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Novel interventional methods in catheter ablation in the treatment of brief cardiac arrhythmias

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PhD Thesis booklet

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Cardiac arrhythmias represent a significant challenge in clinical cardiology, particularly those briefs in duration, which may be difficult to detect and treat. Catheter ablation (CA) has become a cornerstone in the treatment of these arrhythmias. This thesis explores novel methods to enhance the efficacy and precision of CA in treating brief atrial (AT) and ventricular tachycardia (VT) episodes. While advances in medical technology have allowed for more precise diagnostics and treatments, brief episodes of atrial and ventricular arrhythmias pose unique challenges. These short-lived arrhythmias are often transient and may be asymptomatic, making them difficult to detect with traditional methods. However, they can still be indicative of underlying pathophysiology and carry a risk of more severe cardiovascular events if not properly managed.

Robotic technology is one of the most dynamically evolving fields in medicine. Alongside technological advancement, there is a growing demand for automated functions aimed at preventing human errors. The application of robotic technologies in cardiology, especially in electrophysiology, is becoming increasingly widespread. Robots enable more precise and safer interventions, overcoming the limitations of manual methods. Part of this thesis primarily focuses on describing the most widely available cardiac robotic technology at present, the robotic magnetic navigation system (RMN).

Substantial improvements have been achieved over the last couple of years in the development of new mapping techniques of cardiac arrhythmias. These improvements aimed to advance the precision and

speed of mapping. Additionally, some of the new possibilities may have the potential to offer a better understanding of arrhythmia mechanisms. A broad spectrum of new techniques is available in the global mapping of the cardiac chambers, such as dipole density mapping (AcQMap system, Acutus Medical, Carlsbad, CA) which allows for noncontact mapping of a single atrial beat. Alternatively, non-invasive methods either simulation based such as View into Ventricular Onset (VIVO, Catheter Precision Inc., Mt. Olive, NJ), or body surface mapping like CardioInsight (Cleveland, OH, United States) and the non-invasive epi- and endocardial electrophysiology system (NEEES) became available.

Objectives

1. First, we aimed to provide a comprehensive summary of the widely used robotic magnetic navigation system in the setting of treatment of atrial and ventricular arrythmias.

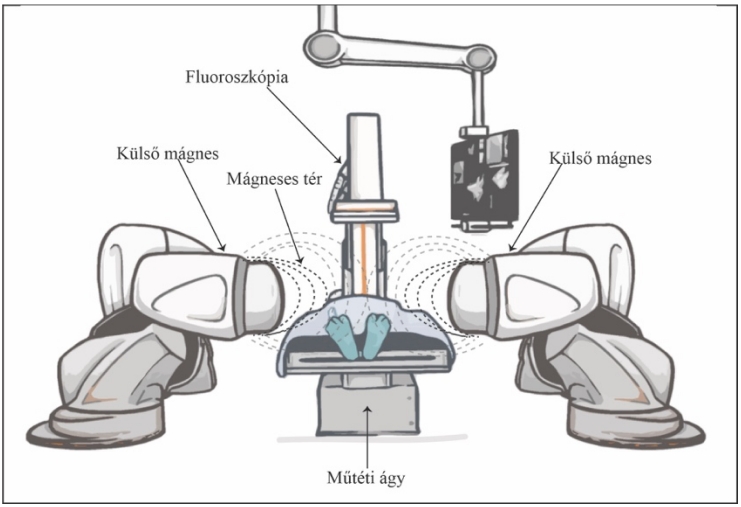
2. Second, performing a methodological review, we aimed to provide a systematic overview about mapping techniques that can be implemented in the diagnosis and treatment of highly symptomatic brief episodes of ATs and VTs. In this review, we emphasize the description of mapping methods and their clinical use.

3. Third, we aimed to demonstrate the value of the novel dipole charge density mapping technique integrated with RMN in the treatment of short-lived ATs using our prospective patient database.

