

ORIGINAL ARTICLE

Remote magnetic navigation for ablation of ventricular arrhythmias

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Abstract: **Introduction** – Remotely-controlled navigation (MNS) has emerged as a novel concept aimed to improve outcomes of catheter ablation for ventricular arrhythmias. It has the potential to increase procedural success, decrease procedure time and minimise catheter-related complications. MNS ablation was proved to be as effective and fast compared with manual radiofrequency (RF) but the results regarding unstable and highly mobile cardiac regions are controversial. **Purpose** – We aimed to describe our experience using magnetic navigation for ablation of ventricular arrhythmias (premature ventricular complexes, sustained ventricular tachycardias or electric storm) in ischaemic and non-ischaemic patients and compare procedural outcomes in relation with arrhythmia type and etiology. **Methods** – A total of 57 patients (57% males, mean age 51 ± 17 years) with ventricular arrhythmias who underwent RF ablation using MNS and CARTO 3 were retrospectively analyzed. Left ventricular sites were targeted by transseptal approach in 53% of the cases, retrograde transaortic in 24% and 8% required epicardial access via pericardial puncture. Clinical and paraclinical variables as well as procedural aspects were noted and short term screening for recurrence was performed. **Results** – Acute procedural success was achieved in 95% of the cases (elimination of clinical arrhythmias). Non-inducibility was documented after programmed ventricular stimulation in 80% of the cases. A third of the patients had structurally normal hearts (34%). Among those that had a subsiding cardiopathy, the ischaemic etiology accounted for 68% of the cases where as dilated idiopathic cardiomyopathy was encountered in 13% of the cases, arrhythmogenic right ventricular cardiopathy 8%, left ventricular non-compaction 5%, postmyocarditis-scar or post-surgical scars in 3%. Difficult ablation sites, such as the proximity of the right bundle branch, coronary cusp or papillary muscle had more frequently previous unsuccessful manual ablations, in all of these cases acute success was obtained with MNS and the non-inducibility rate was 90% (9 out of 10 patients). Acute success rates were higher for ischaemic cases but the difference was not statistically significant. Periprocedural complications were noted in 3.5%. **Conclusion** – MNS is a safe and effective method for catheter ablation for ventricular arrhythmias regardless of etiology or clinical form, with possible superior effects in ischaemic cardiomyopathy with extensive scar and severely dilated LV and for ablation in unstable locations (coronary cusp, papillary muscle).

Keywords: catheter ablation, remote magnetic navigation, ventricular arrhythmias

Rezumat: **Introducere** – Navigația magnetică la distanță (NMD) este o metodă terapeutică inovatoare utilizată pentru optimizarea rezultatelor ablației transcateter pentru aritmii ventriculare. Aceasta are potențialul de a crește ratele de succes, scăzând timpii procedurali și minimizând complicațiile legate de manipularea cateterului. Studiile privind ablația cu NMD au dovedit eficiențe și durate similare în comparație cu ablația manuală, însă rezultatele procedurilor ablativă în regiuni instabile, cu mobilitate crescută sunt încă controversate. **Obiective** – Scopul acestei lucrări este de a descrie experiența centrului nostru în utilizarea navigației magnetice la distanță pentru ablația aritmiilor ventriculare (extrasistole ventriculare (ESV), tahicardie ventriculară susținută (TVS) sau furtună electrică) la pacienți ischemici și non-ischemici și de a compara rezultatele raportate la tipul și etiologia aritmiei. **Materiale și metode** – Un număr total de 57 de pacienți (57% bărbați, cu o vârstă medie de 51 ± 17 ani) cu aritmii ventriculare ablatate cu RF și suport CARTO 3 și navigație magnetică la distanță au fost analizați retrospectiv. Abordul în VS a fost realizat transseptal în 53% dintre cazuri, retrograd transaortic în 24 % iar în 8 % dintre cazuri a fost utilizat și abord epicardic prin puncție pericardică. Variabilele clinice și paraclinice preprocedurale precum și parametrii procedurali au fost înregistrați pentru fiecare pacient și evaluarea rezultatelor ablației pe termen scurt

