Early and long-term outcomes after manual and remote magnetic navigation guided catheter ablation for ventricular tachycardia

Pierre **Qian**[1,2] MBBS, Kasun **De Silva**[1] BMed MD, Saurabh **Kumar**[1] MBBS PhD, Fazlur **Nadri**[1,2] MBBS, Rahul **Samanta**[1,2] MBBS, Abhishek **Bhaskaran**[1,2] MBBS PhD, David **Ross**[1,2] MBBS, Gopal **Sivagangabalan**[1,3] MBBS PhD, Mark **Cooper**[1] MBBS PhD, Eddy **Kizana**[1,2] MBBS PhD, Lloyd **Davis**[1,4] MBBS PhD, Alan Robert **Denniss**[1,2,4] MD, Aravinda **Thiagalingam**[1,2] MB ChB PhD, Stuart **Thomas**[1,2] MBBS PhD, Pramesh **Kovoor**[1,2] MBBS PhD

[1]Department of Cardiology, Westmead Hospital, Sydney, Australia

[2]Sydney Medical School, University of Sydney, Sydney, Australia

[3]School of Medicine, University of Notre Dame Australia, Sydney, Australia

[4]School of Medicine, Western Sydney University, Sydney, Australia

Short title: Manual and remote magnetic navigation guided VT ablation

Word count: 3,742

Address for correspondence:

Dr Pierre Qian

Department of Cardiology, Westmead Hospital

Cnr of Hawkesbury and Darcy Rd

Westmead, New South Wales 2145

Australia

Phone: +61288906511 Fax: +61298458325

Email: pierre.qian@sydney.edu.au

ABSTRACT

Aim: Remote magnetic navigation (RMN) is a safe and effective means of performing ventricular tachycardia (VT) ablation. It may have advantages over manual methods due to ease of manoeuvrability and catheter stability. We sought to compare the safety and efficacy of RMN versus manual VT ablation.

Methods: Retrospective study of procedural outcomes of 139 consecutive VT ablation procedures (69 RMN, 70 manual ablation) in 113 patients between 2009 and 2015 was performed.

Results: RMN was associated with overall higher acute procedural success (80% vs. 60%, p=0.01), with a trend to fewer major complications (3% vs. 9% *P*=0.09). 79 patients were followed up for a median of 17.0 (IQR 3.0 – 41.0) months for the RMN group and 15.5 (IQR 6.5-30.0) months for manual ablation group. In the ischaemic cardiomyopathy subgroup, RMN was associated with longer survival from the composite endpoint of VT recurrence leading to defibrillator shock, re-hospitalisation or repeat catheter ablation and all-cause mortality; single procedure adjusted HR 0.240 (95% CI 0.070-0.821) p = 0.023, multi-procedure HR 0.170 (95% CI 0.046-0.632) p = 0.002. In patients with implanted defibrillators, multi-procedure VT free survival was superior with RMN, HR 0.199 (95% CI 0.060-0.657) p = 0.003.

Conclusion: Remote magnetic navigation may improve clinical outcomes after catheter ablation of VT in patients with ischaemic cardiomyopathy. Further prospective clinical studies are required to confirm these findings.

CONDENSED ABSTRACT

We performed a single centre retrospective study of safety and efficacy of remote magnetic navigation guided and manual VT ablation. Remote magnetic navigation was associated with higher procedural efficacy for ablation of VT in ischaemic cardiomyopathy.

KEYWORDS

Remote magnetic navigation, ventricular tachycardia, catheter ablation, ischaemic cardiomyopathy

WHAT'S NEW?

- Remote magnetic navigation guided ablation can be safe and effective for the treatment of ventricular tachycardia.
- Compared with manual ablation, remote magnetic navigation may enable more effective ablation of ventricular tachycardia in patients with ischaemic cardiomyopathy.

INTRODUCTION

Ventricular tachycardia (VT) is a debilitating and life-threatening arrhythmia that is often poorly controlled by antiarrhythmic medications. Implanted cardiac defibrillators (ICD) reduces mortality by providing a means to terminate VT, however recurrent VT and ICD shocks reduced quality of life and are associated with increased mortality in patients with cardiomyopathy [1, 2]. Catheter ablation can be curative in idiopathic VT and reduce VT burden and appropriate ICD shocks in patients with ischaemic cardiomyopathy[3]. Current practice guidelines and expert consensus advocate the use of catheter ablation for symptomatic idiopathic VT and in the setting of incessant VT, electrical storm or recurrent ICD shocks in patients with VT and structural heart disease[4, 5].

The use of a remote magnetic navigation system may have benefits over manual catheter ablation. Comparative studies performed in retrospective cohorts, case control studies and small randomised control trials report in general lower rates of major complications and radiation dose using remote magnetic navigation for catheter ablation of a range of cardiac arrhythmias[6-9]. For VT ablation procedures, there is emerging evidence that remote magnetic navigation may also be associated with reduced procedure duration and higher or comparable acute and long term success[10, 11]. In vitro data suggest that remote magnetic navigation provides more stable catheter position in the ventricle which would be advantageous for mapping and lesion formation[12]. We therefore compared acute procedural and long-term outcomes after manual and remote magnetic navigation guided VT ablations at our centre, which performs both manual and remote magnetic navigation ablation.

METHOD

Patient cohort

This retrospective study was approved by the Western Sydney Local Health District Human Ethics Committee. Consecutive VT ablations procedures at Westmead Hospital between 1st January 2009 and 24th September 2015 were included. All patients provided informed consent for the procedure.

