REVIEW

Robotics in ablation – a technology at a crossroads

Decebal Gabriel Latcu[1], Bogdan Enache[1], Ahmed Moustafa Wedn[1], Sok-Sithikun Bun[1], Nadir Saoudi[1]

Robotics has been used for radiofrequency ablation of human arrhythmias for more than 15 years; among 2 widely distributed systems[1,2], only Stereotaxis (Saint-Louis, Missouri, USA) is still commercially available. Our experience with the Stereotaxis system goes back more than a decade[3,4] and its advantages still make it the system of choice, in our center, for a number of arrhythmias.

THE REMOTE MAGNETIC NAVIGATION (RMN) SYSTEM

RMN uses a steerable magnetic field which allows the remote manipulation inside the heart chambers of a very soft magnetic catheter embedded with an ablation electrode. The RMN system is composed by two giant magnets (Niobe ES, Stereotaxis) positionned each side of the fluoroscopy table (Axiom Artis, Siemens, Germany), which create a magnetic field of a 0.1 T maximal intensity (Figure 1). The orientation of the magnetic field is remotely controlled by the operator (Figure 2) via a dedicated software (Navigant, Stereotaxis). Additional dedicated systems (V-Drive / V-drive Duo) and disposables (Quick-Cas / V-Cas / V-Cas Deflect[5], Stereotaxis) connected to the ablation catheter allow the advancement and the retraction of the catheter, of the sheath, as well as deflection / undeflection / rotation of a remotely controlled fixed curve or steerable sheath. These may be completed by a remotely controlled system for a rigid circular catheter (V-Loop, Stereotaxis).

In the following paragraphs some evidence-based data for specific arrhythmias ablation with RMN will be presented.

RMN FOR ABLATION OF ATRIAL FIBRILLATION (AF)

AF ablation with RMN has been performed since 2008 when the first irrigated magnetic catheter became available. Retrospective comparison[6] with manual ablation of AF did not show any difference in the ablation result. The longer procedure time for RMN (223 vs 166 min) is compensated by a shorter fluoroscopy time

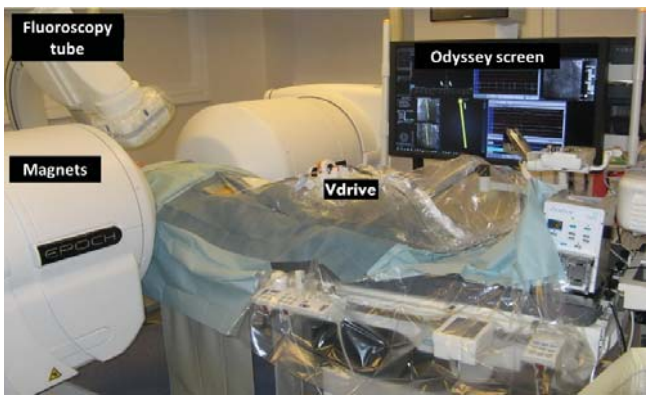

Figure 1. Electrophysiology lab with the RMN: the magnets (Niobe ES), the fluoroscopy tube, the remote catheter control system (Vdrive) and the Odyssey screen.

Figure 2. The control room with the Odyssey screen, the Cardiodrive and the Vdrive controller.

[1] Centre Hospitalier Princesse Grace, Avenue Pasteur, 98000 Monaco

Contact address:
Decebal Gabriel Latcu, MD, Department of Cardiology, Centre Hospitalier Princesse Grace, Avenue Pasteur, 98000, Monaco.
Email: dglatcu@yahoo.com

(13 vs 34 min) and possibly inferior complication rate (without any cardiac perforation in the RMN group vs 2.4% in the manual group) but this difference did not reach significance since the study was underpowered. These results were confirmed by another comparative series[7]; even more, a dedicated prospective study on RMN[8] showed comparable results to historical manual ablation data and lack of serious adverse events. A large international multicenter survey[9] among RMN users does not report any atrio-esophageal fistula when using the system, whilst this complication, even rare, is still present while using manual catheters.