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a fost efectuată. **Rezultate** – Succesul procedural acut a fost obținut în 95% dintre cazuri (eliminarea aritmiei clinice). Non-inductibilitatea a fost documentată după stimulare ventriculară programată în 80% dintre cazuri. O treime dintre cazuri au fost pe cord structural normal (34%). Dintre cei cu o cardiopatie subiacentă, etiologia ischemică a fost întâlnită în 68% dintre pacienți, cardiomiopatia dilatativă non-ischemică 13%, cardiopatie aritmogenă de VD 8%, non-compactarea VS 5%, iar afectarea cicatriceală post miocardică sau post-chirurgicală în 3% dintre cazuri. Regiunile dificil de ablatat, precum proximitatea ramului drept, cuspa coronariană sau mușchii papilari au avut o medie de intervenții anterioare fără succes mai mare și în fiecare caz succesul acut a fost obținut prin NMD, iar rata de non-inductibilitate a fost de 90% (9 din 10 pacienți). Ratele de succes acut au fost mai mari pentru pacienții ischemici, însă diferența nu a fost semnificativă statistic. Complicații periprocedurale au fost observate în 3,5% dintre cazuri. **Concluzie** – NMD este o metodă sigură și eficientă de ablație pentru aritmii ventriculare indiferent de forma clinică și etiologie, cu posibile rezultate superioare în cazurile de cardiopatie ischemică cu cicatrice extensivă și ventricul stâng foarte dilatat precum și în cazurile în care zona de interes este reprezentată de regiuni instabile (cuspa coronariană, mușchi papilar).

Cuvinte cheie: ablație transcater, navigație magnetică la distanță, aritmii ventriculare.

INTRODUCTION

Ventricular arrhythmias are increasingly treated by radiofrequency (RF) catheter ablation. In the last 10 years significant technological developments such as electro-anatomical mapping, integration of cardiac imaging, and improved catheter design have been implemented to improve procedural outcomes^{1,2}. Proper catheter manipulation to access different areas, very accurate mapping and reliable catheter stability are key issues for a successful treatment in more vulnerable regions (like aortic sinus cusps, which in particular carries a significant risk for valve perforation or for coronary artery injury) or in difficult to reach and/or unstable positions (papillary muscles, very dilated ventricles). The innovation of remote magnetic navigation (MNS) has offered important theoretical advantages in safety due to the atraumatic catheter design, less physical stress and less radiation exposure for physicians³. The magnetic navigation system gives more catheter flexibility, steering accuracy and reproducibility to navigate to a desired location without the risk of perforation. MNS ablation was proved to be as effective and fast compared with manual RF⁴ but the results regarding unstable and highly mobile cardiac regions are still debated.

METHODS

All the patients with ventricular arrhythmias treated with RF ablation using the magnetic navigation system (Stereotaxis Inc., Niobe II) and CARTO 3 between may 2015 and june 2017 in our laboratory were retrospectively analyzed. The design was descriptive, not comparative (i.e. vs. manual ablation) due to difficulties in selecting a similar control lot and to a high crossover rate for problematic cases (critical ablation sites that had incomplete succes with manual ablation were then re-ablated using MNS). Clinical and paraclinical

variables as well as procedural aspects were noted and short term (1 month) screening for recurrence was performed. Results are presented as mean $\pm$ SD or median (IQR) and statistical analysis was performed with SPSS 22 and Microsoft Excel Analyse-it software.

STUDY POPULATION

After careful review of all procedural logs a total of 57 patients with different types of ventricular arrhythmias who underwent remote magnetic navigation guided ablation procedures were found. Some of the patients (29%) have had one or more previous manual ablation procedures (mean 1.3 ± 0.5) but experienced arrhythmia recurrence. The study population had predominantly male sex (57%) with a mean age 51 ± 17 years and 34% of the lot had no structural heart disease. Among those that had a subsiding cardiopathy, the ischaemic etiology accounted for 68% of the cases where as dilated idiopathic cardiomyopathy was encountered in 13% of the cases, arrhythmogenic right ventricular cardiopathy 8%, left ventricular non-compactation 5%, postmyocarditis-scar or post-surgical scars in 3% (Figure 1).