Catheter ablation procedure

VT ablation procedures were performed under general anaesthesia. Intravenous heparin was administered to maintain activated clotting time 300-350s if the left ventricle was accessed endocardially. CARTO system (Biosense Webster Inc., Diamond Bar, CA, USA) and EnSite NAVX 3D (St Jude Medical, St. Paul, MN, USA) were used for electroanatomical mapping. Areas of ventricular scar was identified by endocardial bipolar voltages <1.5mV (dense scar <0.5mV) and unipolar voltages <8.3mV (or <5.5mV for RV), and bipolar epicardial voltage <1mV[13, 14]. VT induction was performed with programed ventricular stimulation with a drive train cycle length of 400ms and up to 4 extrastimuli, each introduced at 300ms and decremented in 10ms steps down to ventricular refractoriness as previously described[15]. Isoprenaline with or without adrenaline infusion was required in some patients to induce focal VT. A combination of activation, entrainment, and pace mapping and was used to identify sites for catheter ablation. Substrate modification was also performed by targeting fractionated late potentials. The procedural endpoint was non-inducibility of the clinical VT. Other VTs were that were easily inducible and considered of potential clinical importance by the operator were also targeted for ablation.

Patients were allocated to remote magnetic navigation or manual ablation based on lab availability and operator preference. Remote magnetic navigation guided ablation was performed using the 3.5mm Navistar thermocool RMT catheter (Biosense Webster Inc., Diamond Bar, CA, USA) with the Niobe SE (Stereotaxis, St Louis, MO, USA) from 1st January 2009 to 24th October 2013 and Niobe Epoch thereafter. Manual ablations were routinely delivered with 3.5 or 4mm tip irrigated radiofrequency ablation catheters. Typical ablation settings for manual ablations were 30-50W in the right ventricle and 40-50W in the left ventricle for 30-60s, temperature limited to 40°C, irrigation 15-20mL/min. For remote magnetic navigation ablations, our practice is to use 40W for right ventricle and 50W for left ventricle and up titrate catheter irrigation flow rate from 15mL/min up to 30mL/min to maintain catheter tip temperature <40°C to maximise power delivery, as power delivery rather than catheter tip temperature governs lesion size during irrigated ablation[16]. Indications for ICD implantation was consistent with published society guidelines[17]. Detection algorithms and therapy settings varied with device model and manufacturer. In general to minimise device shock, therapy for nonsustained VT was avoided and antitachycardia pacing was used preferentially to terminate VT.

Acute procedural and follow up data collection

Demographic patient information and indications for the VT ablation procedure was extracted from admission records. The severity of left and right ventricular systolic impairment was determined from the transthoracic echocardiogram (TTE), (^{99m}Tc) sestamibi or gated heart pool scan performed in the 6 months prior to the procedure and graded as normal (≥55%), mild (45-54%), moderate (35-44%) or severe (<35%). The indication for VT ablations procedures was considered elective if planned as an outpatient, and an emergency if performed during unplanned admission to hospital for ventricular tachycardia. The VT ablation procedure report was used to determine the number of VT morphologies induced during the study, the access used for the ablation catheter, procedure duration (from the time of venous puncture to removal of catheters), fluoroscopy time, and acute procedural success. Procedural complications were determined from the discharge summary and procedure report. Complications were considered major if it resulted in death, required an urgent surgical procedure or lead to permanent neurological disability. Other complications such as access site bleeding managed conservatively, pericardial effusions that required pericardiocentesis but not surgical drainage and repair, or transient ischaemic attack were considered minor complications. A combination of outpatient cardiology clinic data, device interrogation reports, hospital admissions coding data and discharge summaries for subsequent hospital admissions were used to determine the outcomes at follow up.

Study endpoints

The primary composite endpoint investigated was the single procedure and multi-procedure freedom from VT recurrence leading to implanted defibrillator shock, re-hospitalisation, or repeat VT ablation and all-cause mortality. This endpoint was chosen to encapsulate major clinical adverse outcomes associated with recurrent VT that reduce quality and length of life. For the single procedure analysis, the first ablation procedure was taken as the index procedure. In the multi-procedure analysis, the last ablation procedure where the patient received post-procedure follow up was taken as the index procedure. Patients were excluded from the multi-procedure analysis if both manual and remote magnetic navigation guided VT ablation procedures had been performed. The secondary endpoints were 1) acute procedural success; 2) procedural complications; 3) freedom from sustained VT in patients with ICDs defined as VT lasting longer than 30s or otherwise treated with device therapy (any antitachycardia pacing or defibrillator shock); and 4) freedom from all-cause mortality. The census date for follow data collection was November 17th 2016.

Statistical analysis

Analysis was performed with IBM SPSS Statistics Version 22 (IBM Corp, NY, USA). Categorical variables were compared between groups using Pearson's chi square, or Fisher's exact test if cell size was less than 5. Continuous variables were compared using Mann Whitney Test, or permutation t test using 10,000 samples if cell size was less than 5. Logistic regression analysis was used to determine multivariate predictors for acute procedural success and complications using univariate predictors with $p<0.2$. Kaplan-Meier survival analysis was performed and significant differences between groups determined using log rank test (Mantel-Cox). Cox regression analysis was performed to identify multivariate predictors using univariate predictors with $p<0.2$ on log rank test. Statistical significance was taken as $p<0.05$.

RESULTS

Patient cohort

Catheter ablation procedures for VT (N = 139) were performed in 113 patients. The etiology of VT was idiopathic in 38 patients, and included RV and LV outflow tract, fascicular, bundle branch re-entry, and papillary VTs; ischaemic cardiomyopathy in 37 patients, and non-ischaemic cardiomyopathy in 38 patients. Manual ablation was used to perform 70 procedures and remote magnetic navigation for 69 procedures. The procedure was converted from remote magnetic navigation to manual in 2 cases due to perceived difficulty with achieving stable contact or adequate contact force.

These were included as a part of the remote magnetic navigation group based on an intention to treat analysis. Baseline patient characteristics were similar between remote magnetic navigation guided and manual ablation groups. There were numerically more females and less non-ischaemic cardiomyopathy in the remote magnetic navigation group that did not reach significance. Both manual and remote magnetic navigation groups had a similar rate of and elective VT ablation and redo procedures (Table 1 and 2).

