

EUR Research Information Portal

Safety and efficacy of the remote magnetic navigation for ablation of ventricular tachycardias-a systematic review

Published in:

Journal of Interventional Cardiac Electrophysiology

Publication status and date:

Published: 01/01/2012

DOI (link to publisher):

[10.1007/s10840-011-9645-2](https://doi.org/10.1007/s10840-011-9645-2)

Document Version

Publisher's PDF, also known as Version of record

Citation for the published version (APA):

Akca, F., Onsesveren, I., Jordaens, L., & Szili-Torok, T. (2012). Safety and efficacy of the remote magnetic navigation for ablation of ventricular tachycardias-a systematic review. *Journal of Interventional Cardiac Electrophysiology*, 34(1), 65-71. <https://doi.org/10.1007/s10840-011-9645-2>

[Link to publication on the EUR Research Information Portal](#)

Terms and Conditions of Use

Except as permitted by the applicable copyright law, you may not reproduce or make this material available to any third party without the prior written permission from the copyright holder(s). Copyright law allows the following uses of this material without prior permission:

- you may download, save and print a copy of this material for your personal use only;
- you may share the EUR portal link to this material.

In case the material is published with an open access license (e.g. a Creative Commons (CC) license), other uses may be allowed. Please check the terms and conditions of the specific license.

Take-down policy

If you believe that this material infringes your copyright and/or any other intellectual property rights, you may request its removal by contacting us at the following email address: openaccess.library@eur.nl. Please provide us with all the relevant information, including the reasons why you believe any of your rights have been infringed. In case of a legitimate complaint, we will make the material inaccessible and/or remove it from the website.

Safety and efficacy of the remote magnetic navigation for ablation of ventricular tachycardias—a systematic review

Ferdi Akca · Ibrahim Önsesveren · Luc Jordaens · Tamas Szili-Torok

Received: 31 May 2011 / Accepted: 13 November 2011 / Published online: 20 December 2011
© The Author(s) 2011. This article is published with open access at Springerlink.com

Abstract

Objective Remote magnetic navigation (RMN) is considered to be a solution for mapping and ablation of several arrhythmias. In this systematic review we aimed to assess the safety and efficacy of RMN in ablation of ventricular tachycardia (VT).

Methods The National Library of Medicine's PubMed database was searched for articles containing any of a predetermined set of search terms that were published prior to November 1, 2011. Quality of evidence was rated using the GRADE system. **Results** The database search resulted in 11 relevant articles evaluating the usefulness of RMN. Three groups of VTs were studied: VT in patients with ischemic cardiomyopathy (ICMP), non-ischemic cardiomyopathy (NICMP) and structurally normal hearts (SNH). The use of RMN in patients with ICMP has been associated with success rates ranging from 71 to 80%. RMN has been shown to be a feasible and effective method for ablation of VT in NICMP and SNH patients. Success rates between 50% and 100% have been reported in NICMP populations. Rates ranging from 86% to 100% have been reported for SNH patients. The lowest rates of arrhythmia recurrence are reported for SNH patients (0–17%). In ICMP and NICMP, recurrence rates of 0–30% and 14–50%, respectively, have been reported. One patient experienced total heart block, and one patient experienced a thromboembolic event after RMN catheter ablation procedures.

Conclusions RMN has been shown to be an effective and safe method for ablation of VT in various patient populations with

low recurrence and complication rates. However, more comparative and randomized studies are necessary, and therefore the true value of RMN for VT ablation remains still unknown.

Keywords Ventricular tachycardia · Magnetic navigation · Catheter ablation · Electrophysiology · Systematic review

1 Introduction

Treatment of ventricular tachycardia (VT) has gone through great improvements in recent years [1–3]. When drug therapy is not effective, catheter ablation of VT can be an effective alternative that has been shown to eliminate ventricular tachycardias with high efficacy [4, 5]. Different approaches can be used depending on the arrhythmia's origin: left endocardial, right endocardial and epicardial approach [6]. Accurate mapping of the area of interest can be difficult to achieve due to complex anatomical structures or structural heart diseases. Remote magnetic navigation (RMN) is considered to be an effective tool for mapping and ablation of arrhythmias that has the potential to overcome some of these challenges [6, 7]. It is a navigation system, which provides good catheter stability during mapping and ablation procedures [8–10]. While the capabilities of manual navigation are limited by the fixed curves of manual catheters, the magnetic catheters have a flexible catheter design enabling them to access otherwise difficult anatomy [11]. The RMN-guided ablation catheter is manipulated by two external magnetic fields situated on either side of the patient. The catheter tip aligns with the magnetic vector produced by the system, allowing the operator to navigate the catheter from its distal tip. Additionally, the RMN system allows the operator to store and reapply

