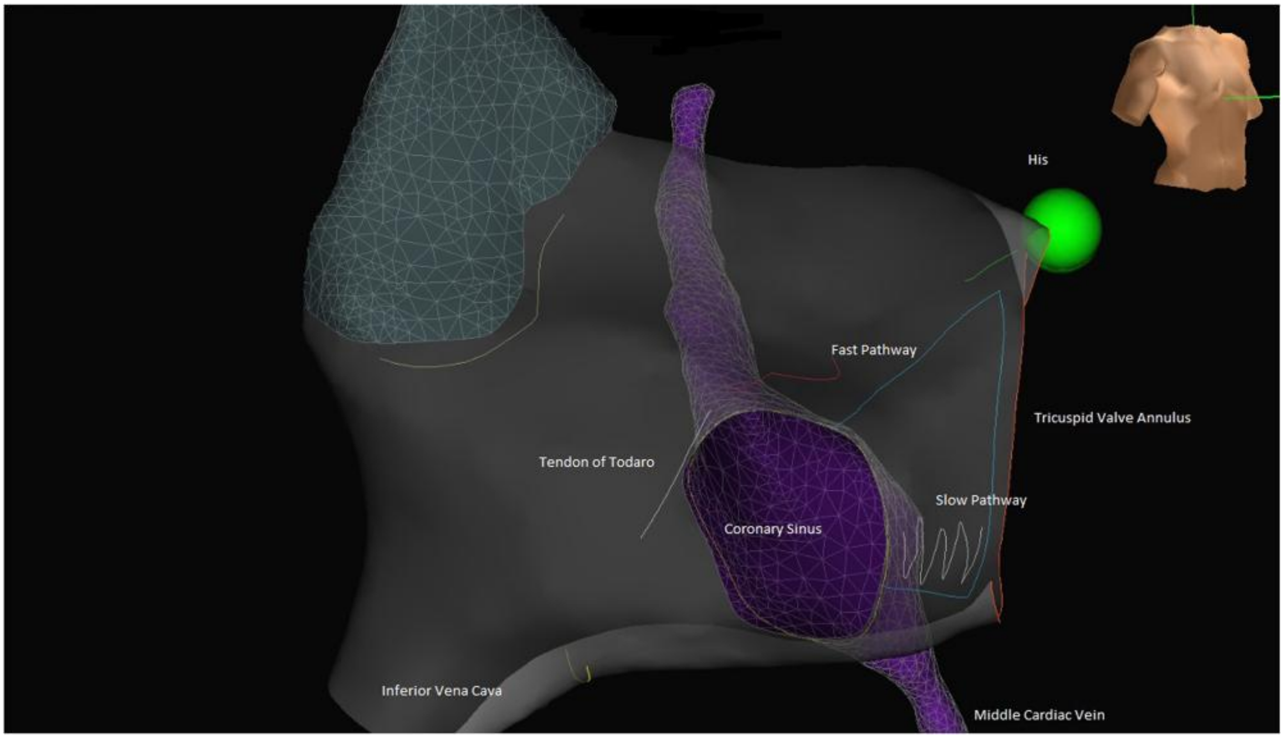

Fig. 2. A 3-D electroanatomic representation of the right atrium in right anterior oblique (RAO) using EnSite NavX (St. Jude Medical, St. Paul, MN). Anatomic landmarks of importance to AVNRT ablation are shown. The triangle of Koch (in *blue)* is bordered by the CS os posteriorly, anteroseptal leaflet of tricuspid valve anteriorly, and tendon of Todaro. The slow pathway is located near the base of the triangle while the His is located near the apex. Image courtesy of Brock Gambill and George Crowell, St. Jude Medical.