Mean left ventricular ejection fraction was $41\% \pm 13.6$ and the arrhythmia burden on preprocedural holter monitoring was between 17% and 46% with a mean of $27.4 \pm 10.9\%$. Invasive mapping allowed the determination of earliest activation sites of 37 ± 13.7 milliseconds (Table I).

The indication for ablation was sustained ventricular tachycardia in 31%, frequent premature ventricular complexes (PVCs) in 43% and electrical storm in 26% of the cases. Electrical storm was defined according to current recommendations as ≥ 2 episodes of sustained ventricular tachycardia in 24 hours regardless of the hemodynamic tolerance/ ventricular tachycar-

Table 1. Patient characteristics

	Minimum	Maximum	Mean	SD
Age (years)	17	81	50.8	16.7
LV ejection fraction	15%	55%	41.4%	13.6
Arrhythmia burden (% holter 24hours)	17%	46%	27.4%	10.9
Earliest activation (milliseconds)	20	62	37	13.7

dia recurring in less than 5 minutes after conversion or sustained/non-sustained VT for more than 50% of the electrical activity in 24 hours⁵. In patients with implantable defibrillators the criteria we considered for diagnosis of electric storm were: ≥ 3 appropriate therapies (including antitachycardia pacing) or ≥ 2 internal shocks in 24 hours⁶.

In our lot 24% (14 patients) had a previously implanted ICD and 15.5% (9 patients) a CRT-D, the device therapies were programmed “off” during the proce-

dure and then re-enabled. No periprocedural interference of the magnetic system with device function was observed.

In the absence of structural heart disease, clinical arrhythmia was mostly PVCs (16 patients), followed by sustained ventricular tachycardia (3 patients) and one electric storm (Purkinje PVC triggered VF) whereas with structural heart disease the proportions were significantly different: 9 patients with PVC/NSVT, 15 patients with sustained ventricular tachycardia and 13 patients with electric storm as shown in Figure 2 ($p=0.0002$, Pearson chi-squared test).

RESULTS

Acute procedural success was defined as complete elimination of the clinical tachycardias and was achieved in 95% (54 of 57 patients) of the cases. Non-inducibility after programmed ventricular stimulation was tested for the patients that presented with sustained

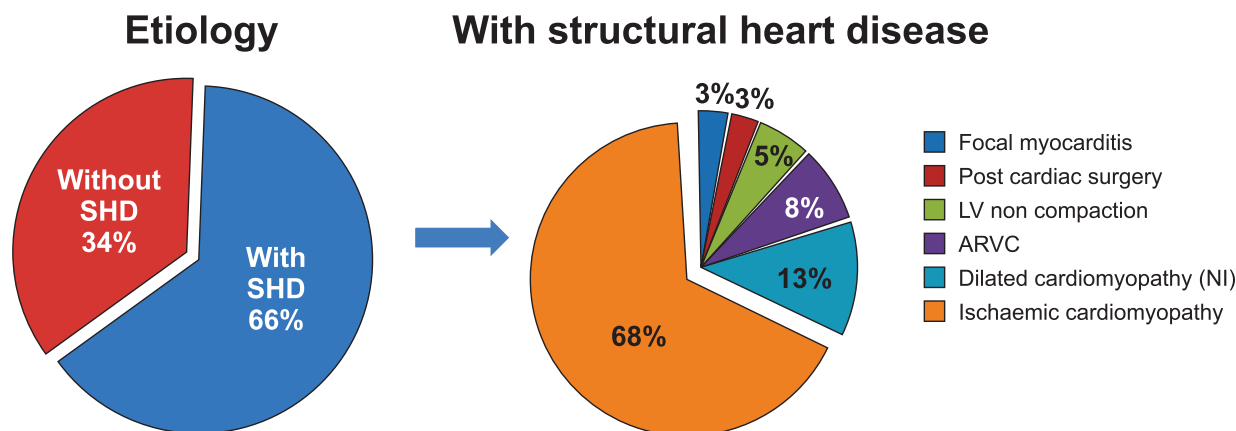


Figure 1. Study population – etiology of ventricular arrhythmias.
SHD=structural heart disease; ARVC=arrhythmogenic right ventricular cardiopathy; NI=non-ischaemic.

