Current management and clinical outcomes for catheter ablation of atrioventricular nodal re-entrant tachycardia

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Aims
Historical studies of ablation of atrioventricular nodal re-entrant tachycardia (AVNRT) have shown high long-term success rates and low complication rates. The potential impact of several recent practice trends has not been described. This study aims to characterize recent clinical practice trends in AVNRT ablation and their associated success rates and complications.

Methods and results
Patients undergoing initial ablation of AVNRT between 1 July 2005 and 30 June 2015 were included in this study. Patient demographics and procedural data were abstracted from procedure reports. Follow-up data, including AVNRT recurrence and complications, was evaluated through electronic medical record review. In total, 877 patients underwent catheter ablation for AVNRT. By the last recorded year, three-dimension (3D) electroanatomical mapping (EAM) was used in 36.2%, 43.2% included anaesthesia, and 23.1% utilized irrigated catheters. Long-term procedural success was 95.5%. The use of anaesthesia, 3D EAM, and irrigated ablation catheters were not associated with differences in success. The presence of an atrial ‘echo’ or ‘AH’ jump at the end of an acutely successful procedure was not associated with long-term recurrence ($P=0.18$, $P=0.15$, respectively). Complications, including AV block requiring a pacemaker (0.4%), were uncommon.

Conclusion
In a large, contemporary cohort, catheter ablation for AVNRT remains highly successful with low complications rates. The increased use of anaesthesia as well as modern mapping and ablation tools were not associated with changes in clinical outcomes. Further prospective evaluation of such contemporary practices is warranted given the lack of evidence to support their escalating use.

Keywords
Atrioventricular nodal re-entrant tachycardia • Catheter ablation • Long-term success • Complications • Dual AV nodal physiology

Introduction
Atrioventricular nodal re-entrant tachycardia (AVNRT) is the most common supraventricular tachycardia (SVT) encountered in adults, accounting for approximately 70% of paroxysmal SVT.¹² Catheter ablation of the AV nodal slow pathway as a treatment strategy for AVNRT was first described by Jackman et al.³ in a cohort of 80 patients in 1992. Subsequent studies soon thereafter reported initial success rates as high as 97% with 5% rate of recurrence over 2 years.⁴ While overall complication rates are low, iatrogenic complete heart
block remains well recognized as one of the primary major complications associated with AVNRT ablation. Prior series have reported rates of complete heart block requiring pacemaker implantation of 0.8–1.0%. Nevertheless, catheter ablation has been shown to be superior to anti-arrhythmic drugs (AAD) and is usually offered as an option for first-line therapy for AVNRT.

The conventional approach to catheter ablation of AVNRT was initially described 25 years ago and involves empirical radiofrequency ablation (RFA) of the slow pathway region using fluoroscopic anatomical landmarks and characteristic intra-cardiac electrograms. More recently, alternative ablation strategies have been introduced including the use of cryoablation, irrigated radiofrequency ablation, and three-dimensional (3D) electroanatomic mapping (EAM) with the goal of reducing procedural complications and radiation exposure. Accordingly, most sizable studies of procedural outcomes and complications predate these recent practice shifts.

We conducted an analysis of catheter ablation for AVNRT at our institution over a recent 10-year period to ascertain contemporary trends in AVNRT patient characteristics, procedural management, mapping and ablation, and their impact upon clinical outcomes and complications.

**Methods**

All patients who underwent an initial electrophysiology study (EPS) and catheter ablation from 1 July 2005 to 30 June 2015 for AVNRT at the Johns Hopkins Hospital (Baltimore, Maryland, USA) were included in this retrospective cohort analysis. The Johns Hopkins Hospital cardiovascular procedural database was utilized for systematic review of the electronic medical record (EMR) to include cases with procedural documentation of EPS, and ablation targeting AVNRT. Each case was then reviewed to confirm that an ablation for a clinical diagnosis of AVNRT was attempted. All available procedural data including anaesthesia status, fluoroscopy time, procedure time (electrophysiology laboratory time), ablation time, acute success, ablation modality and use of 3D-EAM were recorded. All operators were board-certified clinical cardiac electrophysiologists. An operator was deemed to be a ‘higher volume’ practitioner if they performed >25 AVNRT ablation procedures over the study period.