Persistent AF could represent an elective indication for RMN, as longer procedure times are warranted; also, common left atrial dilation facilitates magnetic navigation. In our initial experience[10] on 28 patients having persistent AF ablation with RMN (mean duration of actual AF episode of 10±16 months), with a follow-up 11±6 months after 1.25 procedures/patient, 68% of the cases didn't have any arrhythmia recurrence. No major complication occurred. The advantage for the operator to perform these lengthy procedures (235±68 min) in a seated position without the lead coat is undeniable.

It is worth noting that RMN also renders possible AF ablation by aortic retrograde approach[11], which may be useful in case of impossible transeptal approach in congenital abnormalities with inferior vena cava agenesis / interruption.

AF ablation with RMN may be further optimized by the use of a remotely controlled steerable sheath (V-Cas Deflect); this improves long-term results, allows faster right pulmonary vein isolation and diminishes radiofrequency delivery time and procedure time[5]. We recently investigated whether lesion creation with magnetic catheters is comparable with the contemporary gold standard manual catheters with contact force assessment. We showed that during radiofrequency delivery, the electrical modifications suggesting transmurality is faster achieved with remote magnetic catheters than with optimal use of contact force catheters[12]. This may be in relation with a more stable tissue contact while using magnetic technology[13].

RMN FOR ABLATION OF OTHER SUPRAVENTRICULAR ARRHYTHMIAS.

Post AF ablation atrial tachycardia (AT) was until recently another elective indication for RMN technology. Indeed, without having to continuously hold the catheter, the operator could concentrate on annotation and activation mapping, since it's accuracy determines the procedural success. We compared[14] our initial experience of 25 AT patients (RMN) with a control group of manual ablations (32 AT patients). There was no difference in what concerns acute or long-term success (80% vs 78%, p=ns) between the 2 techniques. Nevertheless, if no serious adverse event occurred in the RMN group, in the control group and transitory ischemic attack and a cardiac perforation requiring drainage were reported. The difference in procedure duration between the 2 techniques did not reach significance (RMN 236±67 min, control group 201±72 min).

Atrio-ventricular nodal reentrant tachycardia ablation has been feasible with RMN technology from the beginning, since no irrigation is necessary. Finely tuned mapping of the atrio-ventricular node extensions, especially of the rightward inferior extension (commonly the slow pathway), with 1 mm step advancement/retraction movements of the ablation catheter with direction changes in 1 degree steps, may be fully exploited in this indication. We reported[15] a 100% success rate for these procedures, without serious adverse events and with a number of junctional beats inferior to manual technique, favoring a better tissue contact with the magnetic catheters.

Typical flutter is a challenge for RMN, possibly because of insufficient catheter pressure on the cavo-tricuspid isthmus. Magnetic non-irrigated catheters were proven inferior to manual technique[16] but irrigation improved results and seems mandatory in case of anatomical complexity[17]. For cost-effectiveness reasons RMN might be an alternative to manual catheters for cavo-tricuspid isthmus ablation only in case of concomitant AF ablation or in case of superior approach[18]. Procedural success of CTI ablation may be warranted with the RMN technology if concomitant use of a steerable sheath.

AT in case of congenital heart disease is difficult for complex anatomies with limited catheter access. Direct robotic manipulation of the distal tip of a soft catheter, specific for RMN, is a great advantage in comparison to rigid, manually driven catheters, in case of twisting path from the puncture site to the ablation target[19]. Fluoroscopy exposure is thus significantly reduced[20,21]. Retrograde transaortic approach for AT ablation in Mustard-Senning or cavo-pulmonary derivation patients seems particularly successful with RMN[22,23,24].

Accessory pathways, incisional flutters and sinus node reentry have all been reported with the successful use of the RMN.

RMN FOR VENTRICULAR TACHYCARDIA (VT) ABLATION

Feasibility and safety of catheter ablation with the RMN have been reported for right ventricular outflow tract VT[25], fascicular VT[26], ischemic scar-related VT[27,28], including epicardial VT[29], as well as in other heart disease-related VT[30]. An increasing amount of data[31,32] seem to suggest even superior results for VT ablation with RMN in comparison to manual technique.

A randomized study is currently including VT patients and will assess whether substrate-based ablation of VT with RMN has clinical advantages over manual catheter manipulation[33].

