

Comparison of atrial fibrillation ablation efficacy using remote magnetic navigation vs. manual navigation with contact-force control

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Aims. This study aims to compare procedural parameters and clinical efficacy of remote magnetic navigation (RMN) vs. manual navigation (MAN) approach for radiofrequency ablation (RFA) in patients with atrial fibrillation (AF).

Methods. 146 patients with AF were enrolled in the study. In the RMN group (n=57), patients were treated with the CARTO® 3 in combination with the Niobe ES system. In the MAN group (n=89), ablation was performed with the EnSite Velocity and TactiCath™ Quartz catheter with direct contact force measurement. Procedural time, ablation time, fluoroscopy time, radiation dose and ablation counts were measured and compared between the groups. Recurrence of AF was evaluated after 6 months of follow-up.

Results. Mean procedure times (236.87 ± 64.31 vs. 147.22 ± 45.19 min, $P < 0.05$), counts of RF applications (74.30 ± 24.77 vs. 49.15 ± 20.33 , $P < 0.05$) and total RFA times (4323.39 ± 1426.69 vs. 2780.53 ± 1157.85 s, $P < 0.05$) were all significantly higher in the RMN than in the MAN group, respectively. In the same order, mean X-ray dose (9722.6 ± 7507.4 vs. 8087.9 ± 6051.5 mGy/cm², $P = 0.12$) and mean total X-ray exposure time (8.07 ± 4.20 vs. 9.54 ± 5.47 min, $P = 0.08$) were not statistically different. At 6-month follow-up, freedom from AF was similar in RMN and MAN group for paroxysmal (60.8% and 73%, respectively, $P = 0.42$) and persistent AF (69.6% and 75.0%, respectively, $P = 0.77$).

Conclusions. Due to the fact that mid-term clinical outcomes showed no significant differences in AF recurrences between groups and manual ablation strategy provided more favorable results regarding acute procedural parameters, we can conclude that the remote magnetic navigation is not superior to the manual approach.

Key words: atrial fibrillation, radiofrequency ablation, electro-anatomical mapping, remote magnetic navigation, contact-force technology

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INTRODUCTION

Currently, radiofrequency catheter ablation (RFA) is the most commonly used invasive treatment strategy for symptomatic, drug-resistant atrial fibrillation (AF). Conventionally, pulmonary vein isolation (PVI) is based on point-by-point lesion formation, applied by irrigated ablation catheters in power control mode^{1,2}. 3D electro-anatomical mapping (EAM) systems, such as the EnSite Velocity™ (Abbott Inc) and CARTO® 3 (Biosense Webster Inc), are routinely used to support complex electrophysiology procedures³. EAM-guided treatment can be performed with either manual (MAN) or by remote magnetic-navigated (RMN) catheters⁴. Concerning manual ablation, steerable sheaths and contact force (CF)-sensing catheters are widely used in clinical practice. CF-sensing catheters allow continuous and real-time measurement of

catheter tip – myocardium contact, thus providing more reliable and effective energy delivery^{5,6}. Procedure optimization strategy, aimed to increase freedom from AF and focused on CF-guided RFA safety and effectiveness, have been described in previous studies^{5,7-9}. In recent years, robotic systems have been developed and introduced as clinical tools for arrhythmia treatment^{4,10-11}. Niobe ES system (Stereotaxis Inc) is based on a homogeneous, permanent, and orientable magnetic field that guides intracardiac movements of the catheter with a magnet-embedded tip. The system is convenient for mapping of challenging anatomies and ablations procedures¹². Despite the fact that the RMN system reduces radiation doses for patients and doctors¹³, several previous studies reported that application of RMN was challenging in comparison to manual approach^{13,14}. Procedural steps are associated with additional time required for patient preparation, sys-

tem configuration and left atrium (LA) mapping/catheter ablation¹⁵. At 1-year follow-up, freedom from AF/atrial flutter was demonstrated to be statistically non different among patients treated with MAN and RMN approach¹⁶. Due to patient pool heterogeneity in previously reported outcomes, this study aims to compare solely AF ablation performed with Niobe ES and remote magnetic-navigated Navistar® Thermocool® RMT catheter (Biosense Webster Inc) to standard CF-guided manual procedure using TactiCath™ Quartz catheter (Abbott Inc).