VT ablation procedure

The remote magnetic navigation group had more cases with ≥3 inducible VT morphologies, 16/69 (24%) vs. 5/70 (7%) $p = 0.009$; and had generally longer procedural duration and ablation times (Table 2). The use of more than one access approach for the ablation catheter was lower with remote magnetic navigation compared to manual ablation, 5/69 (7%) vs. 14/70 (20%) $p = 0.029$, with fewer cases that required retrograde aortic access, 7/69 (10%) vs. 18/70 (26%) $p = 0.017$. The manual ablation group had two cases that required bipolar ablation at the interventricular septum and in one case that used a transapical approach via mini-thoracotomy. The mean procedure duration was longer with remote magnetic navigation, 429±121min vs. 291±101min $p<0.001$, but total fluoroscopy time was lower 32.45±24.24 vs. 38.8±24.08, $p = 0.059$, and lower per hour of procedure, 4.2±3 min/hr vs. 7.8±3.6 min/hr $p<0.001$.

Acute procedural outcomes

Acute procedural success, defined as clinical VT non-inducibility, was higher in with remote magnetic navigation than manual ablation, 55/69 (80%) vs. 42/70 (60%) p =

0.011, odds ratio 2.619 (1.229-5.583), and was the only significant factor in multivariate analysis. Remote magnetic navigation was also associated with a lower rate of unsuccessful ablation, 1/69 (1%) vs. 8/70 (11%), p = 0.033 (Tables 2 and 3).

The procedural complication rate was similar between manual and remote magnetic navigation, 8/70 (11%) vs. 9/69 (13%) p = 0.801. There were numerically more major complications with manual ablation which did not reach significance, 6/70 (9%) vs 2/69 (3%), p = 0.091 (Table 2). The risk of complications was higher for patients in the third age tertile (>67yrs), HR 4.524 (95%CI 1.220-24.359), undergoing redo VT ablations, HR 5.451 (95%CI 1.030-17.859), and have right ventricular impairment, HR 4.289 (95%CI 1.016-20.144) (Table 3). There were 2 deaths, both in the manual group; one due to cardiac perforation and tamponade during mapping of LV scar, and another from cardiogenic shock in a patient with severely impaired left ventricular function. Nonfatal pericardial tamponade occurred in 5 cases (4%), 3 with manual and 2 with remote magnetic navigation. Pericardial bleeding occurred during catheter manipulation in the manual cases, whereas in the remote magnetic navigation cases, one occurred due to coronary laceration at epicardial access and the other after defibrillation thought to be secondary to a quadrapolar catheter perforating the right ventricle. Other complications in the cohort included 5 vascular access site complications (4%), two of which required surgical repair; 3 decompensations of cardiac failure requiring inotropic support post-procedurally; 1 case of high grade AV block after basal right ventricular septum ablation; 1 ventricular septal defect from bipolar ablation and aortic regurgitation caused by retrograde aortic access in a child; and 1 deep vein thrombosis.

Outcomes at follow up

Clinical follow-up data was available for 79 of 113 patients (36 manual and 43 remote magnetic navigation). The median follow-up duration in the manual group was 15.5 (interquartile range 6.5 – 30.0) months and in the remote magnetic navigation group was 17.0 (interquartile range 3.0 – 41.0) months.

In a single procedure analysis, there was a trend towards longer median survival from the primary composite endpoint in the remote magnetic navigation compared with manual ablation, 38.0 (95% CI 5.2-70.8) months vs. 15.0 (95% CI 8.6-21.3) months, p=0.412. Among patients with ischaemic cardiomyopathy, remote magnetic navigation was associated with longer median survival 27 (95% CI 7.2-46.8) months vs. 8 (95% CI 1.5-14.5) p = 0.104, which became significant after adjustment for covariates in multivariate analysis, adjusted HR 0.240 (95% CI 0.070-0.821) p = 0.023 (Fig. 1, Table 3). Emergency indication for VT ablation was the only other multivariate predictor for the primary composite endpoint, HR 3.782 (95% CI 1.080-13.252) p=0.038.

In a multi-procedure analysis that excluded 8 cross-over patients, remote magnetic navigation showed significantly longer median survival from the primary composite endpoint, 46 (95% CI 41.6-50.4) months vs. 15.0 (95% CI 8.6-21.3) months, p = 0.018. The benefit was driven by the effect of remote magnetic navigation in the ischaemic subgroup where the median survival was 43.0 (95% CI 17.1-68.9) months vs. 4.0 (95% CI 0-12.6) months, hazard ratio 0.170 (95% CI 0.046-0.632) (Fig. 2). No other significant multivariate predictors were identified. Among the 64 patients with ICDs, 34 had complete device follow up history at our center. Remote magnetic navigation was associated with longer multi-procedure freedom from sustained VT in patients with ischaemic cardiomyopathy, hazard ratio 0.199 (95% CI 0.060-0.657), p = 0.003 (Fig. 3). There were no significant differences in mortality between manual and remote magnetic navigation groups (Fig. 4).

Operator bias

At our centre, 7 proceduralists performed VT ablations. All were experienced with manual ablations and 5 had performed at least one remote magnetic navigation guided ablation. Two operators predominantly used remote magnetic navigation and performed 60/69 (87%) cases in the remote magnetic navigation group, one of whom performed 54/69 (78%) cases. Combined, they also performed 12/70 (17%) manual ablations. To assess whether the use of remote magnetic navigation was a stronger influence than operator preference on procedural outcomes, we repeated logistic regression analysis for acute procedural success and Cox regression analysis for single and multi-procedure hazard of reaching the primary composite endpoint comparing proceduralists who had performed more remote magnetic navigation guided ablations to those who performed more manual ablations. This did not significantly alter the results of the multivariate analyses.

DISCUSSION

This study is the first to find that remote magnetic navigation guided VT ablation was associated not only with higher overall acute procedural success but also better long-term clinical outcomes and lower arrhythmia recurrence in the subgroup of patients with ischaemic cardiomyopathy. Remote magnetic navigation lead to higher rate of acute success compared with manual ablation, 80% vs 60% p = 0.011, and fewer unsuccessful ablations, 1/69 (1%) vs. 8/70 (11%) p = 0.033, defined as no change in clinical VT inducibility. At follow up, remote magnetic navigation guidance was associated with significantly longer survival from primary composite endpoint in the ischaemic cardiomyopathy subgroup for both single and multi-procedure analyses (Fig 1 and 2, Table 4). This was accompanied by longer freedom from sustained VT among patients with ICDs and ischaemic cardiomyopathy in a multi-procedure analysis (Fig 3).