F. Akca · I. Önsesveren · L. Jordaens · T. Szili-Torok (✉)
Clinical Electrophysiology, Department of Cardiology,
Erasmus MC,
Rotterdam, The Netherlands
e-mail: t.szilitorok@erasmusmc.nl

specific magnetic vectors in order to facilitate repeated access to difficult anatomy [12]. Some data suggest that utilizing an atraumatic catheter design results in less cardiac perforations [13, 14]. Previous research has shown that RMN may allow the operator to reduce fluoroscopy time [14–16]. RMN has been reported as a feasible tool for ablation of several types of arrhythmias, including AV nodal and AV reentrant tachycardias and atrial fibrillation [17–21]. VT can occur in patients with or without structural heart disease (SHD). SHD can be a result of either ischemic cardiomyopathy (ICMP) or non-ischemic cardiomyopathy (NICMP) [22]. Scar-related VT (SRVT) could have several causes such as myocardial infarction (MI), dilated cardiomyopathy (DCMP), arrhythmogenic RV cardiomyopathy (ARVC) and hypertrophic cardiomyopathy (HCMP) [6]. Idiopathic VT originated in most cases from the outflow tract regions or the fascicles of the left ventricle in patients with structurally normal hearts (SNH) [23]. VTs originating from the left ventricular outflow tract (LVOT) and VT originating from above the pulmonary and aortic valve are recognized more often than before [24–26].

This systematic review aims to provide an overview of the safety and efficacy of RMN in VT ablation.

2 Methods

Our aim was to identify all articles that discuss the use of RMN for VT ablation procedures. The National Library of Medicine's PubMed database was searched until November 1, 2011. The following predetermined set of search terms was applied:

“Tachycardia, Ventricular”[Mesh] AND “Magnetics” [Mesh] AND Catheter Ablation“[Mesh] OR ”Ventricular“[All Fields] AND ”Magnetic“[All Fields] AND ”Remote“[All Fields] AND ”Ablation“[All Fields].

The reference list of each returned article was examined for additional studies that may have been missed in the PubMed database search. All studies discussing use of RMN for VT ablation in human were included.

2.1 GRADE system

All data from the included articles were analysed according to the internationally developed GRADE system in order to define the quality of the evidence [27]. The overall quality of the evidence was rated into four categories (high, moderate, low, very low) using the criteria of GRADE. From the studies that met the inclusion criteria, four factors were considered in appraising the overall strength of the evidence according the GRADE system: study design, study quality, consistency of evidence and directness of evidence.

2.2 Data extracting process

Two authors independently reviewed the eligible articles and extracted the following data: VT type, RMN catheter type, acute success rate, manual crossover rate, follow-up time, follow-up recurrence rate and procedural complications. The authors then cross-checked their results to ensure accuracy. If the authors did not reach complete agreement, the results were discussed and a consensus opinion was reached.

2.3 Outcome measurement

The studies on RMN-guided VT ablation were compared with respect to all extracted data.

3 Results

Our PubMed search returned in 22 results based on the predefined search method. Eleven of the returned articles did not evaluate the use of RMN in VT and were consequently excluded [21, 28–37]. In all, data from 11 articles—seven clinical trials, three case reports and one case series—were assessed [6, 7, 11, 20, 22, 38–43]. After quality assessment according to the GRADE system, four studies were considered as low evidence and seven as very low evidence (Table 1). Three main VT subtypes were studied: VT in ICMP, NICMP and SNH. Additionally, studies on SRVT in patients with ICMP, NICMP or both are analyzed.

In Table 1 an overview of the extracted data is presented. As the article by De Torres et al. did not report a recurrence rate, we contacted the authors in order to obtain the missing data [42].

3.1 Overall success rate

Overall success rates ranged from 52% to 86% for studies assessing VT ablation in ICMP, NICMP and SNH. Two studies reported crossover to manual irrigated tip catheters in 14% and 48% of procedures, respectively [22, 38]. Thirty-four of 65 ablation procedures (52%) by Di Biase et al. (2009) utilized only non-irrigated tip RMN ablation catheters. The remaining procedures required the use of manual ablation catheters in order to achieve procedural success. Di Biase et al. (2010) report manual crossover in 15 cases (14%).