MATERIALS AND METHODS

This retrospective single-center study compared two groups of patients with pharmacoresistant symptomatic AF treated with RMN or MAN catheter ablation, both supported by EAM. In accordance to our electrophysiology laboratory logistics and workflow (Niobe ES system available in one room and NavX Velocity in another room), all patients were enrolled consecutively either to RMN or MAN group according to EP lab assignment for procedure. The study adhered to the principles of the Declaration of Helsinki.

Preparation for procedure

In each patient, AF diagnosis was documented by 12-lead ECG or ECG Holter monitoring (episode of AF lasting ≥ 30 s in duration) (ref.¹⁷). All participants had previously failed antiarrhythmic drug therapy. Moreover, all patients were effectively anticoagulated with warfarin (target international normalized ratio of 2 to 3) or direct-acting oral anticoagulants for more than 1 month. Atrial thrombi were excluded by pre-procedure transesophageal echocardiography.

After obtaining femoral vein access, a steerable catheter (Inquiry™, Abbott Inc) was positioned within the coronary sinus. Subsequently, transseptal puncture was performed with Agilis™ and SL1™ (Abbott Inc) sheath advanced to the LA. A single bolus of 50-100 IU/kg body weight of heparin with adequate continuous infusion was administered. The activated clotting time was evaluated every 20 min for additional heparin administration, aiming for value between 300-400 s.

In the MAN group, the SL1™ and Agilis™ sheaths were used for introduction of a circular mapping duodecapolar catheter (Reflexion™, Abbott Inc) and CF-sensing ablation catheter (TactiCath™ Quartz, Abbott Inc), respectively. A 3D electro-anatomical model of the LA was reconstructed with the circular catheter using the NavX Velocity system (Abbott Inc).

In the RMN group, the Agilis™ sheath was used for introduction of the magnetic ablation catheter (Navistar® Thermocool® RMT, Biosense Webster Inc) connected to the Niobe ES (Stereotaxis Inc) and controlled by QuikCAS™ system (Stereotaxis Inc), which allows remote catheter advancement and retraction. Endocardium-tip contact was ensured by proprietary algorithm in the e-Contact™ module (Stereotaxis Inc). A 3D electro-anatomical model was generated with the CARTO® 3

(Biosense Webster Inc). Finally, the circular mapping catheter (Reflexion™, Abbott Inc) was introduced via the SL1™ sheath into the LA for monitoring of pulmonary veins (PVs) electrical activity.

MAN and RMN catheter ablations were performed by 2 experienced electrophysiologists. Attenuating learning curve effect, first 20 RMN-guided AF procedures were excluded from the analysis.

Ablation strategy

All patients underwent circumferential PVI. Additional linear lesions on the roof and mitral isthmus were applied in patients with the persistent form of AF.

In RMN group, anterior and posterior wall ablation was performed at 40W and 35W, respectively. Preferably, if anatomically possible, dragging ablation technique was used to obtain continuous circumferential lines around ipsilateral PVs. In patients treated with MAN, point-by-point strategy (maximum duration of 30 s energy delivery per point) was applied and successful point ablation was confirmed by change of local intracardiac ECG potentials. In this group, anterior wall ablation was carried out at 30W and posterior wall ablation at 25W. For patients in sinus rhythm, persistent PVI and linear lesions block were verified by the stimulation technique. In individuals with AF, electrical cardioversion was performed at the end of the procedure and confirmation of persistent PVI, and blockage of linear lesions was assessed by targeted stimulation^{18,19}.

Clinical follow-up

6-month follow-up was based on 24-hour ECG Holter monitoring¹⁷ and ambulatory visit with the aim to evaluate patient's clinical status and assess potential recurrence of AF based on electrocardiography recording.

Statistical analysis

Statistical analysis was performed using SAS 9.3 (SAS Institute Inc) and was presented as the mean \pm standard deviation (SD) or as median value with 25th-75th interquartile range (IQR). Qualitative data were expressed as absolute values and/or percentages. Differences between groups were analyzed using the t-test for normally distributed data and the Mann-Whitney U test for non-normally distributed data. Categorical data were analyzed using chi-square test analysis or the Fisher exact test where appropriate. Data distribution was verified by the Shapiro-Wilk test. $P < 0.05$ was considered to be statistically significant.