Earlier studies comparing remote magnetic navigation and manual VT ablation have consisted of mostly case series with a majority of idiopathic VT[6]. A meta-analysis of these studies showed a high and similar acute and long-term success with both remote magnetic navigation and manual ablation and a lower procedural complication rate, fluoroscopy use and procedural duration for remote magnetic navigation[18]. Majority of our patients had structural heart disease where acute and long-term success is less readily achievable, enabling differences in outcomes from ablation methods to be apparent.

In contrast to previous studies, remote magnetic navigation was associated with significantly longer procedure and ablation time in our cohort. However, the remote magnetic navigation group had more cases with ≥3 inducible VT morphologies, 24% vs 7% p = 0.009. While not the procedural endpoint, the rate for elimination of all inducible VT was similar with magnetic navigation and manual groups, 49% vs. 41% p = 0.353, suggesting that the longer ablation and procedural times were related to the treatment of more VT circuits. The average fluoroscopy time was shorter with remote magnetic navigation, corrected for the length of the procedure was shorter, 4.2±3 min/hr vs. 7.8±3.6 min/hr p<0.001, consistent with prior reports[18, 19]. Despite more extensive ablation in the remote magnetic navigation group, the overall rate of complications was similar to the manual ablation with no procedural mortalities and fewer major complications overall, which did not reach statistical significance.

Few studies comparing remote magnetic navigation and manual VT ablation have suggested differences in long-term efficacy. Hendriks *et al.* compared remote magnetic navigation to contact force and non-contact force manual VT ablation to find higher acute success and improved long-term arrhythmia-free survival[10]. However, there were more idiopathic VTs treated in the remote magnetic navigation arm than the manual arms of the study (60/86 vs. 66/152, p<0.001), raising the possibility that the observed differences were driven by the type of VT treated. Dinov *et al.* showed in a cohort of 102 ischaemic cardiomyopathy patients that remote magnetic navigation had equivalent acute success compared to manual ablation with a non-significant trend towards improved long term survival from VT recurrence [20]. The remote magnetic navigation group had shorter ablation times than the manual group in their cohort (1590 ± 1047.4s vs 2338 ± 1248s, p=0.049). The opposite trend in ablation time was seen in our cohort with remote magnetic navigation (4030±2143s vs. 2924±1849s, p=0.1), suggesting either more arrthymogenic substrate was identified or more substrate modification performed at ablation. Remote magnetic navigation but not ablation time predicted acute success and long-term outcomes in multivariate analyses (Table 3 and 4), indicating that the differences in outcomes were not driven by the amount of ablation.

Patients with more extensive ischemic arrhythmogenic substrate may benefit the most from remote magnetic navigation guided VT ablation. Di Biase *et al.* showed that remote magnetic navigation guided VT ablation in patients with ischemic scar of large area (>60cm^2) was able to provide higher density substrate mapping, lower mapping time, and led to longer ablation times compared to manual ablation [21]. At follow up, there was significantly longer VT free survival in the remote magnetic navigation group. While mapping time was not recorded in our procedures, we observed that fewer cases in the remote magnetic navigation group required multiple approaches for the ablation catheter for remote magnetic navigation compared to manual ablation, 5/69 (7%) vs. 14/70 (20%) p = 0.029, and fewer needing retrograde aortic access, 7/69 (10%) vs. 18/70 (26%) p = 0.017, suggesting that it may have been easier to achieve more complete endocardial mapping with the ablation catheter using remote magnetic navigation. In combination with greater stability of catheter tip position[12], this may enable more complete identification and modification of arrhythmogenic substrates. Interestingly, better long-term outcomes with remote magnetic navigation was not seen in the non-ischaemic cardiomyopathy subgroup. Improvements in endocardial substrate mapping and ablation would be expected to convey a smaller advantage in this patient group where mid-myocardial and epicardial substrates predominate and biophysical limitations of radiofrequency lesion formation poses a significant challenge for procedural efficacy.

LIMITATIONS

This study was not randomised and hence could be subject to confounding effects of selection and operator bias. However, the remote magnetic navigation group appeared to have more advanced arrhythmogenic substrate with more patients observed to have

≥3 inducible VT morphologies suggesting that selection bias may have acted against improved outcomes observed. The effect of operator was also investigated in multivariate analyses and found to be insignificant. Magnetic VT, a randomised multicentre clinical trial currently underway comparing remote magnetic navigation to manual ablation in patients with ischaemic cardiomyopathy and ICDs, will address the limitations of this and other previous studies to provide a more definitive comparison in the future.

CONCLUSIONS

Remote magnetic navigation appears safe and effective for VT ablation compared with manual ablation. In patients with ischaemic cardiomyopathy, remote magnetic navigation was associated with improved long-term clinical outcomes. The mechanism for this merits further study and may be due to advantages in remote magnetic navigation guidance for more complete endocardial mapping and ablation of arrhythmogenic substrates.

ACKNOWLEDGEMENTS

Dr. Karen Byth Wilson, Research Academic, NHMRC Clinical Trials Centre Medicine, Sydney Medical School, for assistance with choice of statistical testing.

Funding support: Dr. Pierre Qian was supported by a National Health and Medical Research Council (NHMRC) and National Heart Foundation of Australia (NHF) co-funded postgraduate scholarship (NHMRC Scholarship No. 1114408, NHF Scholarship No. 101107).

