Novel approaches to mapping and ablation of supraventricular tachycardia

PhD Thesis

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Publications related to the thesis:

I. **Pap R**, Traykov VB, Makai A, Bencsik G, Forster T, Sághy L. Ablation of posteroseptal and left posterior accessory pathways guided by left atrium-coronary sinus musculature activation sequence. J Cardiovasc Electrophysiol. 2008 Jul;19(7):653-8. IF: 3.798

II. Sághy L, Makai A, Bencsik G, **Pap R**. Coexistent right- and left-sided slow pathways participating in distinct AV nodal reentrant tachycardias. Pacing Clin Electrophysiol. 2008 Oct;31(10):1348-50. IF: 1.590

III. **Pap R**, Sághy L. Convergent double potentials inside the coronary sinus during atrial tachycardia: what is the mechanism? Pacing Clin Electrophysiol. 2008 Sep;31(9):1186-8. IF: 1.590

IV. Bencsik G, **Pap R**, Sághy L. Intracardiac echocardiography for visualization of the Eustachian valve during radiofrequency ablation of typical atrial flutter. Europace. 2009 Jul;11(7):901. IF: 1.706

V. **Pap R**, Klausz G, Gallardo R, Sághy L. Intracardiac echocardiography in a case with previous failed cavotricuspid isthmus ablation. J Interv Card Electrophysiol. 2009 Apr 23. [Epub ahead of print] IF: 1.075

VI. Traykov VB, **Pap R**, Bencsik G, Makai A, Forster T, Sághy L. Ventricular location of a part of the right atrial isthmus after tricuspid valve replacement for Ebstein's anomaly: a challenge for atrial flutter ablation. J Interv Card Electrophysiol. 2009 Sep;25(3):199-201. IF: 1.075

VII. Skanes AC, Jensen SM, **Papp R**, Li J, Yee R, Krahn AD, Klein GJ. Isolation of pulmonary veins using a transvenous curvilinear cryoablation catheter: feasibility, initial experience, and analysis of recurrences. J Cardiovasc Electrophysiol. 2005 Dec;16(12):1304-8. IF: 3.285

INTRODUCTION

Supraventricular tachycardia (SVT) is a relatively common arrhythmia in otherwise healthy individuals and also in patients with organic heart disease. Recent advances in catheter-based therapies have offered a cure for many specific SVTs, but difficulties remain, especially in cases of septal or paraseptal arrhythmia substrates and complex SVTs, like atrial fibrillation.

Mapping and ablation of SVT substrates in the posteroseptal space

The posteroseptal (or inferoparaseptal) space incorporates the converging segments of the atrioventricular (AV) rings and also the coronary sinus (CS) with its proximal branches. Arrhythmia substrates in this region include accessory pathways, the posterior AV nodal extensions (thought to constitute the slow AV nodal pathway) and focal or macroreentrant atrial tachycardias, sometimes incorporating the musculature of the CS. This space on the right atrial side is continuous with the cavotricuspid isthmus, the major target of classical flutter ablation.

Accessory pathways (APs) in this region are usually more difficult to eliminate than in other areas. They can be associated with any of the components of this complex space and can insert in the right or left AV ring or the CS. The CS develops from the sinus venosus, together with the smooth part of the right atrium. As a continuation of right atrial myocardium the proximal CS is covered by a cuff of striated muscle, with connections to the left atrium. "Atrial" electrograms recorded from inside the proximal CS originate not only from left atrial myocardium, but also from activation of the CS myocardial coat. This results in "fragmented" or double potentials, with a low amplitude, blunt ("far field") left atrial component and a larger, sharp ("near field") signal from the CS musculature. The myocardial coat covering the proximal CS extends to the terminal portion of the middle cardiac vein and posterior coronary vein in 3% and 2% of hearts, respectively. These extensions - when connected with the epicardial surface of the ventricle - are thought to constitute the so-called epicardial APs in the posteroseptal and left posterior region. Ablation of these APs requires energy delivery inside the CS or its proximal branches in contrast to the more common APs in this region that are successfully ablated on either the mitral or the tricuspid annulus. Mapping of both sides of the septum however prolongs procedure and fluoroscopy times and carries the risks of potentially unnecessary left heart catheterization. Therefore the ability to discriminate - without instrumentation of the left heart - APs amenable to ablation from the right side (on the tricuspid ring or inside the coronary venous system) from those requiring ablation on the mitral ring, could have great impact on the safety of the procedure. We hypothesized that the sequence of left atrial and CS myocardial coat potentials recorded during retrograde AP conduction by a catheter placed inside the CS can guide mapping of these APs into right or left sided compartments of the inferior paraseptal space.