RESULTS

Overall, 449 patients were ablated for paroxysmal (ParAF) or persistent AF (PerAF) at our department between the 18th of March 2015 and the 9th of November 2016. Most of patients ($n=303$) were found not eligible for the study primarily because they had been treated with different types of ablation catheters or had enrolled in other studies with a possible direct impact on monitored parameters.

Table 1. Baseline characteristics of study groups.

	RMN group n=57	MAN group n=89	<i>P</i>
Males, n (%)	41 (71.93)	68 (76.40)	0.54
Age, years (mean±SD)	63.6±17.6	61.7±30.8	0.19
Paroxysmal AF, n (%)	30 (52.63)	43 (48.31)	0.61
Persistent AF, n (%)	27 (47.37)	46 (51.69)	0.61
Structural heart diseases, n (%)	12 (21.05)	19 (21.35)	0.97
LA diameter (PLAX view), mm (mean±SD)	47.58±12.42	47.36±16.64	0.85
BMI, kg/m ² (mean±SD)	29.08±8.80	29.60±15.42	0.55
LVEF, % (mean±SD)	56±17	57±32	0.68
Hypertension, n (%)	32 (56.14)	45 (50.56)	0.51
Diabetes mellitus, n (%)	15 (26.31)	18 (20.22)	0.40

AF – atrial fibrillation, BMI – body mass index, LA – left atrium, LVEF – left ventricle ejection fraction, MAN – manual navigation, NS – non-significant, PLAX – parasternal long axis, RMN – remote magnetic navigation, SD – standard deviation

Table 2. Procedural parameters.

	AF type	RMN group n=57	MAN group n=89	<i>P</i>
Procedure time, min	ParAF	212.0 (178.0–236.0)	142.0 (118.0–151.0)	<0.05
	PerAF	248.0 (202.0–300.0)	137.5 (118.0–166.0)	<0.05
X-ray exposure time, min	ParAF	7.35 (5.50–9.10)	8.20 (5.00–12.80)	0.39
	PerAF	6.20 (5.20–10.90)	9.25 (5.80–12.30)	0.22
RFA time, s	ParAF	3664.0 (2873.0–4441.0)	2261.0 (1779.0–3107.0)	<0.05
	PerAF	4677.0 (3807.0–6099.0)	2764.5 (2228.0–3396.0)	<0.05
X-ray dose, mGy/cm ²	ParAF	7995.0 (5986.0–10898.0)	5951.0 (3217.0–9916.0)	0.13
	PerAF	6731.0 (4994.0–14143.0)	7515.5 (4094.0–10757.0)	0.45
Count of RFA, n	ParAF	69.0 (51.0–78.0)	40.0 (34.0–57.0)	<0.05
	PerAF	83.0 (53.0–103.0)	45.5 (40.0–58.0)	<0.05
6-month follow-up, freedom from AF episodes, n (%)	ParAF	60.8	73	0.42
	PerAF	69.6	75	0.77

AF – atrial fibrillation, MAN – manual navigation, NS – non-significant, ParAF – paroxysmal atrial fibrillation, PerAF – persistent atrial fibrillation, RFA – radiofrequency ablation, RMN – remote magnetic navigation

Therefore, for the presented analysis, 146 patients were included, presenting in equal share with ParAF and PerAF (73 each). Regarding treatment strategy, 57 and 89 patients underwent RMN and MAN guided RFA procedures, respectively. Baseline clinical characteristics was not significantly different between groups (Table 1). In the RMN and MAN group, mean age was 63.6±17.6 and 61.7±30.8 years with 71.9% and 76.4% of male participants, respectively. Moreover, 52.6% and 44.9% of individuals in the RMN and MAN group were diagnosed with the ParAF, respectively, while the remaining patients suffered from PerAF. Prevalence of adverse events post-procedure was identical among groups (in each cohort 1 case of post-catheterization femoral artery pseudoaneurysm treated with percutaneous thrombin injection).