CONFLICTS OF INTEREST

None from all authors

REFERENCES

1. Kamphuis HC, de Leeuw JR, Derksen R, Hauer RN, Winnubst JA. Implantable cardioverter defibrillator recipients: quality of life in recipients with and without ICD shock delivery: a prospective study. *Europace.* 2003;5:381-9.
2. Poole JE, Johnson GW, Hellkamp AS, Anderson J, Callans DJ, Raitt MH, et al. Prognostic importance of defibrillator shocks in patients with heart failure. *The New England journal of medicine.* 2008;359:1009-17.
3. Reddy VY, Reynolds MR, Neuzil P, Richardson AW, Taborsky M, Jongnarangsin K, et al. Prophylactic Catheter Ablation for the Prevention of Defibrillator Therapy. *New England Journal of Medicine.* 2007;357:2657-65.
4. Priori SGBlomstrom-Lundqvist C. 2015 European Society of Cardiology Guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death summarized by co-chairs. *European heart journal.* 2015;36:2757-9.
5. Pedersen CT, Kay GN, Kalman J, Borggrefe M, Della-Bella P, Dickfeld T, et al. EHRA/HRS/APHRS expert consensus on ventricular arrhythmias. *Heart Rhythm.* 2014;11:e166-96.
6. Aagaard P, Natale A, Briceno D, Nakagawa H, Mohanty S, Gianni C, et al. Remote Magnetic Navigation: A Focus on Catheter Ablation of Ventricular Arrhythmias. *Journal of Cardiovascular Electrophysiology.* 2016;27:S38-S44.

7. Weiss JP, May HT, Bair TL, Crandall BG, Cutler MJ, Day JD, et al. A Comparison of Remote Magnetic Irrigated Tip Ablation versus Manual Catheter Irrigated Tip Catheter Ablation with and Without Force Sensing Feedback. *Journal of Cardiovascular Electrophysiology.* 2016;27:S5-S10.

8. Proietti R, Pecoraro V, Di Biase L, Natale A, Santangeli P, Viecca M, et al. Remote magnetic with open-irrigated catheter vs. manual navigation for ablation of atrial fibrillation: A systematic review and meta-analysis. *Europace.* 2013;15:1241-8.

9. Akca F, Janse P, Theuns DAMJ, Szili-Torok T. A prospective study on safety of catheter ablation procedures: Contact force guided ablation could reduce the risk of cardiac perforation. *International Journal of Cardiology.* 2015;179:441-8.

10. Hendriks AA, Akca F, Dabiri Abkenari L, Khan M, Bhagwandien R, Yap SC, et al. Safety and clinical outcome of catheter ablation of ventricular arrhythmias using contact force sensing: Consecutive case series. *Journal of Cardiovascular Electrophysiology.* 2015;26:1224-9.

11. Di Biase L, Santangeli P, Astudillo V, Conti S, Mohanty P, Mohanty S, 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;7:1029-35.

12. Bhaskaran A, Barry MA, Al Raisi SI, Chik W, Nguyen DT, Pouliopoulos J, et al. Magnetic guidance versus manual control: comparison of radiofrequency lesion dimensions and evaluation of the effect of heart wall motion in a myocardial phantom. *Journal of interventional cardiac*

electrophysiology : an international journal of arrhythmias and pacing. 2015;44:1-8.

13. Tschabrunn CMMarchlinski FE. Ventricular tachycardia mapping and ablation in arrhythmogenic right ventricular cardiomyopathy/dysplasia: Lessons Learned*. World Journal of Cardiology.* 2014;6:959-67.

14. Marchlinski FE, Callans DJ, Gottlieb CD, Zado E. Linear Ablation Lesions for Control of Unmappable Ventricular Tachycardia in Patients With Ischemic and Nonischemic Cardiomyopathy*. Circulation.* 2000;101:1288.

15. Zaman S, Kumar S, Narayan A, Sivagangabalan G, Thiagalingam A, Ross DL, et al. Induction of ventricular tachycardia with the fourth extrastimulus and its relationship to risk of arrhythmic events in patients with post-myocardial infarct left ventricular dysfunction*. Europace.* 2012;14:1771-7.

16. Nakagawa H, Yamanashi WS, Pitha JV, Arruda M, Wang X, Ohtomo K, et al. Comparison of In Vivo Tissue Temperature Profile and Lesion Geometry for Radiofrequency Ablation With a Saline-Irrigated Electrode Versus Temperature Control in a Canine Thigh Muscle Preparation*. Circulation.* 1995;91:2264.

17. Epstein AE, DiMarco JP, Ellenbogen KA, Estes NAM, Freedman RA, Gettes LS, et al. ACC/AHA/HRS 2008 Guidelines for Device-Based Therapy of Cardiac Rhythm Abnormalities: Executive Summary*. Circulation.* 2008;117:2820.

18. Wu Y, Li KL, Zheng J, Zhang CY, Liu XY, Cui ZM, et al. Remote magnetic navigation vs. Manual navigation for ablation of ventricular tachycardia: A meta-analysis*. Netherlands Heart Journal.* 2015;23:485-90.

19. Skoda J, Arya A, Garcia F, Gerstenfeld E, Marchlinski F, Hindricks G, et al. Catheter Ablation of Ischemic Ventricular Tachycardia with Remote Magnetic Navigation: STOP-VT Multicenter Trial. *Journal of Cardiovascular Electrophysiology.* 2016;27:S29-S37.

20. Dinov B, Schãnbauer R, Wojdyla-Hordynska A, Braunschweig F, Richter S, Altmann D, et al. Long-term efficacy of single procedure remote magnetic catheter navigation for ablation of ischemic ventricular tachycardia: A retrospective study. *Journal of Cardiovascular Electrophysiology.* 2012;23:499-505.

21. Di Biase L, Burkhardt DJ, Mohanty P. Scar homogeneization ablation in patients with ischemic cardiomyopathy: Comparison between remote magnetic ablation and manual ablation. *Circulation.* 2015;132.