Experimental and electrophysiological studies, as well as histopathological evidence after successful ablation suggest that the posterior nodal extensions (PNE) represent the anatomic substrate of slow AV nodal conduction and therefore AV nodal reentrant tachycardia (AVNRT). Anatomical studies demonstrated that most hearts have both a left and a right PNE in the posteroseptal region. Out of 21 randomly selected human hearts, Inoue and Becker found 13 to have both a right- and a left-sided PNE, 7 with only right PNE and one with only left PNE. Katritsis and Becker proposed a right or left sided circuit of slow-fast AVNRT using either the right or the left PNE. However no patient with separate left and right sided slow AV nodal pathways supporting two distinct AV nodal reentrant tachycardias has been reported.

Classical right atrial flutter is a common supraventricular tachycardia and can be terminated by the ablation of the cavotricuspid isthmus (CTI). However anatomical variation of the CTI can present an obstacle during ablation. We hypothesized that phased-array intracardiac echocardiography by providing real-time visualization of the anatomy can guide CTI ablation in difficult cases because of previous surgical intervention or uncommon anatomic variant.

Cryoablation of pulmonary veins for the treatment of atrial fibrillation

Since the seminal observations by Haissaguerre et al. the pulmonary veins (PVs) became the main target for ablative therapy of atrial fibrillation (AF). However PV stenosis complicating radiofrequency ablation for atrial fibrillation emerged as a new clinical syndrome. Cryothermal ablation has the potential to cause less tissue disruption and subsequent fibrosis compared to radiofrequency energy and has been shown not to cause PV stenosis after ablation for AF. Electrical isolation of the PVs using focal cryothermal catheters is feasible but associated with long procedure times, therefore we used a novel, curvilinear freezing catheter in patients with AF.

Aims

1. To characterize the substrate and new mapping strategies of different arrhythmias involving the posteroseptal space of the heart, including: accessory pathways, the AV nodal extensions and coronary sinus musculature.
2. To describe the role of intracardiac echocardiography for the visualization of the cavotricuspid isthmus in difficult cases of common right atrial flutter ablation
3. To demonstrate the feasibility and examine the efficacy of a novel transvenous curvilinear cryoablation catheter for the ablation of atrial fibrillation

METHODS

Patients included in these studies were admitted to the 2nd Department of Internal Medicine and Cardiology Centre, University of Szeged or the Arrhythmia Service, University of Western Ontario, London, Ontario, Canada for catheter ablation of SVT. All patients underwent a detailed electrophysiology study, including placement of multipolar catheters in the right ventricle, His bundle region and coronary sinus (CS). The CS electrodes covered approximately the proximal 40 millimeters of the CS. Determination of tachycardia mechanisms was accomplished using activation mapping with or without an electroanatomic mapping system (CARTO, Biosense Webster), as well as resetting and entrainment maneuvers. In cases with difficult CTI ablation a 10 Fr phased array intracardiac echocardiography (ICE) catheter (Acuson AcuNav Diagnostic Ultrasound Catheter, Siemens Medical Systems) was introduced from the left femoral vein into the right atrium to visualize the CTI. To test the hypothesis, that the sequence of left atrial and CS myocardial coat potentials recorded during retrograde AP conduction can guide mapping, bipolar electrograms from the

CS were analyzed during retrograde atrial activation exclusively through the AP. Electrograms from 22 retrospectively studied patients were analyzed by an electrophysiologist blinded to the results of ablation. In the prospective phase (18 patients) the analysis was done before proceeding to ablation.