CONCLUSION: ACHIEVEMENTS AND CHALLENGES

Ablation using RMN has similar efficacy compared to the manual technique in a wide range of arrhythmias. RMN has the advantages of improved safety and an undeniable increased comfort for the operator. Complex procedures became feasible with RMN for a stand-alone operator, manipulating both the ablation catheter and the mapping system. Congenital heart disease arrhythmias are an elective indication for RMN; RMN might be superior to manual technique also for VT ablation. In our center, AVNRT and AF ablation are other procedure types for which RMN is systematically considered.

Nevertheless, RMN is facing today several challenges. First, the irrigated magnetic-tip catheter, available for almost one decade, has not been upgraded. Several technological improvements have been embedded into manual catheters (contact force measurement, more efficient cooling with less irrigation flow) but are still lacking for magnetic catheters. Shortening the rigid part of the distal tip of the magnetic catheters and approaching the three magnets towards the distal end might improve navigation, catheter stability and electrode-tissue contact. A contact assessment module ("eContact™") will be shortly available from Stereotaxis; added to the current catheters it may overcome some of these limitations.

Second, for several years, electrophysiology entered the era of multielectrode mapping (MEM) with automatic annotation. More recently, ultra-high-density mapping became the gold-standard for mapping of complex arrhythmias[34]. Except for the use of the V-loop disposable allowing the use of the circular catheter (Lasso™) for MEM, but with the magnets in the stowed position and less reliably than multielectrode catheters like the PentaRay™ or Orion™, RMN allows only "*point-by-point*" mapping. Moreover, also RMN has been used in junction with other mapping systems like Rhythmia[35] and Navex[36], integration is currently available only with Carto™ (Biosense-Webster, Inc.), which might also be considered a limitation.

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References

1. Faddis MN, Chen J, Osborn J, et al. Magnetic guidance system for cardiac electrophysiology: a prospective trial of safety and efficacy in humans. J Am Coll Cardiol 2003;42:1952-8.
2. Saliba W, Reddy VY, Wazni O, et al. Atrial fibrillation ablation using a robotic catheter remote control system initial human experience and long-term follow-up results. J Am Coll Cardiol. 2008;51(25):2407-11.
3. Saoudi N, Laţcu DG, Rinaldi JP, Ricard P. La robotique dans le diagnostic et le traitement des troubles du rythme cardiaque. Bull Acad. Natle Med 2008;192(5):1029-41.
4. Laţcu DG, Ricard P, Zarqane N, et al. Robotic magnetic navigation for ablation of human arrhythmias: initial experience. Arch Cardiovasc Dis. 2009;102(5):419-25.
5. Errahmouni A, Laţcu DG, Bun SS, Rijo N, Dugourd C, Saoudi N. Remotely controlled steerable sheath improves result and procedural parameters of atrial fibrillation ablation with magnetic navigation. Europace. 2015 Jul;17(7):1045-50. doi: 10.1093/europace/euu388. Epub 2015 Feb 5.
6. Arya A, Zaker-Shahrak R, Sommer Pet al. Catheter ablation of atrial fibrillation using remote magnetic catheter navigation: a case-control study. Europace. 2011;13(1):45-50.
7. L.Vollmann D, Seegers J, Dorenkamp M et al. Remote magnetic versus manual catheter navigation for circumferential pulmonary vein ablation in patients with atrial fibrillation. Lüthje Clin Res Cardiol. 2011; 100(11):1003-11.
8. Pappone C, Vicedomini G, Frigoli E, et al. Irrigated-tip magnetic catheter ablation of AF: a long-term prospective study in 130 patients. Heart Rhythm 2011:8(1):8-15.
9. Danon A, Shurrab M, Nair KM, Laţcu DG, Arruda MS, Chen X, Szili-Torok T, Rossvol O, Wissner EE, Lashevsky I, Crystal E. Atrial fibrillation ablation using remote magnetic navigation and the risk of atrial-esophageal fistula: international multicenter experience. J Interv Card Electrophysiol. 2015 Aug;43(2):169-74. doi: 10.1007/s10840-015-0003-7. Epub 2015 May 3.
10. Arnoult M, Laţcu DG, Ricard P, Saoudi N. Remote magnetic navigation in catheter ablation of persistent atrial fibrillation. Arch Cardiovasc Dis Suppl 2012;4(1):70.
11. Miyazaki S, Nault I, Haïssaguerre M, Hocini M. Atrial fibrillation ablation by aortic retrograde approach using a magnetic navigation system. J Cardiovasc Electrophysiol. 2010;21(4):455-7.
12. Bun SS, Ayari A, Laţcu DG, Errahmouni A, Saoudi N. Radiofrequency catheter ablation of atrial fibrillation: Electrical modification suggesting transmurality is faster achieved with remote magnetic catheter in comparison with contact force use. J Cardiovasc Electrophysiol. 2017 Jul;28(7):745-753. doi: 10.1111/jce.13222. Epub 2017 May 24.
13. Bhaskaran A, Barry MA, Al Raisi SI, Chik W, Nguyen DT, Pouliopoulos J, Nalliah C, Hendricks R, Thomas S, McEwan AL, Kovoor P, Thiagalingam A. Magnetic guidance versus manual control: comparison of ra-