Table 1. Patient characteristics

		Manual n=58	Remote magnetic navigation n=55	p value
Mean age +/- SD		54±22	57±16	0.766
Male gender (%)		41 (71%)	31 (56%)	0.113
VT type (%)	Idiopathic (No structural heart disease)	18 (31%)	20 (36%)	0.076
	Ischaemic cardiomyopathy	15 (26%)	22 (40%)	
	Non-ischaemic cardiomyopathy	25 (43%)	13 (24%)	
LV systolic function (%)	Normal	12/37 (32%)	13/35 (37%)	0.895
	Mild-moderately impaired	14/37 (38%)	13/35 (37%)	
	Severely impaired	11/37 (30%)	9/35 (26%)	
	Recent LV function assessment not available	21	20	
RV systolic function (%)	Normal	18/29 (62%)	16/30 (53%)	0.531
	Mild-moderately impaired	11/29 (38%)	13/30 (43%)	
	Severely impaired	0/29 (0%)	1/30 (4%)	
	Recent RV function assessment not available	29	25	
Biventricular impairment (%)		9/29 (31%)	13/30 (43%)	0.329
ICD at the time of procedure (%)		32 (55%)	32 (58%)	0.514

Table 2. VT ablation procedures

		Manual n=70	Remote magnetic navigation n=69	p value
Referral for VT ablation (%)	Elective adission	43 (65%)	42 (62%)	0.684
	Emergency admission	23 (35%)	26 (38%)	
First or redo procedure at WMH (%)	First procedure	58 (83%)	55 (80%)	0.634
	Redo procedure	12 (17%)	14 (20%)	
Approach used for catheter ablation (%)	LV endocardial via retrograde aortic	18 (26%)	7 (10%)	0.017*
	LV endocardial via transseptal	26 (37%)	27 (39%)	0.809
	RV endocardial approach	34 (49%)	36 (52%)	0.735
	Epicardial	6 (9%)	4 (6%)	0.745
	Other	3 (4%)	0 (0%)	0.496
	More than one approached used	14 (20%)	5 (7%)	0.029*
Procedure time in minutes mean±SD	No structural heart disease	231±95	375±110	<0.001*
	Ischaemic cardiomyopathy	345±87	425±117	0.018*
	Non-ischaemic cardiomyopathy	295±94	495±112	<0.001*
Ablation time in seconds mean±SD	No structural heart disease	868±862	2661±1491	<0.001*
	Ischaemic cardiomyopathy	2924±1849	4030±2143	0.1
	Non-ischaemic cardiomyopathy	1759±1791	3985±2306	0.001*
Average fluroscopy time ±SD (min)		38.8±24.08	32.45±24.24	0.059
Average fluroscopy time/average procedure time ±SD (min/hr)		7.8±3.6	4.2±3	<0.001*
Median number of VT morphologies (interquartile range)	No structural heart disease	1(1-1)	1(1-1)	
	Ischaemic cardiomyopathy	1(1-2)	2 (1-3)	
	Non-ischaemic cardiomyopathy	1 (1-2)	2 (1-5)	0.105
Number of cases with ≥3 morphologies (%)		5 (7%)	16 (24%)	0.009*
Acute procedural outcome (%)	Clinical VT non-inducible	42 (60%)	55 (80%)	0.011*
	Clinical VT more difficult to induce	10 (14%)	10 (15%)	1
	Clinical VT inducibility unchanged	8 (11%)	1 (1%)	0.033*
	Elimination of all inducible VT	29 (41%)	34 (49%)	0.353
	Procedural complication prevented assessment of success	4 (6%)	1 (1%)	0.681
	VT not inducible at baseline, success not assessable	6 (9%)	1 (1%)	0.116
Procedural complications (%)	Total	8 (11%)	9 (13%)	0.801
	Minor	2 (3%)	7 (10%)	
	Major	6 (9%)	2 (3%)	0.091

*Statistically significant on univariate analysis.

Table 3. Predictors of acute procedural outcomes

Acute procedural success (non-inducibility of clinical VT)

Univariate predictors with p<0.20	OR (95% CI)	p value	Multivariate predictors	Adjusted OR (95% CI)	Adjusted p value
Remote magnetic navigation	2.619 (1.229-5.583)	0.011	Remote magnetic navigation	2.750 (1.260-6.002)	0.011
Emergency admission	0.611 (0.288-1.229)	0.199			
Procedure ablation time (> median)	0.196 (0.034-1.129)	0.121			

Procedural complications

Univariate predictors with p<0.20	OR (95% CI)	p value	Multivariate predictors	Adjusted OR (95% CI)	Adjusted p value
Redo VT ablation	3.943 (1.402-11.086)	0.006	Redo VT ablation	5.451 (1.030-17.859)	0.026
Age >67 (3rd tertile)	5.559 (1.318-9.606)	0.009	Age >67 (3rd tertile)	4.524 (1.220-24.359)	0.048
RV impairment	4.556 (1.130-18.364)	0.023	RV impairment	4.289 (1.016-20.144)	0.045
LV impairment	3.078 (0.817-11.601)	0.085			
Biventricular impairment	4.000 (1.090-14.683)	0.051			
RV endocardial approach	0.313 (0.106-0.923)	0.029			
Epicardial approach	3.080 (0.722-13.133)	0.135			
Idiopathic VT	0.384 (0.106-1.396)	0.134			

Table 4. Univariate and Multivariate predictors of the primary endpoint in patients with ischaemic cardiomyopathy after single and multiple procedures