**Electrophysiology study**

Informed written consent was obtained prior to all procedures. For all intra-cardiac electrophysiology studies, vascular access was obtained via one or both femoral veins with or without the right internal jugular vein in a sterile fashion using the modified Seldinger technique. Electrode catheters were then advanced under fluoroscopic guidance to the lateral high right atrium, His bundle, right ventricular apex, and coronary sinus. Baseline AV node block cycle lengths, and atrial, ventricular and AV node effective refractory periods were obtained. Attempts at SVT induction were made, with the aid of isoproterenol (2–6 mcg/kg/min) and/or atropine (0.6–1.0 mg) to increase the sinus rate to >100 b.p.m., if necessary, and diagnostic pacing manoeuvres were performed to confirm the mechanism of the SVT which included documentation of an atrio-His (AH) jump >50 ms and atrial ‘echo’ beats indicative of dual AV nodal physiology. Atrioventricular nodal re-entrant tachycardia was also assumed to be the clinical arrhythmia when dual AV nodal physiology was ascertained in the absence of inducible tachycardia in a patient with a documented history of SVT compatible with AVNRT on electrocardiogram or ambulatory monitor.

Among patients undergoing 3D-EAM (CARTO®, Biosense Webster, Diamond Bar, California, USA or Ensite™, St. Jude Medical, St. Paul, Minnesota, USA), a mapping/ablation catheter was advanced to the right atrium and an anatomical shell was created. In particular, the locations of the proximal coronary sinus, and tricuspid valve were ascertained, and sites with His Bundle potentials were routinely annotated with the mapping system (see representative example in Figure 1). The ‘slow pathway’ region anterior to the inferior level of the coronary sinus exhibiting a multiphasic atrial component and an atrial:ventricular electrogram ratio of 1:4–1:8 was targeted for the initial ablation site with radiofrequency energy. Typically, the initial power settings were 20–30 W with an irrigated catheter and 40–50 W with a max temperature of 70°C with a non-irrigated catheter. Re-attempts at arrhythmia induction were then made. If AVNRT was still inducible (with or without isoproterenol) then additional ablation lesions were applied, and, if necessary, were directed more superiorly or within the proximal coronary sinus. In some cases, when AVNRT remained inducible despite accelerated junctional rhythm/junctional tachycardia or transient atrioventricular block during radiofrequency delivery, further AV node modification was performed with cryoablation as previously described. Trans-septal left atrial mapping has rarely been undertaken for AVNRT at our centre. In one case after AVNRT was still inducible following an extensive right sided slow pathway ablation, a left sided ablation approach was performed. Atrioventricular nodal re-entrant tachycardia was non-inducible following successful modification of the fast pathway. The procedure was concluded after non-inducibility post-ablation was confirmed or at the discretion of the operator. Non-inducibility was defined as the absence of sustained SVT. If a sustained SVT was inducible, then AVNRT was excluded as the mechanism based on established electrophysiology diagnostic manoeuvres.

**Clinical outcomes**

Outcome data including long-term procedural success and complications were documented based on review of the EMR regarding the last documented cardiology or primary care clinic visit. It has been our institution’s longstanding practice to arrange for clinical follow-up approximately 6 weeks post-procedure. A procedure was determined to be acutely successful if (i) a previously inducible arrhythmia was rendered non-inducible at the end of the case or (ii) there was elimination of dual AV nodal physiology in a patient with a documented history of SVT that proved non-inducible during the procedure. Long-term success was defined as no documented recurrence of SVT based on the last available primary care/cardiology clinic record. Major complications were defined as death, stroke, vascular access complications requiring an intervention or blood transfusion, heart block requiring a permanent pacemaker, or pericardial effusion requiring an intervention within thirty days of the procedure.
Statistical analysis
Categorical variables were summarized by number and percentage. Continuous variables were summarized as a mean and standard deviation. The baseline characteristics and the association of clinical outcomes with baseline characteristics were tested using the $\chi^2$ test or Student’s $t$-test where appropriate. The non-parametric test for trend was used to assess the differences in procedural details and outcomes over time. Statistical analyses were performed using STATA statistical software (Version 9.0, College Station, TX). A two-tailed $P$-value $< 0.05$ was considered significant.

This study was approved by the Johns Hopkins University School of Medicine institutional review board.