Table 2. Subgroup comparison (Pearson χ^2)

	No SHD	IHD	NI-SHD	P-value
Male sex	15%	76%	84.6%	0.0001
Arrhythmia type_PVC	80%	24%	23%	0.017
Tachycardia-induced CMP	20%	12%	7%	0.51
First procedure with MNS	50%	80%	85%	0.04
Transseptal approach used	1%	84%	61.5%	0.0001
Retrograde transaortic approach used	50%	12%	7.7%	0.003
Epicardial approach used	0	4%	38.5%	0.0007
Substrate_based ablation	0	64%	45.2%	0.0001
Activation_based ablation	100%	75%	92.3%	0.04
Acute success	95%	100%	84.6%	0.38%
Non-inducibility	84.2%	72%	66.7%	0.49

SHD = structural heart disease; IHD = ischaemic heart disease; NI = non-ischaemic; PVC = premature ventricular contraction.

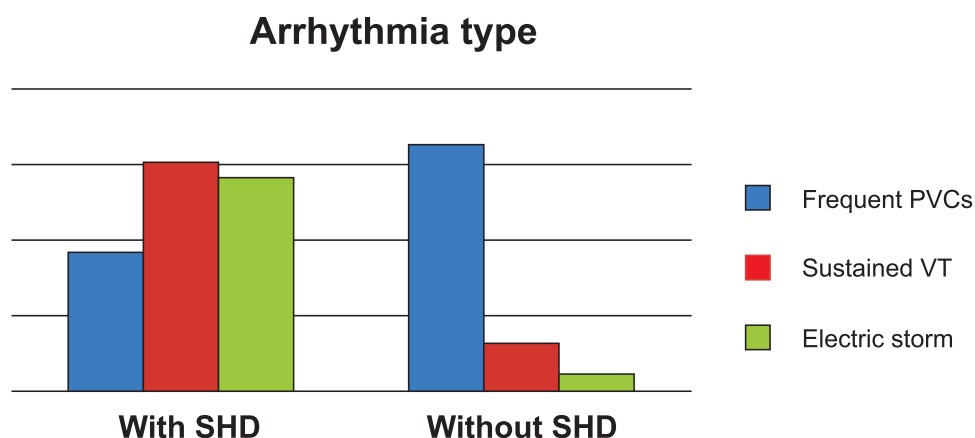


Figure 2. Clinical arrhythmia before ablation.

Table 3. Wilcoxon Mann Whitney test for predictors of non-inducibility – shown median values (IQR)

	Subgroup with non-inducibility obtained	Subgroup with non-inducibility not possible	P-value
Age -years	60 (24.3)	62 (10)	0.37
LV EF (%)	40 (25)	30 (25.4)	0.36
LV volume CARTO 3 (ml)	213.5 (97.92)	278.5 (96.33)	0.93

Table 4. Fischer's exact test – predictors of non-inducibility

	Subgroup with non-inducibility obtained	Subgroup with non-inducibility not possible	Odds ratio
Ischaemic etiology	58 %	57%	1.022
NI dilated CMP	15.4%	14.3%	1.088
Structurally normal heart	12%	14%	0.78
Male sex	69.2%	71.4%	0.9

or non-sustained VT and was obtained in 80% of the cases. The protocol for stimulation usually included up to three extrastimuli with the coupling interval decreased progressively up to refractory period but not below 200 ms.

Patient age had a similar distribution in the two lots (with or without non-inducibility obtained), whereas median left ventricular ejection fraction was smaller and median left ventricular volume was bigger in the subgroup in which non-inducibility was not possible, although not reaching statistic significance - see Table 3. No difference was noted in the frequency of different etiologies between those two subgroups mentioned above (Table 4).

Left ventricular sites were targeted by transseptal approach in 63% of the cases, retrograde transaortic in 24%, through coronary sinus ventricular tributaries 4.3% and 8.7% required epicardial access via pericardial puncture.

Among the 3 patients in which acute success was not possible, 1 had electrical storm and intramural VT (endo-epicardial mapping was performed, but RF delivery was unsuccessful both endocardially and epicardially) and the other 2 were frequent PVCs with an intramural localisation (LV summit).