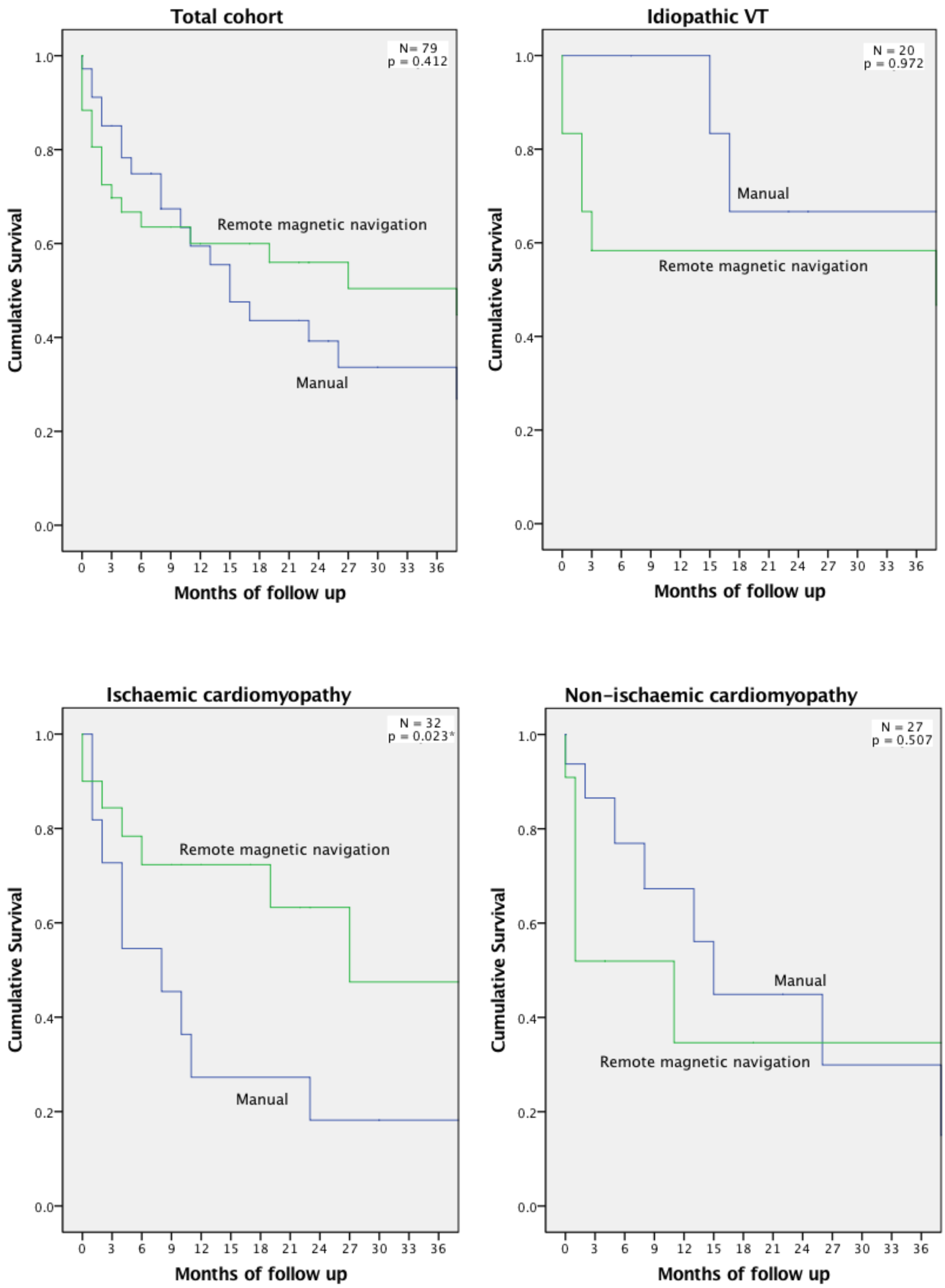
Hazard of reaching the primary endpoint after a single procedure

Univariate predictors with p<0.20	HR (95% CI)	p value	Multivariate predictors with p<0.05	Adjusted HR (95% CI)	Adjusted p value
Remote magnetic navigation	0.466 (0.179-1.212)	0.104	Remote magnetic navigation	0.240 (0.070-0.821)	0.023
Emergency admission	1.842 (0.702-4.832)	0.198	Emergency admission	3.782 (1.080-13.252)	0.038
Female gender	1.968 (0.689-5.624)	0.189			
Epicardial approach	5.619 (0.655-48.166)	0.070			
Retrograde aortic approach	2.034 (0.798-5.183)	0.122			
Multiple approaches	4.765(1.425-15.935)	0.005			

Hazard of reaching the primary endpoint after multiple procedures

Univariate predictors with p<0.20	HR (95% CI)	p value	Multivariate predictors with p<0.05	Adjusted HR (95% CI)	Adjusted p value
Remote magnetic navigation	0.170 (0.046-0.632)	0.002	Remote magnetic navigation	0.460 (0.227-0.934)	0.032
Female gender	2.505 (0.750-8.371)	0.111			
Last procedure ablation time > median	0.275 (0.056-1.344)	0.083			
Retrograde aortic approach	3.374 (1.121-10.156)	0.018			
Multiple approaches	2.918 (0.865-9.850)	0.065			

Figure 1. Single procedure freedom from VT leading to implanted defibrillator shock, re-hospitalization, or repeat catheter ablation and death of any cause



*adjusted p value, unadjusted p = 0.104 (Table 4)

Figure 2. Multi-procedure procedure freedom from VT leading to implanted defibrillator shock, re-hospitalization, or repeat catheter ablation and death of any cause