diofrequency lesion dimensions and evaluation of the effect of heart wall motion in a myocardial phantom. J Interv Card Electrophysiol. 2015 Oct;44(1):1-8. doi: 10.1007/s10840-015-0023-3. Epub 2015 Jun 30.

14. Laţcu DG, Massaad Y, Mahjoub M, Squara F, Saoudi N. Left atrial flutter occuring after atrial fibrillation ablation: ablation using remote magnetic navigation versus manual technique. Archives of Cardiovascular Diseases Supplements 2013: 5(1) :69.
15. Ricard P, Laţcu DG, Yaïci K, Zarqane N, Saoudi N. Slow pathway radiofrequency ablation in patients with AVNRT: junctional rhythm is less frequent during magnetic navigation ablation than with the conventional technique. Pacing Clin Electrophysiol. 2010;33(1):11-5.
16. Steven D, Rostock T, Servatius H et al. Robotic versus conventional ablation for common-type atrial flutter: a prospective randomized trial to evaluate the effectiveness of remote catheter navigation. Heart Rhythm 2008;5:1556-60.
17. Koektuerk B, Chun JK, Wissner E et al. Cavotricuspid Isthmus Anatomy Determines The Success Of Remote Controlled Magnetic Bidirectional Block: A Comparision Between Magnetic 8-mm Solid Tip And 3.5-mm Magnetic Irrigated Tip Catheter. Indian Pacing Electrophysiol J. 2011;11(4):103-14.
18. Laţcu DG, Bun SS, Ricard P, Saoudi N. Hepatico-Tricuspid Isthmus Ablation for Typical-Like Atrial Flutter by Femoral Approach in Absence of the Inferior Vena Cava: Use of Magnetic Navigation and Three-Dimensional Mapping with Image Integration. Pacing Clin Electrophysiol. 2011 Mar 16. doi: 10.1111/j.1540-8159.2011.03051.x.
19. Ueda A, Suman-Horduna I, Mantziari L, Gujic M, Marchese P, Ho SY, Babu-Narayan SV, Ernst S. Contemporary outcomes of supraventricular tachycardia ablation in congenital heart disease: a single-center experience in 116 patients. Circ Arrhythm Electrophysiol. 2013 Jun;6(3):606-13. doi: 10.1161/CIRCEP.113.000415. Epub 2013 May 17.
20. Schwagten B, Witsenburg M, De Groot NM et al. Effect of magnetic navigation system on procedure times and radiation risk in children undergoing catheter ablation. Am J Cardiol. 2010;106(1):69-72.
21. Wu J, Pflaumer A, Deisenhofer I et al. Mapping of atrial tachycardia by remote magnetic navigation in postoperative patients with congenital heart disease. J Cardiovasc Electrophysiol. 2010:21(7):751-9.
22. Wu J, Pflaumer A, Deisenhofer I et al. Mapping of intraatrial reentrant tachycardias by remote magnetic navigation in patients with d-transposition of the great arteries after mustard or senning procedure. J Cardiovasc Electrophysiol. 2008;19(11):1153-9.
23. Schwagten B, Jordaens L, Witsenburg M et al. Initial experience with catheter ablation using remote magnetic navigation in adults with complex congenital heart disease and in small children. Pacing Clin Electrophysiol. 2009;32 Suppl 1:S198-201.
24. Ernst S, Babu-Narayan SV, Keegan J et al. Remote Controlled Magnetic Navigation and Ablation with 3D Image Integration as an Alternative Approach in Patients with Intra-Atrial Baffle Anatomy. Circ Arrhythm Electrophysiol. 2011 Nov 7. [Epub ahead of print]
25. Konstantinidou M, Koektuerk B, Wissner E et al. Catheter ablation of right ventricular outflow tract tachycardia: a simplified remote-controlled approach. Europace. 2011 ;13(5):696-700.