In patients undergoing cryoablation of pulmonary veins (PVs) a multipolar circular mapping catheter was used to map the PVs during freezing with the novel circular cryoablation catheter (Arctic Circler, CryoCath Technologies, Kirkland, PQ, Canada) at the ostium. Effective lesions were continued for 4 minutes. Isolation was completed when necessary by a focal 7 F, 4 mm cryoablation catheter (Freezor, CryoCath Technologies). The right lower PV was not targeted due to its small size, minimal or no electrical activity and because it was technically difficult to reach with the cryoablation catheter. Patients underwent spiral computed tomography (CT) scanning prior to and three months after ablation to measure the ostial diameter of the PVs. Patients were followed-up at one, three and six months in the outpatient clinic and by telephone interview every five to six months thereafter. Antiarrhythmic drugs were discontinued in patients without recurrent AF beyond three months. AF in the first eight weeks after ablation was not considered an indicator of therapeutic failure. Freedom from AF was defined as the absence of symptomatic AF beyond eight weeks post ablation, without antiarrhythmic drug therapy. Marked improvement in AF was considered as >90% reduction in the frequency of symptomatic episodes, off all antiarrhythmic medications.

RESULTS AND DISCUSSION

We studied forty patients with posteroseptal or left posterior AP. The LA-CS activation sequence was determined by examination of electrograms recorded in the CS at the earliest site during retrograde AP conduction. Eleven APs (27.5%) were ablated on the tricuspid annulus (right endocardial), nine (22.5%) inside the coronary venous system (epicardial), and 20 (50%) on the mitral annulus (left endocardial) by a transseptal approach. A "fragmented" or double "atrial" potential was recorded in all patients inside the CS at the earliest site during retrograde AP conduction. Sharp potential from the CS preceded the LA blunt component (sharp/blunt sequence) in all patients with an epicardial AP, and in 10 of 11 (91%) patients with a right endocardial

AP. Therefore 18 of 19 (95%) APs ablated by a right sided approach produced this pattern. The reverse sequence (blunt/sharp) was recorded in 19 of 20 (95%) patients with a left endocardial AP. We concluded therefore, that the sequence of left atrium-CS musculature activation determined by the analysis of the earliest "atrial" electrograms in the CS during retrograde AP conduction can predict the successful approach for ablation of posteroseptal or left posterior APs. This finding can have great significance by reducing procedure and fluoroscopy times, the number of unsuccessful radiofrequency applications and preventing unnecessary mapping of the left side of the septum along with the potential complications of left heart access.

Not only can the CS musculature participate in AP conduction, but it can take part in atrial macroreentry. We demonstrated this through a case of a 61-year old man with atrial tachycardia. We observed a unique pattern of atrial activation recorded by the CS catheter during the tachycardia: double potentials in the proximal CS, which fused in the mid CS. Electroanatomic (CARTO) mapping, entrainment and resetting techniques as well as the result of ablation demonstrated the two potentials to be generated by different arms of the reentry circuit, which involved part of the right atrium and the CS musculature itself. Participation of the CS myocardial coat in atrial macroreentry has been reported after left atrial ablation for AF and one case also without a previous ablation. We reported that a peculiar pattern of activation can be recorded during this arrhythmia inside the CS with double potentials showing a converging pattern and demonstrated that the CS musculature (with or without adjacent LA myocardium) can form a critical isthmus of this unusual atrial macroreentry.

Support for the notion of the posterior nodal extension (PNE) - another posteroseptal SVT substrate - to be responsible for slow AV nodal pathway conduction was provided by the case of a 40-year-old man. He had two distinct jumps in AH interval and two AVNRTs inducible with atrial pacing. Ablation in the right posteroseptal region eliminated the first tachycardia and the second jump, however did not influence the other AVNRT and AH jump. After repeated unsuccessful lesions left sided posteroseptal ablation was carried out via transseptal puncture, resulting in the generation of junctional beats and elimination of both the remaining AH jump and the tachycardia. This case demonstrates that the biatrial nature of the PNEs can manifest in distinct right- and left-sided slow pathways, which can support distinct right- and left-sided circuits of AVNRT in the same patient.

Intracardiac echocardiography (ICE) adequately visualized the cavotricuspid isthmus (CTI) in a series of cases where reliance on fluoroscopy ± electroanatomic mapping (CARTO) failed.