Mean procedure time was significantly longer in the RMN than in the MAN group (236.87±64.31 vs. 147.22±45.19 min, respectively, $P<0.05$). Counts of RF applications (74.30±24.77 vs. 49.15±20.33, $P<0.05$) and total RFA times (4323.39±1426.69 vs. 2780.53±1157.85 s, $P<0.05$) were also statistically significantly greater in the RMN group. Mean X-ray dose for RMN and MAN group

(9722.6±7507.4 vs. 8087.9±6051.5 mGy/cm², respectively, $P=0.12$), together with mean total X-ray exposure time (8.07±4.20 and 9.54±5.47 min, respectively, $P=0.08$) were not statistically different (Table 2). MAN- and RMN-guided catheter ablation procedures are representatively illustrated in Fig 1 and Fig 2.

Procedurally, to confirm the durability of the bidirectional electrical block between PVs and the LA, the entry/exit stimulation was performed for each PVs after 15-20 min post-ablation using circular mapping duodecapolar catheter (Reflexion™, Abbott Inc).

Moreover, in patients with PerAF treated with RMN and MAN approach, roof line was bidirectionally tested with block confirmation in 65% and 82.8%, respectively, $P=0.44$. Moreover, the mitral isthmus line was bidirectionally tested with block confirmation in 31.58% and 43.75%, respectively, $P=0.39$.

After 6 months post-RFA, 18 participants were lost from follow-up. In patients diagnosed with ParAF, freedom from AF episodes was not statistically different between groups (60.8% and 73% in RMN and MAN group, respectively, $P=0.42$). Similarly, no statistically

significant differences in efficacy of evaluated ablation approaches were observed in PerAF group after 6 months, where 69.6% subjects treated with RMN and 75% individuals treated with MAN were free from AF recurrence ($P=0.77$).

DISCUSSION

Over the last decade, a significant technological advancement has been made in the management of AF patients, with a special focus on 3D EAM and remotely-navigated PVI (ref.⁴). FDA-approved EAM technology has been consistently developed and marketed by medical product manufacturers such as Abbott (NavX), Biosense Webster (CARTO) and Boston Scientific (Rhythmia). Importantly, open-irrigated tip catheters with a real-time catheter-tissue CF measurement function (TactiCath™ Quartz, Abbott and ThermoCool SmartTouch®, Biosense Webster) became available, improving efficacy and safety of ablation procedures²⁰. Contact sensing estimation is also available, albeit without direct CF quantification, for RMN procedures (e-Contact, Stereotaxis Inc).

Currently, among magnetic remote navigation solutions, the Stereotaxis Niobe system is clinically used. Previously published studies provide inconclusive data regarding the utility of the RMN in comparison to standard manual approach suggesting that MAN-guided RFA was associated with shorter ablation times^{10,15,21} and higher success rates of PVI (ref.^{15,22}). By contrast, Yuan et al. found superiority for RMN over the MAN strategy with respect to mid- and long-term (up to 3.5 years) outcomes measured by: AF-free rate and clinical improvement, shorter fluoroscopy time, and no significant differences in terms of total procedure time²³. With respect to remote navigation, clinical data confirmed reduced radiation exposure for patients and doctors¹³. Nevertheless, there has been no consensus regarding optimal treatment strategy because of the heterogeneity of protocols (i.e., catheter types, measured parameters, end points) used in a relatively small number of studies.

In the presented study, RMN and MAN approach were retrospectively confronted across two selected patients' cohorts with no statistically significant difference in clinical history. Moreover, both RFA strategies were assisted by two non-fluoroscopic cardiac mapping systems, EnSite Velocity™ and CARTO® 3, both of which are designed to provide precise anatomical and local electrical information (i.e., local activation time and unipolar/bipolar voltage measurements).