catheter pointed caudally. Clockwise torque on the catheter is applied so as to maintain a septal position, and the catheter is slowly pulled back until a 1:1 AV electrogram amplitude ratio is noted. The catheter is further withdrawn with continued clockwise torque until this ratio is 1:2 or 1:3 with fractionation of the atrial EGM. Fluoroscopic position of the ablation catheter in RAO is anterior to the CS os and inferior to the His catheter whereas in LAO, it is in the posteroseptal right atrium. We perform ablation in sinus rhythm for several reasons: (1) ablation in AVNRT with resultant termination to sinus during ablation could lead to the catheter jumping significantly from point of contact (2) a slow pathway activation potential is more likely to be evident, and (3) examination of the PR interval, discrimination of junctional beats from continued AVNRT, and presence of VA block are more apparent. Furthermore, in typical AVNRT, there is little utility in mapping the earliest retrograde atrial activation in tachycardia, which is near the apex of triangle of Koch (near the His). Radiofrequency (RF) is delivered in a temperature-limited mode at 60 °C and 50 W for 15–20 s or until the appearance of junctional beats. If a junctional rhythm is not observed, the ablation catheter is withdrawn away from the tricuspid valve annulus, closer to the CS ostium. It is well recognized that the presence of junctional beats is a marker of successful ablation. More specifically, the pattern of the junctional rhythm in regard to timing of onset, number of total beats, and duration is also useful in predicting the successful modification of slow pathway conduction [10–12]. Our approach is to stop ablation on the first emergence of a junctional response after which catheter position is reconfirmed and ablation is re-initiated. When apparent junctional beats are first seen, these may represent AV block with isoelectric dissociation, and continued ablation could result in complete heart block. Coming off at the first sign of junctional beats allows confirmation that these are junctional and decreases the risk of heart block. This process is repeated once more, and upon commencement of the third lesion, we proceed to ablate through the junctional rhythm completing a 45–60-s lesion, observing closely for the presence of VA block during junctional beats or a fast junctional rhythm (<350 msec) [13]. If VA block, defined as loss of retrograde conduction from the ventricle to the atrium during a junctional beat is noted, ablation is immediately terminated and the catheter is moved to prevent further delivery of energy to the site. During ablation, catheter position is constantly monitored using 3-D mapping and the AH interval is closely monitored to evaluate for any prolongation suggestive of impending AV block. If stability of the ablation catheter is suboptimal, a long sheath should be used; we prefer either a non-steerable SRO sheath (St. Jude Medical, St. Paul, MN) or a steerable Agilis sheath (St. Jude Medical, St. Paul, MN). Although ablation success has been reported in the absence of a junctional rhythm during RF delivery, our approach is to apply serial lesions at different sites within the triangle of Koch until this response is noted. Intracardiac electrogram findings that are predictive of success include a multicomponent atrial signal, longer duration of the atrial signal, and a smaller AV ratio [14]. Our preference is to start ablation in the inferior septum near the CS os prior to encroaching upon the His where the risk of AV block increases. Because successful ablation can occur with a single lesion, provided that an adequate impedance drop is noted, in addition to a junctional response as mentioned earlier, one could refrain from delivering any more lesions prior to re-testing for inducibility. However, our preference is to deliver another 45-s lesion in the same vicinity to increase durability of the lesion set. The approach described earlier can be safely used in both adult and pediatric patients.

In cases that do not result in elimination of AVNRT when ablated from the usual right septal approach, one should consider several possibilities. If the catheter position was more anterior resulting in a large ventricular signal, then pulling back towards the CS os where a larger atrial electrogram is present should be tried. A maneuver to assure septal positioning during ablation is applying clockwise torque on the ablation catheter which allows it to fall within the CS. The catheter is then withdrawn slowly with the application of slight counterclockwise torque and upon exit from the CS is advanced anteriorly towards the ventricle while it maintains a septal position. It is safer to start inferiorly, but lesion delivery should occur progressively higher towards the His especially if no junctional response during ablation is noted. We respect the notion that it is not customary to use an irrigated-tip catheter for slow pathway modification given the increased risk of causing permanent AV nodal damage. Our preference is to use a higher-temperature ceiling with a non-irrigated catheter rather than resorting to an irrigated-tip catheter because this approach has still shown to achieve a higher primary success rate in the absence of a higher risk of permanent AV block (if VA conduction during the junctional response is carefully monitored) [15]. If stability of the ablation catheter becomes an issue due to either cardiac or respiratory motion, we upgrade to a long sheath and deeper levels of sedation. Although each patient will require a different total number of RF lesions to achieve success, the presence of any of the aforementioned signs of AV block during ablation is a harbinger of being too aggressive with the current approach. As described in a later section, the ablation endpoint for RF is the absence of 1:1 conduction over the slow pathway and no more than a single echo beat. If this endpoint is not achieved with the conventional techniques described earlier, then other strategies such as cryoablation, ablation within the CS, or a left-sided approach to ablation need to be considered. These techniques are described individually in the sections that follow. Finally, the ablationist must always consider whether or not the initial diagnosis is the correct one. Septal accessory pathways and atrial tachycardia can sometimes mimic AVNRT, and appropriate pacing maneuvers to reconfirm the correct diagnosis should be performed prior to any further ablation [16].