Endovascular robotic ablation

The application of robotic technologies in cardiology began to develop in the early 2000s. Today, robotic technology is increasingly used in various cardiological procedures, including minimally invasive atrial septal defect closure, mitral valve repair, coronary artery bypass surgery, and more recently, electrophysiological procedures. In recent years, RMN has become the most utilized robotic technology in cardiac electrophysiology.

Since its introduction in 2003, the RMN system (Stereotaxis, Inc., St. Louis, MO, USA) has become the most widely used robotic system in electrophysiology. The system consists of two large external magnets positioned on either side of the patient. These magnets generate a magnetic field of 0.08-0.1 Tesla in the patient's chest to steer specially designed catheters, which contain three small magnets at their flexible distal ends. The magnetic field is optimized for a theoretical heart model of 20 × 20 cm. Using a computer system, the catheter can be navigated by altering the magnetic vector. A motor control system (Cardiodrive; Stereotaxis, Inc., St. Louis, MO, USA) directs the catheter's advancement and retraction, allowing movement in 1 mm increments using a mouse scroll wheel. The procedure is controlled by the physician from outside the operating room, in the console room.



The RMN system facilitates the navigation of the ablation catheter in anatomically challenging locations. In patients with congenital heart disease, the system eases access to target areas that would be difficult to reach with manual catheter manipulation. For patients who have undergone corrective procedures for atrial septal defects or more complex surgeries such as Mustard, Senning, or Fontan operations, robotically-guided catheters can achieve a retrograde approach by assuming multiple curves. RMN can also be applied to pediatric patients, where the small size of the atria and ventricles would make manual catheter navigation difficult, as well as in patients with prior surgical interventions. When transseptal or trans-baffle access is not feasible, RMN enables access to the left heart using a retrograde transaortic approach. Various mapping systems (CARTO, EnSite electroanatomical mapping systems) can be integrated into the RMN

system, playing a crucial role in accurately locating arrhythmias and understanding their mechanisms.

Numerous clinical studies have examined the effectiveness of RMN in the treatment of atrial and ventricular arrhythmias, although there are few large, multicentre randomized trials. Most clinical studies comparing RMN-guided ablation of atrial fibrillation and ventricular arrhythmias to manual RF ablation report superior outcomes for RMN in terms of acute and long-term success rates. Additionally, the use of X-ray radiation during the procedures was significantly lower in RMN-guided catheter ablation compared to manual catheter ablation, and the complication rates were also lower, particularly due to a significant reduction in myocardial perforation and cardiac tamponade occurrences.

Based on the available scientific evidence, robotically-guided catheter ablation of atrial and ventricular arrhythmias clearly reduces the use of fluoroscopy. Additionally, its implementation in everyday practice is expected to decrease procedural times and number of complications. RMN offers a valuable alternative particularly for patients with congenital heart disease, those who have undergone surgical interventions, and those suffering from complex arrhythmias such as brief episodes of tachycardias. RMN might be advantageous in the treatment of various arrhythmias. With its unique image integration capabilities and precise catheter navigation, RMN has proven to be a safe and effective system in the field of electrophysiology.

Treatment of brief episodes of highly symptomatic supraventricular and ventricular arrhythmias: a methodological review

Cardiac mapping has evolved in the last few years from a direct single point-by-point registration of electrical activity to furthermost complex multimodal real-time techniques. The improvements of the technology have offered electrophysiologists a better understanding of cardiac arrhythmias and more precise ablation procedures resulting in higher success rate in arrhythmia management. Activation mapping is the cornerstone of mapping technologies in CA therapy. With improved understanding of cardiac arrhythmias, the concept of combining the electrical activation data obtained using mapping catheters with anatomical data guided by catheter position and contact, has been crucial in the successful outcome of CA procedures. Multiple mapping systems have been developed for this purpose. The most frequently used 3D mapping systems are the CARTO system (Biosense Webster, Diamond Bar, CA, USA), the EnSite Precision system (Abbott Laboratories, Chicago, IL, USA), and the Rhythmia HDx mapping system (Boston Scientific, Cambridge, Massachusetts). The novel AcQMap High-Resolution Imaging and Mapping System (Acutus Medical, Carlsbad, USA) provides maps of electrical activation across an ultrasound-acquired cardiac chamber surface. We describe each of these mapping system in detail in the thesis. The evaluation of these novel mapping techniques highlights their ability to accurately identify arrhythmogenic substrates, even in challenging cases with brief and infrequent arrhythmias.