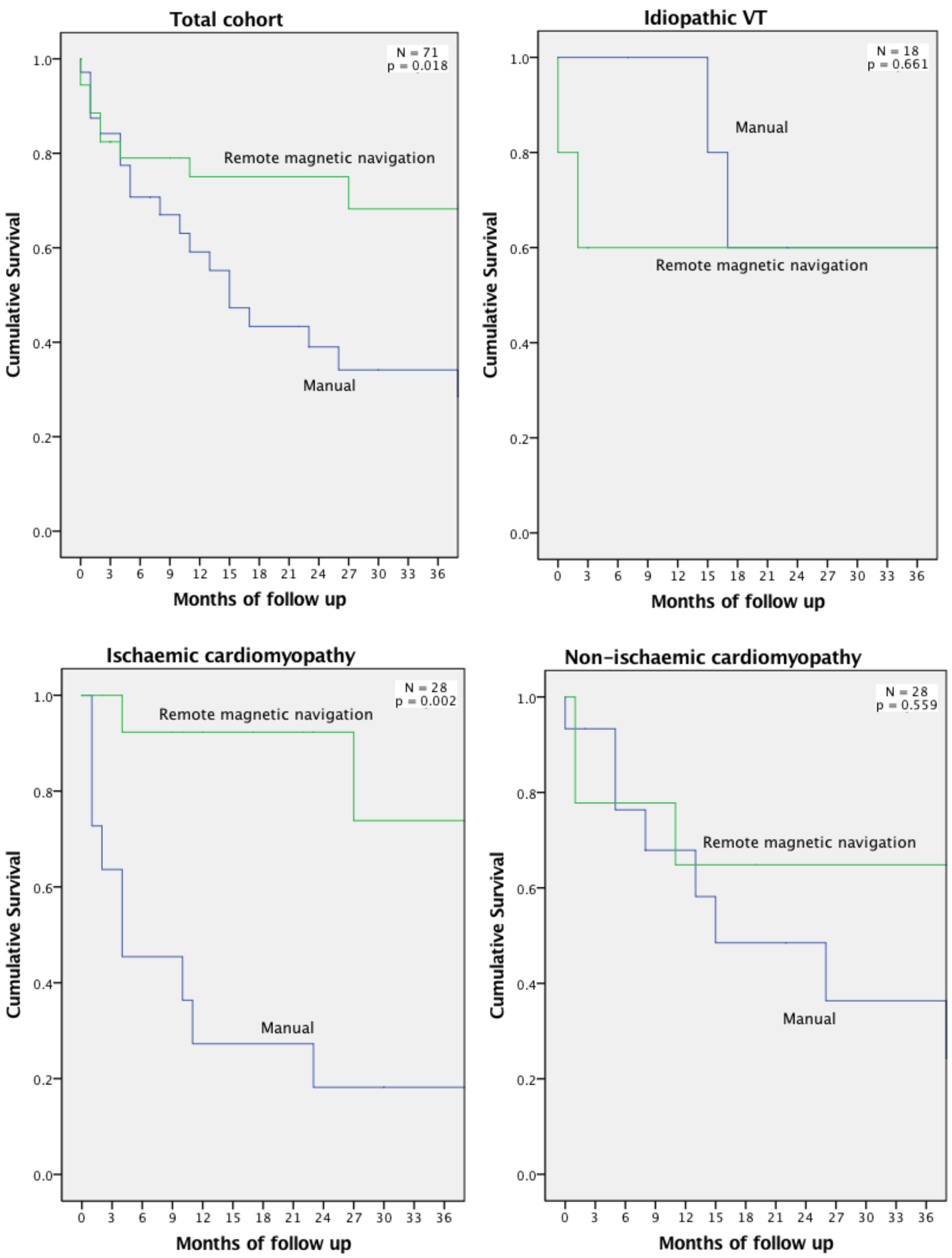


Figure 3. Multi-procedure freedom from recurrent VT in patients with structural heart disease and ICDs

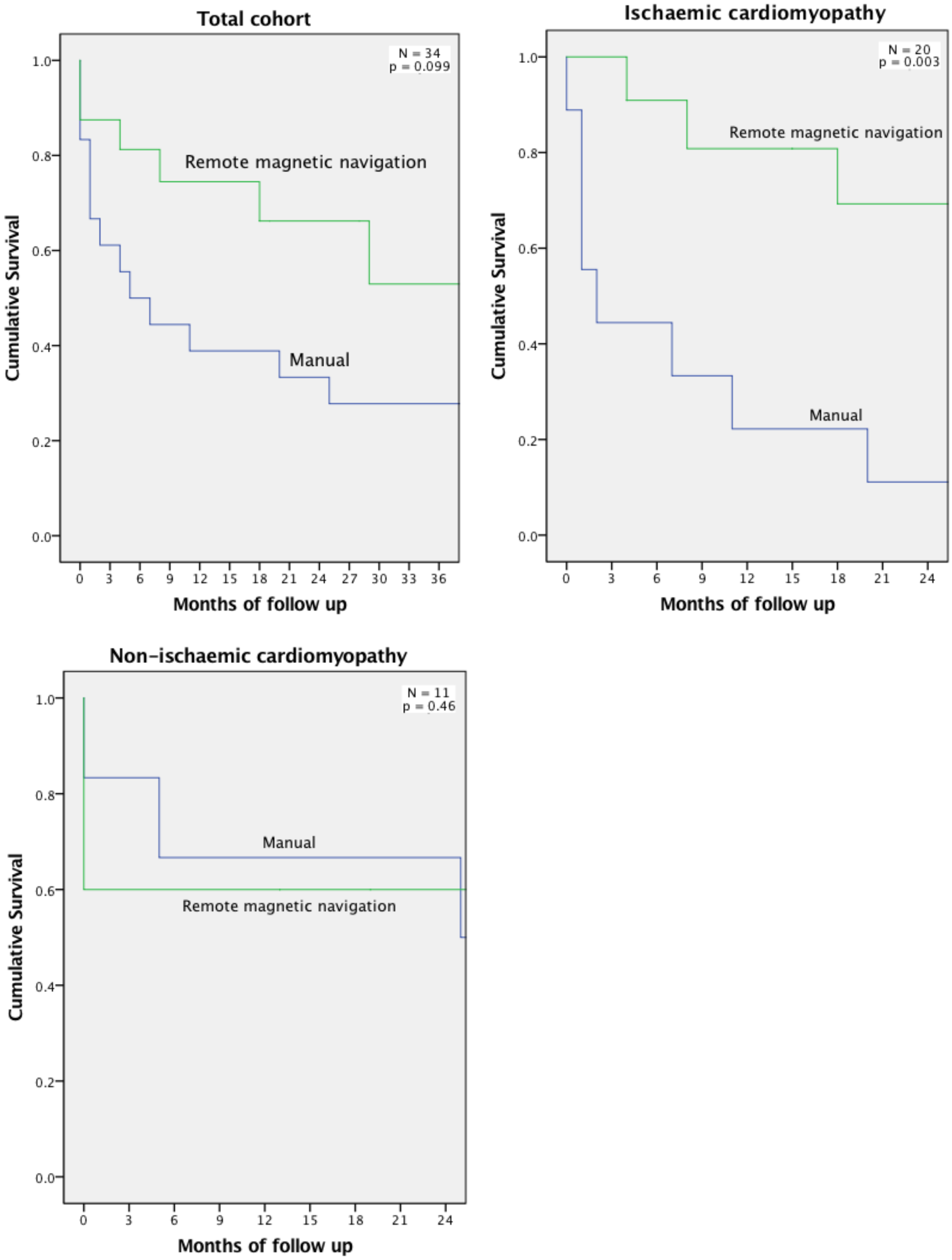


Figure 4. Single procedure freedom from death of any cause in patients with structural heart disease