Results
A total of 1116 cardiovascular procedural reports were screened identifying 877 patients who underwent catheter ablation for AVNRT at Johns Hopkins Hospital from 1 July 2005 to 30 June 2015. We excluded 61 patients who underwent repeat ablation for AVNRT. We also separated a subset of 73 patients from our primary analysis due to concomitant ablation of another arrhythmia at the same procedure setting as their AVNRT ablation (this group was analysed independently). Thus, our primary analysis included 743 patients who underwent an initial catheter ablation for AVNRT over this 10-year period (see flow chart in Figure 2). The average age was 51.1 $\pm$ 16.8 years and 67.8% were female. The average procedure time was 162.0 $\pm$ 54.9 min and the average fluoroscopy time was 28.8 $\pm$ 17.4 min. Of the 743 patients, 91.5% had typical (slow-fast) AVNRT. The average follow-up was 549.7 $\pm$ 33.1 days.

Trends in procedural volume and workflow
Over the course of the study the total volume of electrophysiology procedures increased while the number of AVNRT ablation cases remained constant. However, over this 10-year period there was a progressive increase in the use of 3D EAM, from 0% during the 2005–06 academic year up to 36.2% of cases during the 2014–15 academic year ($P \leq 0.001), (Figure 3). Concomitantly, there was a significant increase in the total procedure time from 154.7 $\pm$ 8.5 min to 181.5 $\pm$ 8.0 min ($P \leq 0.001). Use of irrigated ablation catheters increased from 0–23.1% during this same time period ($P \leq 0.001), (Figure 4). Of note, there was also a significant steady rise in the use of the anaesthesia service to provide deep sedation or general anaesthesia, with less reliance upon a nurse-supervised sedation protocol from 1.4–43.2% ($P \leq 0.001), (Figure 5). Those under the care of the anaesthesiology team were noted to have a higher average BMI compared to those under a nurse sedation protocol (30.6 kg/m$^2$ vs. 26.8 kg/m$^2$, $P < 0.001$).

Atrioventricular nodal re-entrant tachycardia inducibility
In general, atropine was utilized if isoproterenol failed to induce AVNRT. In this series of cases, AVNRT was inducible in six patients using atropine alone when baseline pacing did not induce AVNRT. In another 12 cases, atropine was administered after isoproterenol failed to induce AVNRT. Of those 12 cases AVNRT was induced in 9 (75%). Isoproterenol alone was used in 317 cases in an attempt to induce AVNRT. Of those 317 cases AVNRT was inducible in 256

*Figure 1* Three-dimensional electroanatomic mapping & ablation of the right atrium. (A) Right anterior oblique (RAO) and (B) Left anterior oblique (LAO) projections of the right atrium. The yellow dots depict the location of the His bundle as recorded by an electrode mapping catheter. The purple structure in the LAO and the RAO projections represents the location of the coronary sinus ostium. The green circle outlines the tricuspid annulus. The pink, red and blue dots are ablation lesions as marked by the mapping system in the slow pathway region anterior to the CS ostium.
The use of nurse administered sedation or deeper sedation with an anaesthesiologist had no effect on AVNRT inducibility ($P = 0.095$) or in the need to use isoproterenol to initiate AVNRT ($P = 0.556$).

Procedural success

Overall, both acute procedural success and long-term AVNRT ablation success was high at 98.5% and 95.5%, respectively. Female sex ($P = 0.001$), and higher fluoroscopy times ($P = 0.003$) were associated with long-term failure (Table 1). Over the course of the 10 years of this study there was no significant difference over time in acute or long-term procedural success rates ($P = 0.119$, $P = 0.343$, respectively), (Figure 6). Furthermore, there was no significant difference in success rates among ‘higher volume’ operators (95.9% ± 0.19, ablations $n = 522$) vs. ‘lower volume’ operators (94.5% ± 0.22, ablations $n = 221$) ($P = 0.395$). The use of 3D EAM was not associated with significant difference in acute or long-term success rates ($P = 0.460$).

Similarly, the use of an irrigated ablation catheter was not associated with significant difference in acute ($P = 0.460$) or long-term ($P = 0.830$) success rates. The utilization of an anaesthesiologist in lieu of nurse-supervised sedation was not associated with a significant difference in long-term success rate ($P = 0.54$).

Atrial AVNRT ($n = 63$) did not portend a significantly different long-term success rate as compared to typical AVNRT ($n = 680$, $P = 0.71$), (Figure 7). A total of 641 patients had inducible AVNRT at baseline, of which 58 had no evidence of dual AV nodal physiology (AH jump or atrial echo beat). Nevertheless, the presence of an atrial echo or AH jump at the end of an acutely successful procedure was not associated with long-term recurrence ($P = 0.18$, $P = 0.15$, respectively).