3.2 Ischemic cardiomyopathy

For ablation of VT in ICMP, success rates ranging from 71% to 80% were achieved [6, 20, 39]. Arya et al. and Haghjoo et al. report success rates of 80% using the irrigated RMN ablation catheter. In both studies 20% of the cases resulted in partial

Table 1 Data from included publications

Publication	GRADE score	RMN catheter type	Number of VT ablation procedures/VT type				Acute success				Manual crossover	Follow-up (months)	Recurrence				Complications
			ICMP	NICMP	SNH	Overall	ICMP	NICMP	SNH	Overall			ICMP	NICMP	SNH	Overall	
Di Biase et al. 2010 (USA)	Low	Irrigated	33	14	63	–	–	–	86% (95/110)	14% (15/110)	11.8	30% (10/33)	14% (2/14)	8% (5/63)	15% (17/110)	Total heartblock (n=1)	
Di Biase et al. 2009 (USA)	Low	Non-irrigated	44	SR	21	36% (16/44)	–	–	86% (18/21)	SR: 64% (28/44) SNH: 14% (3/21)	12	–	–	40%	Groin hematoma (n=2)		
Arya et al. 2010 (GER)	Low	Irrigated	30	–	–	80% (24/30)	–	–	–	0%	7.8	25% (6/24)	–	–	No		
Aiyana et al. 2007 (USA)	Low	Non-irrigated	17	ARVC (n=3) HCM (n=2) DCM (n=3) CS (n=2)	–	71% (12/17)	ARVC: 100% (3/3) DCM: 50% (1/2) CS: 50% (1/2)	–	–	92% (22/24)	7	27% (3/11)	CS: 50% (1/2)	–	–	Right uhar nerve palsy (n=1)	
Konstantinidou et al. 2011 (GER)	Very low	Non-irrigated	–	–	13	–	–	92% (12/13)	–	0%	8.4	–	–	17%	No		
Thornton and Jordaens 2006 (NL)	Very low	Non-irrigated	–	–	7	–	–	100% (7/7)	–	0%	12	–	–	14% (1/7)	No		
Haghjoo et al. 2009 (GER)	Very low	Irrigated	5	–	–	80% (4/5)	–	–	–	0%	4.2	0%	–	–	No		
Thornton et al. 2006 (NL)	Very low	Non-irrigated	–	–	1	–	–	100% (1/1)	–	0%	12	–	–	0%	No		
De Torres et al. 2008 (NL)	Very low	Non-irrigated	–	–	1	–	–	100% (1/1)	–	0%	12	–	–	0%	No		
Schwagten et al. 2009 (NL)	Very low	Non-irrigated	–	–	3	–	–	100% (3/3)	–	0%	6	–	–	0%	No		
Burkhardt et al. 2006 (USA)	Very low	Non-irrigated	–	–	1	–	–	100% (1/1)	–	0%	1 day	–	–	–	No		

ARVC arrhythmogenic RV cardiomyopathy, CS cardiac sarcoidosis, DCM dilated cardiomyopathy, DVT deep venous thrombosis, HCM hypertrophic cardiomyopathy, LVT left ventricular outflow tract, NICMP non-ischemic cardiomyopathy, RV right ventricle, RVOT right ventricular outflow tract, SNH structural normal heart, SR scar-related

success, defined as inducibility of non-clinical VT following the ablation procedure [20, 39]. Manual crossover was never necessary to achieve procedural success in these studies. Aryana et al. report a 71% success rate for VT ablation in patients with ICMP [6].

Di Biase et al. report an acute success rate of 36% for SRVT ablation [38]. This study combines the ICMP and NICMP populations into a single cohort. In 64% of the procedures the non-irrigated tip RMN ablation catheter was unable to achieve acute success, so the procedure was crossed-over to manual technique.

3.3 Non-ischemic cardiomyopathy

Aryana et al. evaluated the use of RMN for VT ablation in patients with NICMP and report an acute success rate of 50% in patients with cardiac sarcoidosis after two VT ablation procedures [6]. In patients with ARVC and DCMP acute success was achieved in 100% and 50% of procedures, respectively. Because of lack of VT inducibility, successful catheter ablation could not be performed in HCMP population.

3.4 Structurally normal heart

Success rates for RMN ablation in patients with SNH vary from 86% to 100% [7, 11, 38, 40–43]. Di Biase et al. report manual crossover in 14% of cases. Thornton et al., Konstantinidou et al., De Torres et al., Schwagten et al. and Burkhardt et al. completed all cases without crossover to manual catheters.