Cryoablation of AVNRT

The other technique utilized for ablation of AVNRT is cryoablation, which is delivered via a unidirectional catheter (small, medium, or large curve) with a tip size measuring 4 to 8 mm in length and a 2-5-2 electrode spacing (Freezor, Medtronic, Minneapolis, MN) [17]. The process involves delivery of a pressurized refrigerant (liquid nitrous oxide) to the catheter tip via the CryoConsole (Medtronic, Minneapolis, MN) where it is vaporized, absorbing heat from the surrounding tissue and allowing temperatures to reach −75 °C resulting in cryoadhesion. The primary reason for choosing this modality over RF is its superior safety profile leading to a virtually 0% risk of iatrogenic complete AV block. However, this comes at the expense of a higher risk of recurrence of arrhythmia [18]. The larger tip sizes (6 mm and above) have, however, been shown to reduce the recurrence risk by up to 2.5-fold and therefore may be preferable although a larger sheath size (9 vs 8 Fr) is required for delivery [19]. We use a 6-mm catheter in our institution. Our approach to ablation is similar to that of RF in regard to catheter positioning within the borders of the triangle of Koch starting in an inferior location near the CS os while achieving an AV electrogram ratio of 1:2 or 1:3. Due to the negligible risk of AV block, the final location of a successfully delivered ablation freeze may ultimately be more superior when compared to RF. An advantage of cryoablation is the ability to perform cryomapping, first described in the original series [17]. Using this technique, cryothermal energy is delivered allowing for temperatures to reach −30 °C for a period of 45–60 s with concomitant testing for slow pathway elimination using atrial extrastimulus testing. This process allows for the reversible assessment of slow pathway injury without the risk of permanent AV block. Our approach is similar in that we initiate a freeze in an area of interest during which atrial extrastimulus testing is performed to evaluate for slow pathway modification (absence of an AH jump and non-inducibility of tachycardia). Attention is paid to prolongation of the PR interval as a harbinger of impending AV nodal damage; if noted, ablation should be immediately terminated. If no adverse effect is noted, we continue the freeze for 4 min. In our experience, any noted prolongation of the PR interval reverses upon rewarming of the tissue. If the desired end point is achieved without PR prolongation, then a second 4-min freeze is performed (freeze-thaw-freeze cycle) to increase the durability of the lesion. If slow pathway conduction persists, a different location, typically more superior, is chosen and the process repeated. Junctional rhythm does not occur during cryoablation. Following ablation, testing for AVNRT non-inducibility and the absence of an AH jump is performed over a 30-min waiting period both on/off isoproterenol. We have not noted a significant difference in fluoroscopy exposure or procedural times with this technique because we utilize 3-D electroanatomic mapping. The decision to choose one energy source over the other is operator dependent although the absence of documented permanent AV block in the literature to date with cryoablation makes it an appealing first choice. Some institutions have chosen cryoablation as the primary modality in pediatric patients because of its exceptional safety profile. In our opinion, it is reasonable to choose cryoablation in any of the following circumstances: (1) inability to reach an acceptable endpoint despite multiple RF lesions from the right side, (2) RF resulting in transient AV block, or (3) an inferiorly displaced His, especially in congenital patients.