Treating brief episodes of tachycardias remains a challenge and can cause significant frustration for the practicing electrophysiologist. In the early years of electrophysiology, these arrhythmias were simply not attempted with interventions. In recent years, however, due to the increased number of patients and the improvement of mapping speed many more patients are scheduled for catheter ablation. Despite this, it remains a difficult issue due to the lack of dedicated mapping systems designed to treat this unique and slowly growing patient population. Although the broadening of the indication is clearly visible, currently available sequential mapping techniques often fail to map short-lived arrhythmias. Most importantly, most non-invasive mapping techniques suffer from the lack of a real-time anatomical map and adequate spatiotemporal resolution.

Currently, we implemented the above-described techniques in our routine by taking advantage of their global mapping capabilities. All patients undergoing CA for possible short-lived arrhythmias are currently planned by using one of the above-mentioned technologies. For unusual PVCs the major advantage is at the outpatient setting. For atrial tachycardias the AcQMap technology is exclusively used since there is no available alternative. Beyond this obvious indication we always consider this for ablation persistent atrial fibrillation since during the ablation it can convert into unstable ATs. Post-MAZE patients are also planned with AcQMap almost exclusively at our centre due to the high likelihood of multiple short tachycardias during the procedure.

The mapping techniques used to guide catheter ablation procedures depend on the characteristics of the arrhythmias, with each technique having its own strengths and limitations. Choosing an appropriate mapping and ablation system for every patient may effectively ameliorate clinical results. However, in order to perform a personalized ablation, the chosen mapping system must incorporate all needed features for the mapping of the particular arrhythmia. Currently, the majority of patients with short-lived arrhythmias are initially planned for EP study using conventional mapping systems, but due to the non-inducible characteristics of their arrhythmias they are often rescheduled for a second procedure using a more adequate mapping system. Ideally, a complete mapping system should embody all available techniques, with the possibility of rapid strategy changing, in order to effectively treat patients with various arrhythmias. With such kind of system, we could reduce procedure times and significantly lower procedural costs.

New Possibilities in the Treatment of Brief Episodes of Highly Symptomatic Atrial Tachycardia: The Usefulness of Single-Position Single-Beat Charge Density Mapping

In the retrospective study of the AcQMap system twenty of 175 patients (men, n=4; women, n=16) had brief episodes of AT. Fourteen underwent a repeat procedure (redo group); 6 patients had a de novo procedure (de novo group). The average time between onset symptoms and the final procedure was 46 ± 49 months (mean ± SD)

and was significantly shorter in the de novo than redo group (15 ± 14 versus 59 ± 54; P=0.02).

Total procedural time was 160 ± 46 minutes, with a total fluoroscopy time of 16 ± 8 minutes. Total radiofrequency application duration was 653 ± 444 s. Left atrial localization of AT was identified in 50% of patients, right atrium localization in 37.5%, and septal origins in 12.5% of patients. Regarding the mechanism of the mapped arrhythmias, we found atrioventricular reentrant tachycardia/atrioventricular nodal reentry tachycardia in 1 patient, focal AT in 15, perinodal focal in 2, and reentry mechanism in 2 patients (Figure 8B). An average number of 1.1 of high-resolution charge density maps were performed in the left atrium and 2.0 in right atrium. In all cases, focal activation pattern was identified on the AcQMaps as target of ablation. Using AcQMap, we documented mapping times of 3.2 ± 2.5 minutes.