3.5 Recurrence rates

Following acutely successful ablation procedures, 0–30% of ICMP patients experienced recurrence [6, 20, 22, 39]. Recurrence rates ranging from 14% to 50% are reported for the NICMP population [6, 22]. Recurrence rates ranged from 0% to 17% for patients with SNH after VT ablation procedures [11, 22, 40–43]. Thornton et al. note one patient (14%) who experienced non-sustained VT after an acutely successful catheter ablation procedure. Because this patient had sustained VT prior to ablation, the procedure was considered as partial success [40].

Di Biase et al. reported an overall recurrence rate of 40% in a mixed sample of patients treated with 4 mm RMN, 8 mm RMN and manual catheters. The same group reported an overall recurrence rate of 15% in 2010. For the RMN subgroup, VT recurrence was 14% and 27% for patients that were crossed over to manual technique [22].

3.6 Complications

Four complications were associated with VT ablation procedures. Di Biase et al. noted heart block in one patient with a

right bundle branch block (RBBB) [22]. Two additional patients developed groin hematomas [38]. Another study reports an uncomplicated bilateral lower-extremity deep venous thrombosis in one patient [6]. This thromboembolic complication occurred during left-sided ablation with a non-irrigated tip catheter, so the risk of similar events is likely to be reduced by using irrigated tip RMN ablation catheters [44]. Aryana et al. report a case of right ulnar nerve palsy after an epicardial RV mapping procedure. It is unclear whether the palsy is caused by an embolic stroke or was a result of long immobilization under general anesthesia [6].

3.7 Crossover to manual ablation

In this systematic review the use of RMN in ablation of VT has been investigated. Several groups report use of RMN ablation to treat patients with ICMP, but these results are quite varied [6, 20, 38, 39]. Three groups reported favorable success rates between 71% and 80%. Two of 15 ablation procedures (13%) by Aryana et al. utilized only non-irrigated tip RMN ablation catheters. The remaining procedures required the use of manual irrigated tip ablation catheters in order to achieve acute procedural success. Di Biase et al., however, achieved a rate of only 36% for SRVT ablation procedures. This low success rate may not accurately reflect the potential of RMN as the study employs only non-irrigated RMN catheters and showed a low threshold for manual crossover [38]. The most recent trial by Di Biase et al. (2010) with irrigation demonstrated a considerable lower crossover rate of 14%. Previous research has shown that catheter irrigation improves ablation efficacy and decreases the risk of thrombotic events [44]. However, very scarce data are available on SRVT using an irrigated ablation catheter.

3.8 Idiopathic VT

RMN is most effective when used in patients with SNH and is successful in 86% to 100% of these procedures [7, 11, 38, 40–43]. The usefulness of RMN in ablation of idiopathic VTs has been investigated by several groups. Although they evaluate RMN in a relatively small sample of patients, these studies demonstrate the feasibility of RMN for successful ablation of RVOT, LVOT, left fascicular and aortic cusp VT. Still, more evidence is needed to assess the efficacy and safety of RMN in different subtypes of idiopathic VT.

3.9 Future studies or areas of investigation

This review showed successful results in patients with ARVC, DCMP and sarcoidosis [6]. However, these groups included a minimal number of patients, and more research is needed in this patient population. Therefore, we call for more research on the use of RMN in ablation of VT in NICMP.

The safety and efficacy of RMN in ablation of VT is evaluated in multiple studies. Schwagten et al. report on the superior capabilities of RMN in VT ablation [45]. A higher rate of acute success (97% vs. 81%, $p=0.03$) and lower rate of arrhythmia recurrence (14% vs. 50%, $p<0.01$) were achieved in RMN procedures compared to manual catheter ablation.

The use of RMN compared to manual procedures has been evaluated for multiple arrhythmias, including VT [13]. Bauernfeind et al. evaluated the safety and long-term efficacy of RMN in a large number of patients. These data showed that the use of RMN reduced the occurrence of major complications (0.34 vs 3.2%, $p=0.01$) without compromising efficacy compared to manual ablation. Further, RMN was significantly more successful for VTs (93 vs 72%, $p<0.05$). In this population both SNH and SR VT were studied; however, the superiority of RMN in SNH VT was largely responsible for the difference. Di Biase et al. (2010) stated that procedure times were longer using RMN, although with decreased use of fluoroscopy. To achieve similar results, a statistically greater number of RF lesions needed to be applied in RMN group. However, Bauernfeind et al. report both decreased procedure times and fluoroscopy times using RMN. This could be explained by the steep learning curve for the RMN system. This demonstrates that new methods are needed to increase efficacy of ablation compared to conventional manual techniques. However, no randomized studies have been executed to prove superiority.