Left-sided ablation of AVNRT

A left-sided approach constitutes ablation of the slow pathway (1) from within the CS, (2), anywhere along the inferior aspect of the mitral annulus or (3) ablation along the left atrial septum adjacent to the RA slow pathway region. The leftward inferior extension of the slow pathway participates in <5% of cases of typical AVNRT and leads to failure of ablation using the traditional approach [20]. The atrial insertion of the slow pathway is instead located in the roof of the CS about 2–4 cm from the os, and therefore, ablation is performed here. The primary reason to consider ablation within the CS is lack of success from the usual approach. Although cryoablation in the CS has been reported, our approach is to use a 4-mm non-irrigated tip RF catheter in a temperature-limited mode with a power between 20 and 30 W so as to avoid excessive injury to the CS, the fast pathway, or the left circumflex coronary artery [21]. If there is a high impedance or low power during ablation in the CS, we switch to a 3.5-mm irrigated-tip catheter in a temperature-limited mode with 10–20 W of power, which can allow for improved energy delivery. It should be noted that with improvement in catheter design, if an irrigated-tip catheter is chosen, we prefer the use of a contact force (CF) ablation catheter (TactiCath Quartz, St. Jude, St. Paul, MN) allowing the delivery of a safer and more durable lesion [22]. The presence of a junctional response is still sought as a marker for a potentially successful ablation site during any of the left-sided approaches. Ablation within the CS appears to be safe [23]. There are still, however, approximately 1% of cases in which neither traditional right-sided ablation within the triangle of Koch nor ablation within the CS is successful. In these circumstances, left atrial (LA) ablation should be considered [20]. Excluding studies reporting CS ablation, to date, there have been 12 case reports comprising approximately 30 patients in the literature, which have reported ablation of AVNRT from a left-sided approach (either transseptal or retrograde aortic) including a single case report of successful ablation of typical AVNRT from within the left ventricle [24]. Failure to achieve the endpoint from the right side (starting inferiorly and moving progressively higher in the triangle of Koch) including the CS or the presence of features suggesting AV nodal damage (VA block during ablation or an acceleration of the junctional response, i.e., <350 msec) should prompt the operator to consider a left-sided approach. One may also consider discussing with the patient a trial of medical therapy and watchful waiting prior to considering a left-sided procedure given the slightly higher risk for complication. We recommend the use of an irrigated-tip catheter, for reasons mentioned earlier, with either the retrograde or transseptal approaches. Heparin is administered to maintain an activated clotting time (ACT) of >300 s to prevent peri-procedural thromboembolism. Transseptal access is obtained with intracardiac echocardiography (ICE) guidance. If the transseptal approach is chosen, the use of a steerable sheath (Agilis, St. Jude Medical, St. Paul, MN) is recommended, which provides greater stability and allows for easier access to the posteroseptal left atrium. A multicomponent or low-amplitude atrial electrogram with an AV electrogram ratio <1 is sought in the posteroseptal region of the left atrium opposite to the usual location of right-sided lesions (in the LAO view). Locations higher along the septum will result in a smaller ventricular component as compared to locations closer to the annulus. A His catheter recording is helpful in avoiding fast pathway damage. Previous lesions delivered along the roof of the CS that resulted in a junctional response during ablation can be consolidated from the LA side. A marker for success, as reported in nearly all the reported cases, is the emergence of a junctional rhythm during RF current delivery. In the case of "left-ventricular" ablation, the authors utilized the benefit of the anatomic offset between the tricuspid (more inferiorly displaced) and mitral valves, which exposes the left side of the triangle of Koch almost analogous to a Gerbode defect allowing for successful ablation [24].

Challenges of AVNRT ablation

Some special circumstances which may arise during the ablation of AVNRT include patients with a preexisting first-degree AV block, repeated/immediate induction of AVNRT during RF application, and the utilization of voltage mapping for direct visualization of the slow pathway. Firstly, although an uncommon finding, the presence of a prolonged PR interval in patients with AVNRT is estimated between 2 and 3%. This is more common in the elderly and those with structural heart disease [25]. In the largest series consisting of 346 consecutive patients in which 18 patients had a preexisting prolonged PR interval and who underwent complete elimination of the slow pathway, a higher incidence of delayed AV block was noted [26]. This suggests that RF, which modifies the slow pathway, as opposed to cryoablation, which results in complete slow pathway elimination, is the preferred energy choice in this population.

An interesting fact is that after ablation, it has actually been noted that the AH interval can shorten, an effect believed to be the result of resolution of electrotonic interaction between the fast and slow pathways [27]. It appears then that in the carefully selected patient and with extreme vigilance on AV conduction during ablation, these individuals can be treated safely using RF.

A second challenge which can arise during AVNRT ablation is the repetitive recurrence of tachycardia with any initiation of ablation, a characteristic unique to RF perhaps secondary to thermal induction leading to atrial irritability. This can increase the risk of AV block not only due to catheter instability which occurs due to the abrupt initiation and termination of tachycardia but also because a reliable assessment of intact AV nodal conduction cannot be made. Our approach to this issue is to initially reposition the catheter and then attempt a long sheath to assure stability. Resorting to cryoablation usually results in resolution of this finding allowing for safe and effective ablation. If one is faced with premature atrial complexes (PACs) or patients with absent VA conduction with junctional ectopy during RF, we would suggest pacing from a durable atrial location (usually the CS catheter) during lesion delivery to allow for monitoring of antegrade intact AV conduction.

Lastly, the novel concept of voltage gradient mapping of the slow pathway using 3-D electroanatomic guidance has become a useful technique in identification and ablation of the slow pathway in both adults and adolescents [28, 29]. The so-called "low-voltage bridge" is determined by mapping in the area of the usual location of the slow pathway and serves as a surrogate to guide ablation with either RF or cryoablation and has shown promise with high success rates achieved. Although we do not rely solely on this technique, we do find it useful to utilize in combination with the traditional anatomic and electrogram features of the slow pathway in guiding ablation.