Classically considered difficult ablation sites, such as the proximity of the His (2 patients) or right bundle branch (2 patients), coronary cusp (3 patients) or papillary muscle (3 patients) had more frequently previous unsuccessful manual ablations and in all cases acute success was obtained with MNS and the non-inducibility rate was 90% (9 out of 10 patients).

Periprocedural complications were noted in 3.5% (2 cases) one was strictly related to the transseptal puncture and the other was an right coronary air embolization through patent foramen ovale during RA-RV mapping in a patient with VT due to ARVC/D (which was rapidly resolving without any clinical consequence).

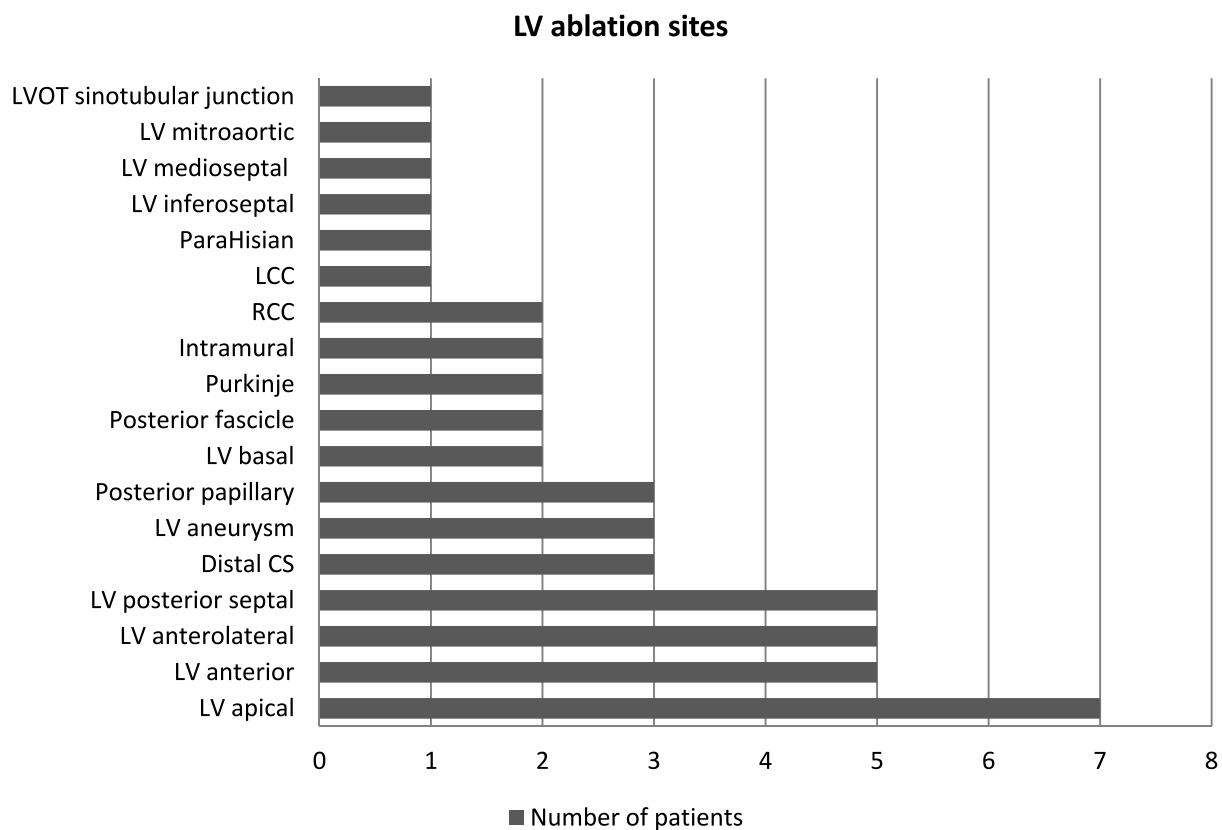


Figure 3. LV ablation sites.
LVOT=left ventricular outflow tract; RCC=right coronary cusp; LCC=left coronary cusp.