3.10 Limitations of the study

In this review we evaluated the safety and efficacy of RMN in VT ablation. Several studies show advantages of RMN for VT ablation, although this is based on low quality evidence according to the GRADE system. High quality randomized studies are needed for more consistent evidence to assess the efficacy and safety of RMN in ablation of VT.

4 Conclusion

The available data on RMN suggests that it is an effective and safe method for ablation of VT with relatively low recurrence and complication rates. RMN has been used to achieve successful outcomes in various patient populations and VT subtypes. SNH VT appears to have the best outcome using RMN in comparison to ICMP and NICMP VT. In case of NICMP extremely limited data are available for the effectiveness of RMN. Although these are promising results, more comparative and randomized studies are necessary to assess superiority. The true value of RMN for VT ablation remains still unknown.

Disclosure Tamas Szili-Torok is a consultant of Stereotaxis, Inc., St. Louis, MO, USA.

Open Access This article is distributed under the terms of the Creative Commons Attribution Noncommercial License which permits any noncommercial use, distribution, and reproduction in any medium, provided the original author(s) and source are credited.

References

1. Reddy, V. Y., Reynolds, M. R., Neuzil, P., Richardson, A. W., Taborsky, M., Jongnarangsin, K., Kralovec, S., Sediva, L., Ruskin, J. N., & Josephson, M. E. (2007). Prophylactic catheter ablation for the prevention of defibrillator therapy. *The New England Journal of Medicine*, *357*, 2657–2665.
2. Zipes, D. P., Camm, A. J., Borggrefe, M., Buxton, A. E., Chaitman, B., Fromer, M., Gregoratos, G., Klein, G., Moss, A. J., Myerburg, R. J., Priori, S. G., Quinones, M. A., Roden, D. M., Silka, M. J., Tracy, C., Smith, S. C., Jr., Jacobs, A. K., Adams, C. D., Antman, E. M., Anderson, J. L., Hunt, S. A., Halperin, J. L., Nishimura, R., Ornato, J. P., Page, R. L., Riegel, B., Blanc, J. J., Budaj, A., Dean, V., Deckers, J. W., Despres, C., Dickstein, K., Lekakis, J., McGregor, K., Metra, M., Morais, J., Osterspey, A., Tamargo, J. L., & Zamorano, J. L. (2006). *Acc/aha/esc 2006 guidelines for management of patients with ventricular arrhythmias and the prevention of sudden cardiac death: a report of the American College of Cardiology/American Heart Association Task Force and the European Society of Cardiology Committee for practice guidelines (writing committee to develop guidelines for management of patients with ventricular arrhythmias and the prevention of sudden cardiac death): developed in collaboration with the European Heart Rhythm Association and the Heart Rhythm Society. Circulation*, *114*, e385–484.
3. Carbucicchio, C., Santamaria, M., Trevisi, N., Maccabelli, G., Giraldo, F., Fassini, G., Riva, S., Moltrasio, M., Cireddu, M., Veglia, F., & Della Bella, P. (2008). Catheter ablation for the treatment of electrical storm in patients with implantable cardioverter-defibrillators: short- and long-term outcomes in a prospective single-center study. *Circulation*, *117*, 462–469.
4. Bansch, D., Oyang, F., Antz, M., Arentz, T., Weber, R., Val-Mejias, J. E., Ernst, S., & Kuck, K. H. (2003). Successful catheter ablation of electrical storm after myocardial infarction. *Circulation*, *108*, 3011–3016.
5. Borger van der Burg, A. E., de Groot, N. M., van Erven, L., Bootsma, M., van der Wall, E. E., & Schalij, M. J. (2002). Long-term follow-up after radiofrequency catheter ablation of ventricular tachycardia: a successful approach? *Journal of Cardiovascular Electrophysiology*, *13*, 417–423.
6. Aryana, A., d'Avila, A., Heist, E. K., Mela, T., Singh, J. P., Ruskin, J. N., & Reddy, V. Y. (2007). Remote magnetic navigation to guide endocardial and epicardial catheter mapping of scar-related ventricular tachycardia. *Circulation*, *115*, 1191–1200.
7. Burkhardt, J. D., Saliba, W. I., Schweikert, R. A., Cummings, J., & Natale, A. (2006). Remote magnetic navigation to map and ablate left coronary cusp ventricular tachycardia. *Journal of Cardiovascular Electrophysiology*, *17*, 1142–1144.
8. Di Biase, L., Fahmy, T. S., Patel, D., Bai, R., Civello, K., Wazni, O. M., Kanj, M., Elayi, C. S., Ching, C. K., Khan, M., Popova, L., Schweikert, R. A., Cummings, J. E., Burkhardt, J. D., Martin, D. O., Bhargava, M., Dresing, T., Saliba, W., Arruda, M., & Natale, A. (2007). Remote magnetic navigation: human experience in pulmonary vein ablation. *Journal of the American College of Cardiology*, *50*, 868–874.