Our study showed that 6 months post PVI, there was no statistical difference in arrhythmia recurrence rate in patients with ParAF and PerAF who underwent RMN or MAN procedure. This results accord with two meta-analyses by Bradfield et al.¹³ and Proietti et al.¹⁴, however, our result must be interpreted with caution due to relatively small number of patients and retrospective study design. Moreover, the abovementioned meta-analyses^{13,14} revealed that the RMN-guided RFA is associated with a longer

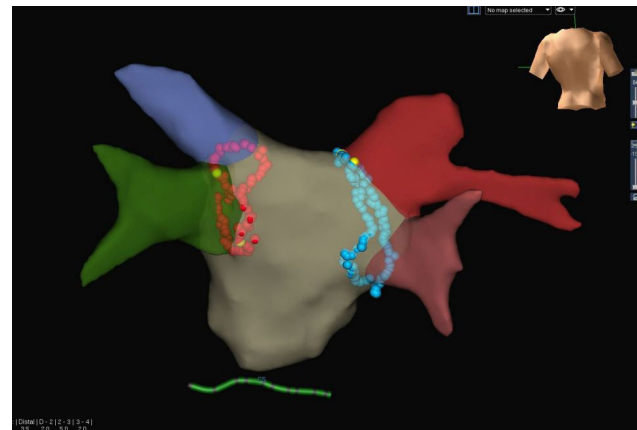


Fig. 1. Manual navigation-guided catheter ablation.

3D electro-anatomical map of the left atrium during ablation of paroxysmal atrial fibrillation using system EnSite Velocity from postero-anterior view. Red and blue dots highlight circular radiofrequency ablation lesions around the left and right pulmonary veins respectively. Yellow dots are places of isolation of the pulmonary veins.

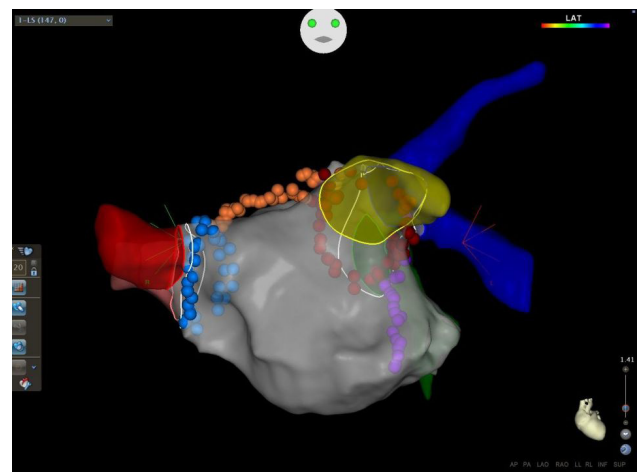


Fig. 2. Remote magnetic navigation-guided catheter ablation.

3D electro-anatomical map of the left atrium during ablation of persistent atrial fibrillation using system CARTO® 3 from antero-posterior view. Red and blue dots highlight circular radiofrequency ablation lesions around the left and right pulmonary veins respectively, orange dots highlight roof ablation line and violet dots highlight mitral isthmus line.

overall procedure duration. We observed the same procedural features in our study, and this was attributed to:

- (1) Configuration and set-up
 - a. EAM system (CARTO patch placement and position calibration)
 - b. Stereotaxis system (preparation of the catheter-advancing device, magnet set-up, and need for manual repositioning of the circular catheter during the procedure)
- (2) The use of low-density 2-pole catheter for mapping in RMN group. Correspondingly, duodecapolar map-

ping catheter was used during MAN procedures, which reduced LA mapping time

(3) RMN procedure performed without Vdrive™/V-Loop™ system for remote navigation of circular mapping catheter; necessity of manual placement of the circular mapping catheter to different PVs during the procedure for conduction block confirmation

Our study results are in line with multi-center German ablation registry data published by van den Bruck et al.²⁴. Sub-cohort analysis included 2442 patient undergoing AF catheter ablation using MAN (89%), RMN (3.3%) and Sensei robotic navigation system (Hansen Medical Inc) (7.7%). Authors concluded that remotely navigated systems are safe providing high acute success ablation rate. Regarding mapping and ablation parameters, procedure duration time was 150 min (120–200 min) and 265 min (210–305 min) for MAN and RMN, respectively. Novel systems were associated with reduced fluoroscopy exposure and higher radiofrequency energy delivery. It is worth noting however, that the registry included few RMN procedures (80 out of 2442) over the course of ~3 years (July 2008 – May 2011) (ref.²⁴) and technology has advanced since that time. Furthermore, similar to our study, Lim et al. retrospectively analysed 443 consecutive AF patients (229 MAN and 214 RMN cases). Attenuating learning curve effect for RMN procedures, total procedural time was 186.3±65.6 in MAN and 249.5±65.5 min in RMN group, with comparable acute procedural success rate and number of procedure-related complications²⁵.