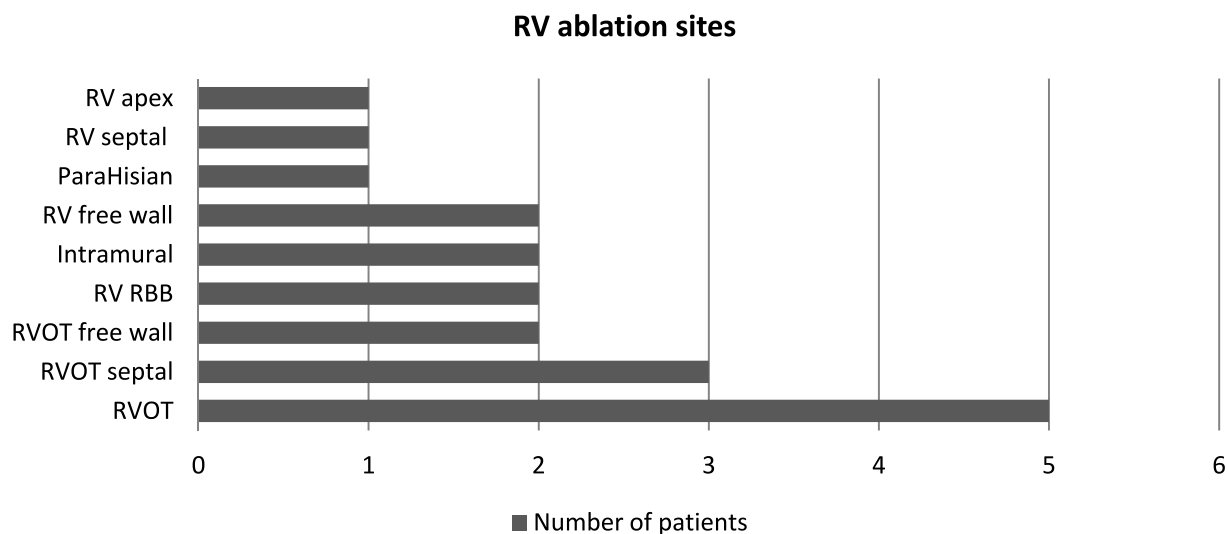


Figure 4. RV ablation sites.
RVOT=right ventricular outflow tract; RBB=right bundle branch.

DISCUSSION

RF ablation of ischemic ventricular tachycardia has evolved rapidly due to improved technical facilities and understanding of the arrhythmia substrate. The

success rates obtained with remote magnetic navigation for different types of ventricular arrhythmias in our study was 95%, comparable with those described in recent publications. One study reports 80% acute

success rate using irrigated magnetic catheters in a small series of 30 patients with ischemic heart disease and electrical storm⁷. Another publication⁸ reported a 100% acute success rate using MNS but in a more heterogeneous group including only 30% patients with ischemic heart disease (similar to our study) but in that study, three-quarters of the cases were referred for ablation of ventricular premature beats and only 24% had sustained VT (in our retrospective only 43% of the patients were referred for PVCs). Our findings suggest that adding remote magnetic navigation has the possibility to increase effectiveness and safety, especially in difficult regions (papillary muscle, aortic cusps, His region etc.) but also in patients with very large ventricles. One recent paper that analysed patients with idiopathic ventricular arrhythmias and failed manual ablation that were re-ablated with MNS found that catheter ablation using a MNS system is more effective in selected patients primarily by greater success with ablation in the posterior RVOT and posterior-basal RV (tricuspid annulus)⁹. In our study, the overall estimated incidence of major procedure related complications was 3.5%, which is comparable to the complication rates in previously reported studies (2.94%)¹⁰.

LIMITATIONS

The study was a single-center retrospective study and is subjected to bias typical in retrospective studies. We realize that although no preselection criteria were applied, a certain selection bias could occur. The small number of patients (57 patients) could be also a limitation, although the published studies on this topic are few and also comprised small patient groups. Another important limitation is that effective comparison of ablation results with MNS between subgroups is not possible due to their significant heterogeneity (see Table 2) and small number.

CONCLUSION

MNS is a safe and effective method for catheter ablation for ventricular arrhythmias regardless of etiology

or clinical form, with possible superior effects in ischaemic cardiomyopathy with extensive scar and severely dilated LV and for ablation in unstable locations (coronary cusp, papillary muscle).

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