9. Pflaumer, A., Hessling, G., Luik, A., Wu, J., & Zrenner, B. (2007). Remote magnetic catheter mapping and ablation of permanent junctional reciprocating tachycardia in a seven-year-old child. *Journal of Cardiovascular Electrophysiology*, *18*, 882–885.
10. Davis, D. R., Tang, A. S., Gollob, M. H., Lemery, R., Green, M. S., & Birnie, D. H. (2008). Remote magnetic navigation-assisted catheter ablation enhances catheter stability and ablation success with lower catheter temperatures. *Pacing and Clinical Electrophysiology*, *31*, 893–898.
11. Schwagten, B. K., Szili-Torok, T., Rivero-Ayerza, M., Jessurun, E., Valk, S., & Jordaens, L. J. (2009). Usefulness of remote magnetic navigation for ablation of ventricular arrhythmias originating from outflow regions. *Netherlands Heart Journal*, *17*, 245–249.
12. Ernst, S. (2008). Magnetic and robotic navigation for catheter ablation: “joystick ablation”. *Journal of Interventional Cardiac Electrophysiology*, *23*, 41–44.
13. Bauernfeind, T., Akca, F., Schwagten, B., de Groot, N., Van Belle, Y., Valk, S., Ujvari, B., Jordaens, L., & Szili-Torok, T. (2011). The magnetic navigation system allows safety and high efficacy for ablation of arrhythmias. *Europace*, *13*, 1015–1021.
14. Xu, D., Yang, B., Shan, Q., Zou, J., Chen, M., Chen, C., Hou, X., Zhang, F., Li, W. Q., Cao, K., & Tse, H. F. (2009). Initial clinical experience of remote magnetic navigation system for catheter mapping and ablation of supraventricular tachycardias. *Journal of Interventional Cardiac Electrophysiology*, *25*, 171–174.
15. Luthje L, Vollmann D, Seegers J, Dorenkamp M, Sohns C, Hasenfuss G, Zabel M. Remote magnetic versus manual catheter navigation for circumferential pulmonary vein ablation in patients with atrial fibrillation. *Clin Res Cardiol* 2011.
16. Schwagten, B., Witsenburg, M., De Groot, N. M., Jordaens, L., & Szili-Torok, T. (2010). Effect of magnetic navigation system on procedure times and radiation risk in children undergoing catheter ablation. *The American Journal of Cardiology*, *106*, 69–72.
17. Ernst, S., Hachiya, H., Chun, J. K., & Ouyang, F. (2005). Remote catheter ablation of parahisian accessory pathways using a novel magnetic navigation system—a report of two cases. *Journal of Cardiovascular Electrophysiology*, *16*, 659–662.
18. Ernst, S., Ouyang, F., Linder, C., Hertting, K., Stahl, F., Chun, J., Hachiya, H., Krumdordf, U., Antz, M., & Kuck, K. H. (2004). Modulation of the slow pathway in the presence of a persistent left superior caval vein using the novel magnetic navigation system niobe. *Europace*, *6*, 10–14.
19. Pappone, C., Vicedomini, G., Manguso, F., Gugliotta, F., Mazzone, P., Gulletta, S., Sora, N., Sala, S., Marzi, A., Augello, G., Livolsi, L., Santagostino, A., & Santinelli, V. (2006). Robotic magnetic navigation for atrial fibrillation ablation. *Journal of the American College of Cardiology*, *47*, 1390–1400.
20. Haghjoo, M., Hindricks, G., Bode, K., Piorkowski, C., Bollmann, A., & Arya, A. (2009). Initial clinical experience with the new irrigated tip magnetic catheter for ablation of scar-related sustained ventricular tachycardia: a small case series. *Journal of Cardiovascular Electrophysiology*, *20*, 935–939.
21. Latcu, D. G., Ricard, P., Zarqane, N., Yaici, K., Rinaldi, J. P., Maluski, A., & Saoudi, N. (2009). Robotic magnetic navigation for ablation of human arrhythmias: initial experience. *Archives of Cardiovascular Diseases*, *102*, 419–425.
22. Di Biase, L., Santangeli, P., Astudillo, V., Conti, S., Mohanty, P., Mohanty, S., Sanchez, J. E., Horton, R., Thomas, B., Burkhardt, J. D., & Natale, A. (2010). 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*, *7*, 1029–1035.
23. Schreiber, D., & Kottkamp, H. (2010). Ablation of idiopathic ventricular tachycardia. *Current Cardiology Reports*, *12*, 382–388.