Acute success was achieved in 19 of 20 (95%). In 1 patient, ablation was unsuccessful because of parahisian location of a perinodal reentry circuit. Recurrence during follow-up developed in one additional patient (5%).

The major finding of the retrospective study is that brief episodes of highly symptomatic ATs can be mapped using single-position single-beat dipole density charge mapping and ablated successfully with low recurrence rates during follow-up. Although, at first sight, our patient population seems to be small, it is very important to recognize that we describe successful ablation in a group of patients that was previously

considered untreatable. Most of the time these patients were either not scheduled for ablation, or even when they underwent diagnostic EP study, due to the lack of appropriate map, they did not undergo catheter ablation. This was a major source of frustration for both the patients and physician.

A very interesting aspect of the current topic is that there is limited literature focused on this specific population. We do believe this problem is underreported; in fact, we could not find any available literature data about successful ablative therapy of brief episodes of ATs or PACs. Therefore, our results can be interpreted as the first in man systematic report of an interventional approach for patient suffering from brief episodes of ATs.

Conclusions (new findings)

1. Although the RMN system has minimized the need for manual operations during catheter ablation procedures, venous or arterial puncture and the placement of catheters into the sheath still require human intervention. In the near future, the rapid advancement of technology may make fully robot-controlled electrophysiology procedures possible.

2. Brief atrial and ventricular arrhythmias are challenging to treat using standard sequential electrophysiology mapping techniques. New beneficent technological features permit the mapping of these previously considered unmappable arrhythmias. The MEA mapping system was the first non-contact technology able to map brief arrhythmias in the atria and ventricles too, however, due to the numerous limitations of this technique it is no longer used in clinical electrophysiology. The AcQMap high-resolution mapping system is a promising technique, which allows global chamber mapping in the atria, however it cannot be utilized in the mapping of brief ventricular arrhythmias. Due to the global mapping and single-beat mapping features, the noninvasive CardioInsight mapping system can be utilized in both atrial and ventricular arrhythmias, however this system is limited by the lack of an accurate 3D representation of chamber anatomy. The VIVO technique is a simulation-based mapping system, which offers a unique approach to localization of ventricular arrhythmias exclusively.

3. Brief episodes of highly symptomatic AT can be mapped using single-position single-beat charge density mapping (AcQMap) and ablated successfully with high acute and long-term success rate. In addition, brief episodes of AT can be eliminated in a shorter period of time, when patients are scheduled directly for AcQMap-guided procedures.

Authorship statement

Undersigned, Prof. Med. Habil. Tamás Szili-Török, MD, PhD, hereby certify that Rita Beáta Gagyi, MD actively and independently participated in the preparation of the scientific material, the execution of the studies, the collection and processing of scientific data, the statistical analysis, and the submission for publication of the following publications included in her PhD thesis entitled "Novel interventional methods in catheter ablation in the treatment of brief cardiac arrhythmias".

Endovascular robotic ablation (original title: Endovaszkuláris robotabláció) Dr. Gagyi Rita Beáta, Dr. Vámos Máté, Prof. Dr. Nemes Attila, Dr. Szili-Török Tamás. Cardiologia Hungarica. 2024 May; 03.

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New Possibilities in the Treatment of Brief Episodes of Highly Symptomatic Atrial Tachycardia: The Usefulness of Single-Position Single-Beat Charge Density Mapping. Gagyi RB, Noten AME, Lesina K, Mahmoodi BK, Yap SC, Hoogendijk MG, Wijchers S, Bhagwandien RE, Szili-Torok T. Circulation Arrhythmias Electrophysiol. 2021 Nov.;14(11):e010340. doi: 10.1161/CIRCEP.121.010340. D1

I also confirm that the above-mentioned articles are exclusively part of this PhD thesis.

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