Endpoints for ablation of AVNRT

The endpoints for successful ablation are dependent on the type of energy source utilized. In those with readily inducible AVNRT pre-ablation, the absence of an inducible arrhythmia post-ablation is certainly a widely accepted endpoint for successful ablation especially if isoproterenol was not required for initial induction. Regardless of how easily the arrhythmia was induced pre-ablation, our approach has been to test for re-inducibility both on/off isoproterenol post-ablation, although studies have shown that the use of this drug after ablation to confirm non-inducibility of AVNRT does not appear to alter the recurrence rate and perhaps this step can be omitted [30]. As mentioned previously, with RF, it is acceptable to still demonstrate the presence of the slow pathway as is the presence of at most a single echo beat as this has still shown to portend a good prognosis [31]. With cryoablation, reduction in arrhythmia recurrence is dependent on complete slow pathway elimination as demonstrated by the absence of an AH jump or AV reentrant echo beats [32, 33] during post-ablation testing.

Medical therapy for AVNRT

Given the greater than 95% success rate of catheter ablation for the treatment of AVNRT and the failure rate of greater than 50% for antiarrhythmic drug (AAD) therapy (beta-blockers, non-dihydropyridine calcium channel blockers, flecainide, or propafenone), ablation has remained the current treatment of choice in symptomatic patients [34•]. According to the most recent SVT guidelines, for patients who do not prefer ablation or are otherwise not candidates, medical therapy with AV nodal blocking agents is a class I indication, and if ineffective, AAD therapy carries a class II indication [2••]. In at least a single randomized controlled trial, success rate (<2 arrhythmia recurrences in 12 months) for flecainide or propafenone, given to patients with paroxysmal SVT and absence of structural heart disease, was between 86 and 93% leading to their class IIa indication in the guidelines [35]. In at least two other studies, the use of agents such as sotalol or amiodarone in patients with AVNRT and structural heart disease appear to be safe, but given their adverse effects when compared to other agents, these should be third-line agents and carry a class IIb indication in the current guidelines [36, 37]. Flecainide is the AAD of choice given its safety profile in both the adult and pediatric populations [38, 39]. In our opinion, although a trial of AV nodal blocking agents (beta-blockers or calcium channel blockers) is reasonable in a patient with a first documented episode of suspected AVNRT, we rarely in our practice resort to the use of AAD's for long-term management of this arrhythmia. However, strong consideration to drug therapy with these agents could be given in individuals with a pre-existing first-degree AV block because total elimination of the slow pathway leads to a significant risk of developing delayed AV block months to years after the procedure, as mentioned previously.

Potential complications

In looking strictly at catheter ablation of SVT, the rates of major and minor complications have been cited at 3 and 8%, respectively [40]. The risk of permanent AV block necessitating pacemaker implant approaches 1% in these studies and has been shown to be lower with cryoablation as compared to RF. In fact, in multiple meta-analyses (between 2400 and 5600 patients) to date, cryoablation has not been associated with permanent AV block and this may be of value when ablating in children albeit at the expense of a higher recurrence rate [41•, 42•].

Conclusion

In summary, if catheter ablation is chosen for treatment of AVNRT, the electrophysiologist has at his or her disposal a variety of tools to successfully and safely perform the procedure. While slow pathway modification can usually be accomplished with a non-irrigated RF catheter in the usual position within the triangle of Koch, there are alternative energy sources and anatomic considerations which can help achieve success in challenging cases.

Compliance with Ethical Standards

Conflict of Interest
Darpan S. Kumar, Thomas A. Dewland, and Charles A. Henrikson each declare no potential conflicts of interest. Seshadri Balaji reports a research grant from Medtronic for research on pediatric hypertophic cardiomyopathy.

Human and Animal Rights and Informed Consent
This article does not contain any studies with human or animal subjects performed by any of the authors.

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Large meta-analysis consisting of 2340 patients comparing radiofrequency ablation to cryo ablation of AVNRT showing lower recurrence with RF but with a higher risk of permanent AV block

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Another large meta-analysis consisting of 5617 patients comparing radiofrequency ablation to cryo ablation of AVNRT showing similar results to the trial by Santangeli et al where a lower risk of recurrence with RF comes at the expense of a slightly higher risk of AV block