24. Kamakura, S., Shimizu, W., Matsuo, K., Taguchi, A., Suyama, K., Kurita, T., Aihara, N., Ohe, T., & Shimomura, K. (1998). Localization of optimal ablation site of idiopathic ventricular tachycardia from right and left ventricular outflow tract by body surface ECG. *Circulation*, *98*, 1525–1533.
25. Krebs, M. E., Krause, P. C., Engelstein, E. D., Zipes, D. P., & Miles, W. M. (2000). Ventricular tachycardias mimicking those arising from the right ventricular outflow tract. *Journal of Cardiovascular Electrophysiology*, *11*, 45–51.
26. Timmermans, C., Rodriguez, L. M., Crijns, H. J., Moorman, A. F., & Wellens, H. J. (2003). Idiopathic left bundle-branch block-shaped ventricular tachycardia may originate above the pulmonary valve. *Circulation*, *108*, 1960–1967.
27. Guyatt, G. H., Oxman, A. D., Vist, G. E., Kunz, R., Falck-Ytter, Y., Alonso-Coello, P., Schunemann, H. J., & Group, G. W. (2008). Grade: an emerging consensus on rating quality of evidence and strength of recommendations. *BMJ*, *336*, 924–926.
28. Perez-David, E., Arenal, A., Rubio-Guivernau, J. L., del Castillo, R., Atea, L., Arbelo, E., Caballero, E., Celorrio, V., Datino, T., Gonzalez-Torrecilla, E., Atienza, F., Ledesma-Carbayo, M. J., Bermejo, J., Medina, A., & Fernandez-Aviles, F. (2011). Noninvasive identification of ventricular tachycardia-related conducting channels using contrast-enhanced magnetic resonance imaging in patients with chronic myocardial infarction: comparison of signal intensity scar mapping and endocardial voltage mapping. *Journal of the American College of Cardiology*, *57*, 184–194.
29. Luthje, L., Vollmann, D., Seegers, J., Sohns, C., Hasenfuss, G., & Zabel, M. (2010). Interference of remote magnetic catheter navigation and ablation with implanted devices for pacing and defibrillation. *Europace*, *12*, 1574–1580.
30. Eitel, C., Hindricks, G., Sommer, P., Wetzel, U., Bollmann, A., Gaspar, T., Piorkowski, C., & Arya, A. (2010). Safety of remote magnetic navigation in patients with pacemakers and implanted cardioverter defibrillators. *Journal of Cardiovascular Electrophysiology*, *21*, 1130–1135.
31. Sarrazin, J. F., Labounty, T., Kuhne, M., Crawford, T., Armstrong, W. F., Desjardins, B., Good, E., Jongnarangsin, K., Chugh, A., Oral, H., Pelosi, F., Morady, F., & Bogun, F. (2009). Impact of radiofrequency ablation of frequent post-infarction premature ventricular complexes on left ventricular ejection fraction. *Heart Rhythm*, *6*, 1543–1549.
32. Katsiyannis, W. T., Melby, D. P., Matelski, J. L., Ervin, V. L., Laverne, K. L., & Gornick, C. C. (2008). Feasibility and safety of remote-controlled magnetic navigation for ablation of atrial fibrillation. *The American Journal of Cardiology*, *102*, 1674–1676.
33. Arya, A., Kottkamp, H., Piorkowski, C., Bollmann, A., Gerdes-Li, J. H., Riahi, S., Esato, M., & Hindricks, G. (2008). Initial clinical experience with a remote magnetic catheter navigation system for ablation of cavotricuspid isthmus-dependent right atrial flutter. *Pacing and Clinical Electrophysiology*, *31*, 597–603.
34. Ray, I. B., Dukkupati, S., Houghtaling, C., McPherson, C. D., Kastelein, N., Ruskin, J. N., & Reddy, V. Y. (2007). Initial experience with a novel remote-guided magnetic catheter navigation system for left ventricular scar mapping and ablation in a porcine model of healed myocardial infarction. *Journal of Cardiovascular Electrophysiology*, *18*, 520–525.
35. Thornton, A. S., Rivero-Ayerza, M., Knops, P., & Jordaens, L. J. (2007). Magnetic navigation in left-sided AV reentrant tachycardias: preliminary results of a retrograde approach. *Journal of Cardiovascular Electrophysiology*, *18*, 467–472.
36. van Dockum, W. G., Kuijer, J. P., Gotte, M. J., Ten Cate, F. J., Ten Berg, J. M., Beek, A. M., Twisk, J. W., Marcus, J. T., Visser, C. A., & van Rossum, A. C. (2006). Septal ablation in hypertrophic obstructive cardiomyopathy improves systolic myocardial function in the lateral (free) wall: a follow-up study using CMR tissue tagging and 3D strain analysis. *European Heart Journal*, *27*, 2833–2839.