Interestingly, Lin et al. described an initial experience using the EnSite Precision (Abbott Inc), that integrates magnetic and impedance technology (CARTO® 3 equivalent), combined with a circular magnetic catheter (Advisor™ FL, Sensor Enabled™, Abbott Inc) for manual mapping and open-irrigated magnetic catheter (Celsius® ThermoCool® RMT, Biosense Webster Inc) for ablation. This novel EAM system was compared to the CARTO® 3, applying an open-irrigated, magnetic catheter (Navistar® Thermocool® RMT, Biosense Webster Inc) for mapping and ablation. In both groups, RMN Niobe ES was used. The authors concluded that there were no significant differences in procedure parameters between the EnSite Precision and the CARTO® 3; the overall procedure durations were 117.9±29.6 and 119.2±29.7 min, ablation times were 28.0±12.9 and 27.9±15.8 min, and fluoroscopy time were 6.1±2.4 and 4.8±2.2 min, respectively²⁶.

In our opinion, AF treatment strategy should be in line with a particular EP lab operation mode. Medical-logistic decision must be balanced, taking into consideration:

(1) The type of treated arrhythmias (RMN is an excellent tool for ventricular arrhythmias, especially for complex anatomy in patients with congenital heart defects) (ref.^{27,28})

(2) Clinical experience of electrophysiologists in a specific method, since remote navigation requires specialized training further than conventional RFA

(3) Financial aspects, due to the extensive cost of the machinery and system installation

Operator clinical experience is especially important factor. All RMN and MAN catheter ablations were performed by two cardiac electrophysiologists, with more than 10 years of clinical experience each. Noteworthy, in our center, since 2015, all ventricular arrhythmia cases are treated using Niobe ES system navigated by the same operators, who carried out RFA in patients enrolled to the presented study.

It is important to note that this work has several inherent limitations. The first is the retrospective single-center character of the study. Secondly, the number of enrolled patients was relatively small. We did not perform a quantitative evaluation of X-ray exposure of the medical staff involved in catheter ablations performance. We did not account for different inherent mapping time when employing a quadripolar catheter (RMN) versus a duodecapolar one (MAN). This pivotal study limitation could be overcome using the Vdrive™ with V-Loop™ system allowing remote navigation of circular mapping catheters. In comparison to manual PVI procedures, Nölker et al. demonstrated non-inferiority of the Vdrive/V-Loop technology in regard to procedure safety and clinical effectiveness²⁹. It is important to note that different power setting were used in RMN and MAN groups for ablation (10 Watts higher power in RMN group as recommended by Stereotaxis Inc.), however, contact force data were not reported in the presented study. Finally, the recurrence of AF was assessed 6-month post-RFA procedure during ambulatory follow-up visit using 12-lead ECG and 24-hour ECG Holter. More detailed and longer clinical observation especially with more detailed monitoring using implantable loop recorder might have revealed asymptomatic recurrences reflecting true success rate. The number of “lost to follow-up” patients (18 individuals) could be reduced using a telemedical reminder system based on automatic phone calls or SMS technology. Regarding above mentioned limitations, randomized, multi-center clinical trial, with comparable mapping catheters, should be carried out to evaluate clinical usability of RMN approach for AF.

CONCLUSIONS

AF catheter ablation procedures employing Niobe ES remote magnetic navigation system are not more clinically effective than the manual strategy, as freedom from AF at 6-month follow-up was not significantly different between groups. Moreover, in comparison to RMN, MAN-guided catheter ablation of AF showed favorable results in terms of certain peri-procedural parameters.

ABBREVIATIONS

AF, Atrial fibrillation; CF, Contact sensing; EAM, Electro-anatomical mapping; IQR, Interquartile rang; LA, Left atrium; LVEF, Left ventricle ejection fraction; MAN, Manual navigation; ParAF, Paroxysmal atrial fibrillation; PerAF, Persistent atrial fibrillation; PLAX, Parasternal long axis; PVI, Pulmonary veins isolation;

PVs, Pulmonary veins; SD, Standard deviation; RF, Radiofrequency; RFA, Radiofrequency ablation; RMN, Remote magnetic navigation.

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