26. Thornton AS, Res J, Mekel JM, Jordaens LJ. Use of advanced mapping and remote magnetic navigation to ablate left ventricular fascicular tachycardia. Pacing Clin Electrophysiol. 2006;29(6):685-8.
27. Arya A, Eitel C, Bollmann A et al. Catheter ablation of scar-related ventricular tachycardia in patients with electrical storm using remote magnetic catheter navigation. Pacing Clin Electrophysiol. 2010; 33(11):1312-8. doi: 10.1111/j.1540-8159.2010.02818.x.
28. Skoda J, Arya A, Garcia F, Gerstenfeld E, Marchlinski F, Hindricks G, Miller J, Petru J, Sediva L, Sha Q, Janotka M, Chovanec M, Waldauf P, Neuzil P, Reddy VY. Catheter Ablation of Ischemic Ventricular Tachycardia With Remote Magnetic Navigation: STOP-VT Multicenter Trial. J Cardiovasc Electrophysiol. 2016 Mar;27 Suppl 1:S29-37. doi: 10.1111/jce.12910.
29. Di Biase L, Santangeli P, Astudillo V et al. Endo-epicardial ablation of ventricular arrhythmias in the left ventricle with the Remote Magnetic Navigation System and the 3.5-mm open irrigated magnetic catheter: results from a large single-center case-control series. Heart Rhythm. 2010;7(8):1029-35.
30. Aryana A, d'Avila A, Heist EK et al. Remote magnetic navigation to guide endocardial and epicardial catheter mapping of scar-related ventricular tachycardia. Circulation. 2007;115(10):1191-200.
31. Bauernfeind T, Akca F, Schwagten B et al. The magnetic navigation system allows safety and high efficacy for ablation of arrhythmias. Europace. 2011;13(7):1015-21.
32. Turagam MK, Atkins D, Tung R, Mansour M, Ruskin J, Cheng J, Di Biase L, Natale A, Lakkireddy D. A meta-analysis of manual versus remote magnetic navigation for ventricular tachycardia ablation. J Interv Card Electrophysiol. 2017 Jun 17. doi: 10.1007/s10840-017-0257-3. [Epub ahead of print]
33. Di Biase L, Tung R, Szili-Torok T, Burkhardt JD, Weiss P, Tavernier R, Berman AE, Wissner E, Spear W, Chen X, Neužil P, Skoda J, Lakkireddy D, Schwagten B, Lock K, Natale A. MAGNETIC VT study: a prospective, multicenter, post-market randomized controlled trial comparing VT ablation outcomes using remote magnetic navigation-guided substrate mapping and ablation versus manual approach in a low LVEF population. J Interv Card Electrophysiol. 2017 Apr;48(3):237-245. doi: 10.1007/s10840-016-0217-3. Epub 2017 Jan 7.
34. Laţcu DG, Bun SS, Viera F, Delassi T, El Jamili M, Al Amoura A, Saoudi N. Selection of Critical Isthmus in Scar-Related Atrial Tachycardia Using a New Automated Ultrahigh Resolution Mapping System. Circ Arrhythm Electrophysiol. 2017 Jan;10(1). pii: e004510. doi: 10.1161/CIRCEP.116.004510.
35. Laţcu DG, Bun SS, Saoudi N. Combined remote magnetic navigation and ultra-high-density mapping (Rhythmia™) in slow pathway ablation. Europace. 2016 Jun;18(6):814. doi: 10.1093/europace/euv459. Epub 2016 Feb 5.
36. Nölker G, Gutleben KJ, Muntean B, Vogt J, Horstkotte D, Dabiri Abkenari L, Akca F, Szili-Torok T. Novel robotic catheter manipulation system integrated with remote magnetic navigation for fully remote ablation of atrial tachyarrhythmias: a two-centre evaluation. Europace. 2012 Dec;14(12):1715-8. doi: 10.1093/europace/eus169. Epub 2012 Jun 20.