37. van Dockum, W. G., Beek, A. M., ten Cate, F. J., ten Berg, J. M., Bondarenko, O., Gotte, M. J., Twisk, J. W., Hofman, M. B., Visser, C. A., & van Rossum, A. C. (2005). Early onset and progression of left ventricular remodeling after alcohol septal ablation in hypertrophic obstructive cardiomyopathy. *Circulation*, *111*, 2503–2508.
38. Di Biase, L., Burkhardt, J. D., Lakkireddy, D., Pillarisetti, J., Baryun, E. N., Biria, M., Horton, R., Sanchez, J., Gallinghouse, G. J., Bailey, S., Beheiry, S., Hongo, R., Hao, S., Tomassoni, G., & Natale, A. (2009). Mapping and ablation of ventricular arrhythmias with magnetic navigation: comparison between 4- and 8-mm catheter tips. *Journal of Interventional Cardiac Electrophysiology*, *26*, 133–137.
39. Arya, A., Eitel, C., Bollmann, A., Wetzel, U., Sommer, P., Gaspar, T., Husser, D., Piorkowski, C., & Hindricks, G. (2010). Catheter ablation of scar-related ventricular tachycardia in patients with electrical storm using remote magnetic catheter navigation. *Pacing and Clinical Electrophysiology*, *33*, 1312–1318.
40. Thornton, A. S., & Jordaens, L. J. (2006). Remote magnetic navigation for mapping and ablating right ventricular outflow tract tachycardia. *Heart Rhythm*, *3*, 691–696.
41. Thornton, A. S., Res, J., Mekel, J. M., & Jordaens, L. J. (2006). Use of advanced mapping and remote magnetic navigation to ablate left ventricular fascicular tachycardia. *Pacing and Clinical Electrophysiology*, *29*, 685–688.
42. de Torres, F., Szili-Torok, T., Orellana, F. J., & Jordaens, L. J. (2008). Ablation of idiopathic left ventricular tachycardia using remote magnetic navigation integrated with advanced mapping. *Revista Española de Cardiología*, *61*, 1104–1106.
43. Konstantinidou, M., Koektuerk, B., Wissner, E., Schmidt, B., Zerm, T., Ouyang, F., Kuck, K. H., & Chun, J. K. (2011). Catheter ablation of right ventricular outflow tract tachycardia: a simplified remote-controlled approach. *Europace*, *13*, 696–700.
44. Weiss, C., Antz, M., Eick, O., Eshagzai, K., Meinertz, T., & Willems, S. (2002). Radiofrequency catheter ablation using cooled electrodes: impact of irrigation flow rate and catheter contact pressure on lesion dimensions. *Pace-Pacing and Clinical Electrophysiology*, *25*, 463–469.
45. Schwagten, B., Bauernfeind, T., De Groot, N., Van Belle, Y., Haitsma, D., Jordaens, L., & Szili-Torok, T. (2010). Usefulness of the magnetic navigation system in ablation of ventricular tachycardia: acute and follow-up results compared to manual ablation. *European Heart Journal*, *31*, 932–932.