In one of the cases a tricuspid bioprosthesis was sutured onto the CTI during corrective surgery for severe tricuspid regurgitation accompanying Ebstein's anomaly. Therefore a part of the CTI was situated in the functional right ventricle. The patient underwent an electrophysiology study with electroanatomic (CARTO) mapping for persistent atrial flutter, suggesting clockwise CTI-dependent atrial flutter. Radiofrequency (RF) ablation at the atrial side of the CTI did not terminate flutter. When lesions were delivered across the artificial valve ring, in the functional right ventricle to complete the ablation line, the flutter terminated and subsequently bidirectional CTI block was shown, which persisted after a 30 min waiting period. However five months after the initial procedure the patient presented with recurrent symptoms and was found to have a recurrence of the same AFL with reconduction in the part of the CTI located in the functional right ventricle during redo electrophysiology study. ICE imaging of the CTI and the prosthetic valve ring with improved ablation catheter-tissue contact resulted in successful CTI ablation and the patient was arrhythmia free during long-term of follow up. ICE imaging also proved useful in cases where an unusually prominent Eustachian ridge (ER) was the likely reason for failure of conventional CTI ablation. In one of the cases a previous ablation session failed at another institution, where ablation of the CTI was unsuccessful despite irrigated RF ablation. ICE imaging revealed a very prominent ER, which precluded the ablation catheter from reaching the sub-Eustachian part of the CTI. The ablation catheter was curved in the right atrium and pulled down with ICE guiding to come into contact with the sub-Eustachian isthmus. After RF delivery at this site bidirectional CTI block was demonstrated. In a similar case ICE imaging showed a very prominent and actively contracting Eustachian valve as a likely cause for prolonged unsuccessful ablations at the CTI, eliminating all recordable atrial signals. Using ICE the ablation catheter was curved into full circle thus engaging the Eustachian valve and blocking CTI conduction by ablation.

Eighteen consecutive patients referred for AF underwent cryoablation to isolate the pulmonary veins (PVs). Complete PV isolation was achieved in 41 of 45 PVs (91%) by cryoablation (2.5 +/- 0.7 veins per patient). A mean of 27.2 +/- 11 applications per patient (9.2 +/- 4.7 per vein) with a mean temperature -79.8 +/- 4 degrees C were delivered. Recorded temperatures did not predict complete or incomplete isolation. Focal cryothermal ablation using a 7 F, 4-mm tip cryoablation catheter was required in ten PVs to complete isolation. During 14.8 +/- 6.2 months follow-up, 4 patients (22%) had no recurrence of atrial fibrillation, and 7/18 (39%) had >90% reduction in symptoms without antiarrhythmic drugs. CT scans at 3 months showed no stenosis (14.1 +/- 2.5 mm, 13.9 +/- 2.4 mm; P = 0.2). Eight patients underwent repeat ablation. Mapping demonstrated 13 of 14 (93%) previously isolated veins had recovery of conduction over 64 +/- 24% of the ostium. Our initial experience with the circular cryothermal catheter demonstrates a moderate efficacy, which is similar to that published using a focal cryoablation technique, but with shorter procedure and fluoroscopy times. The success rate using the cryoablation catheter was likely limited by the number of veins isolated per patient and the learning curve associated with a new catheter. Reconnection of PVs probably due to inadequate lesion depth resulting in the failure to achieve permanent PV disconnection was invariably observed after clinical recurrence. Reducing heat load due to high flow, by occlusion of the pulmonary veins using a cryoballoon may improve results.

CONCLUSIONS

1. Careful observation of coronary sinus (CS) recordings during retrograde conduction through posteroseptal or left posterior accessory pathways (AP), with the aim to determine the sequence of activation of the CS musculature and the left atrium is useful to establish before left heart catheterization whether a right or left sided approach to AP ablation is appropriate. The CS musculature can participate in atrial macroreentry producing a peculiar pattern of double potentials recorded along the CS. The left and right posterior AV nodal extensions - both present in most hearts - can support distinct left- and right sided circuits of AV nodal reentry tachycardia in the same patient.

2. Intracardiac echocardiography is helpful when conventional ablation of the cavotricuspid isthmus fails because of a very prominent and/or actively contracting Eustachian ridge or previous surgical intervention on the tricuspid valve.
3. Pulmonary vein (PV) isolation is feasible and safe using a circular cryothermic ablation catheter for the treatment of atrial fibrillation. However long-term success is limited by a high rate of reconnection of PVs, likely due to the heat load generated by ongoing PV flow during freezing.

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