Complications

Overall, major complications rates were low, occurring in 9 of 743 primary cases (1.2%). Pericardial effusion requiring pericardiocentesis occurred in 4/743 (0.5%). Vascular access site complications requiring blood transfusion occurred in 2/743 cases (0.3%). High degree AV block requiring a permanent pacemaker occurred in 3/743 cases (0.4%). Over the course of this study there was a statistically significant decline in rates of pacemaker insertions and, in fact, no pacemaker insertions were observed in the last six years of the study period ($P = 0.036$) although there was no change in the rate of overall complications ($P = 0.277$).

Concomitant ablation

In total, 73 patients (9.8% overall) underwent an ablation for AVNRT combined with an ablation for another clinical arrhythmia. The concomitant ablation types were distributed between atrial fibrillation (12.2%), atrial tachycardia (23.3%), atrial flutter (20.6%), premature ventricular contractions (23.3%), and atioventricular re-entrant tachycardia (AVRT) ablation (20.6%). There were no major complications in this group. The acute and long-term success rates for AVNRT ablation were 98.6 and 97.2%, respectively (Figure 7).

Discussion

In this large contemporary cohort analysis, catheter ablation of AVNRT was highly efficacious with a long-term success rate of 95.5% and a major complication rate of 1.2% among patients undergoing first time ablation. In addition, the occurrence of iatrogenic complete heart block necessitating pacemaker insertion appeared to decrease over time.

Procedural outcomes

In this recent cohort, acute and long-term procedural outcomes were excellent with greater than 98% and 95% success rates, respectively. These findings are comparable to historic cohorts from 25 years ago reporting long-term success rates of approximately 96% for ablation of typical AVNRT. Of interest, operator procedural volume did not seem to impact overall success or complication rates, suggesting a relatively short ‘learning curve’ for performance of this procedure. Therefore, this observation would support the
recommendation published in the 2015 ACC/AHA/HRS Advanced Training Statement on Clinical Cardiac Electrophysiology specifying the performance of 25 AVNRT ablations during fellowship prior to independent practice. Female sex and total fluoroscopy time were the only factors that were associated with a decrease in long-term procedure efficacy. One can hypothesize that an increased use in fluoroscopy time may be a marker for a more difficult ablation procedure, however, generalizations as to why female sex and the use of increased fluoroscopy would lead to worse efficacy are difficult to make given the extremely low failure rate seen overall. One explanation for the slight decrease in long-term efficacy in the female sex may be due to increased contact with the medical field and thus more recognized recurrence of symptomatic AVNRT compared to men.

It is well accepted that non-inducibility of AVNRT is an important procedural endpoint for putative successful slow pathway ablation. However, it is still not clear if residual evidence of dual AV nodal physiology, including an AH jump or atrial echo beat, might be associated with a significantly increased risk of long-term AVNRT recurrence. In our large patient series, an AH jump or atrial echo in a patient non-inducible for AVNRT post-ablation was not associated with a decrease in long-term efficacy. This finding conforms with the results from a meta-analysis of 10 smaller prior studies involving 1204 patients, indicating that further ablation in patients who have evidence of dual AV node physiology but are non-inducible for AVNRT is not routinely warranted.

**Procedural complications**

Complications related to catheter ablation of AVNRT are uncommon. High grade AV block requiring a permanent pacemaker (0.4%) was reduced compared to previously reported studies which observed rates of 0.8–1.0%. Due to the relatively low event rates, it is unclear what factors may be driving this reduction, which could include interval data on intra-procedural endpoints, technologic changes in both mapping and ablation, anaesthesia utilization, or collective accumulated procedural experience. Among the three patients in our cohort who developed AV block following catheter ablation, all had normal AH and HV intervals at baseline. One developed 3rd degree AV block during ablation at a location superior to the CS ostium, underlying the importance of recognizing the increased risk of advanced AV block with ablation lesions applied closer to the AV node fast pathway region.

Cardiac tamponade in this study population was uncommon, and most ablation procedures were performed with non-contact force sensing catheters. Given the low number of cardiac tamponade events, clinical or statistical differences between contact force and non-contact force sensing catheters or irrigated vs. non-irrigated catheters could not be ascertained.
Contemporary ablation workflow

The use of 3D EAM, routinely employed at our centre for atrial fibrillation and ventricular tachycardia ablations, increased significantly over the course of the study. This increase might be due to the belief that 3D-EAM would make AVNRT ablation procedures safer. The use of irrigated radiofrequency ablation catheters (almost always coupled with 3D EAM) also increased significantly over the course of this study, likely due to increased familiarity resulting from its widespread adoption in atrial fibrillation ablation procedures during this same time period as recently described.16 The use of these modern technologies, however, were not associated with differences in acute or long-term success rates and, in fact, were associated with a significant increase in procedural times likely due to the added time spent with non-fluoroscopic diagnostic imaging. This observation is consistent with other smaller cohort and case-control studies, which reported comparable success and complication rates for EAM-alone and fluoroscopy-alone ablation strategies.7,10,17 One postulated advantage of EAM, in addition to reduction in fluoroscopy, is the ability to specifically mark the anatomical location of the His bundle to avoid radiofrequency applications in close proximity, thereby potentially reducing the risk of iatrogenic AV block. In this cohort, direct assessment of the impact of EAM on AV block avoidance was not possible due to the paucity of these adverse events overall, suggesting an opportunity for further investigation utilizing a larger multi-centre cohort.

Over the course of the study period there was a significantly increased reliance on the anaesthesia service in lieu of nurse-supervised sedation during AVNRT ablation procedures. Prior data on the use of general anaesthesia for catheter ablation of atrial fibrillation have shown an increase in efficacy of the ablation procedure,18 however, this clinical finding was not replicated in our study probably due to the simpler nature of AVNRT ablation and a high baseline success rate. Part of the explanation for greater use of anaesthesia services at our institution is that our clinical providers now face greater scrutiny to fulfill rising expectations for patient experience and safety than they have in the past, particularly due to more stringent enforcement of state mandated nurse-supervised sedation protocols. Regardless, greater anaesthesia utilization also paralleled increased procedure times (data not shown).

Concomitant ablation

Sauer et al.19 have previously noted the clinical need for concomitant AVNRT ablation in 4.3% of patients undergoing atrial fibrillation ablation. Considering the high prevalence of AVNRT, it is
likely not surprising that 9.8% of such ablations at our centre involved concomitant ablation of another relevant arrhythmia. Reassuringly, despite the increased complexity of such procedures, we still observed a high long-term success rate for AVNRT ablation (97.2%) and a low rate of complications. These findings mirror a recently published single centre study examining 493 consecutive patients diagnosed with AVNRT of whom 9% underwent concomitant arrhythmia ablation.20

**Limitations**

Assessment of outcomes in this study was performed through retrospective review of our health system’s EMR which could be associated with under-reporting of both recurrence and complications.

Additionally, assessment of these endpoints was limited to patients who underwent both electrophysiologic study and AVNRT ablation which could introduce selection bias by excluding those patients with AVNRT who underwent electrophysiologic study alone and were deemed to be at high risk of complication with AVNRT ablation. We believe this to have been a rare occurrence.

As a retrospective cohort analysis, diagnosis, procedural strategies, and treatment decisions were not specified by protocol, but rather were at the discretion of the attending clinical cardiac electrophysiologist. Finally, it should be noted that our centre is a teaching hospital and as such the vast majority of AVNRT ablation cases involved clinical cardiac electrophysiology fellows. Hence, the total procedural and fluoroscopic times reported at our institution may not be representative of the temporal workflow employed at non-teaching centres.
In a large, contemporary, retrospective cohort analysis of patients undergoing first-time ablation for AVNRT, success rates remained high with low overall complication rates as compared to historic cohort analyses. These current findings reinforce the use of catheter ablation as a first-line therapy for AVNRT and can help aid physicians and patients in making informed decisions when considering this procedure.

Temporal trends demonstrated rapid escalation in the utilization of 3D EAM, irrigated catheter ablation, and anaesthesia services corresponding with significantly longer procedural times but without association with any substantial change in clinical outcomes. Accordingly, our data show recent significant practice shifts without significant evidence to support them. Further cost analysis based upon economic modelling may help elucidate the value of these current trends in the modern healthcare environment. Ultimately, data...
from a larger prospective multi-centre study will be required to validate our procedural and clinical observations.

Conflict of interest: none declared.

References


