Remote magnetic catheter navigation for cavotricuspid isthmus ablation
in patients with common-type atrial flutter

Vollmann: Remote magnetic isthmus ablation

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Abstract

Background: Conventional catheter ablation (CON) of cavotricuspid isthmus (CTI)–dependent atrial flutter (AFL) is a widely applied standard therapy. Remote magnetic catheter navigation (RMN) may provide benefits for different ablation procedures, but its efficacy for CTI-ablation has not been evaluated in a randomized controlled trial.

Methods and Results: Ninety patients undergoing de-novo ablation of AFL were randomly assigned to CON (n=45) or RMN-guided (n=45) CTI-ablation with an 8mm tip catheter. Complete bidirectional isthmus block was achieved in 84% (RMN) and 91% (CON) of the cases (p=.52). RMN was associated with shorter fluoroscopy time (median 10.6 min, inter-quartile range (IQR) 7.6-19.9 vs. 15.0 min, IQR 11.5-23.1, p=.043) but longer total radiofrequency application (17.1 min, IQR 8.6-25. vs. 7.5 min, IQR 3.6-10.9, p<.0001), ablation time (55 min, IQR 28-76 vs. 17 min, IQR 7-31, p<.0001) and procedure duration (114±35 vs. 77±24 min, p<.0001). Procedure duration in the RMN-group did not decrease significantly with case experience. Long-term procedure success, defined as achievement of complete CTI block and freedom from AFL recurrence during 6 months of follow-up, was lower in the RMN group (73% vs. 89%, p=.063). Right atrial angiography after ablation revealed no significant differences between groups in terms of right atrial diameter or CTI length, morphology and angulation. Furthermore, none of these parameters was predictive for difficult (ablation time >20min) or unsuccessful ablation.

Conclusions: RMN-guided CTI-ablation is associated with reduced radiation exposure but prolonged ablation and procedure times as compared to conventional catheter navigation. Our findings suggest that ablation lesions produced with an RMN-guided 8mm catheter are less effective, irrespective of CTI anatomy.

Key words: catheter ablation · atrial flutter · remote navigation
Introduction

Conventional radiofrequency ablation of cavotricuspid isthmus (CTI) - dependent (‘common-type’) atrial flutter (AFL) can be considered as a widely applied standard therapy with high success and low complication rates.\(^1\) It is well recognized, however, that varying anatomical properties of the CTI can complicate the procedure and may result in prolonged ablation and fluoroscopy times or even procedural failure despite the use of large (8mm) tip ablation catheters.\(^2,3\) Thus, efforts continue to improve the efficacy of this commonly applied procedure.\(^4,5\)

Recently, a magnetic catheter navigation system (Niobe II, Stereotaxis Inc., St. Louis, MO) for remote mapping and ablation of cardiac arrhythmias has been introduced.\(^6\) The use of this system may reduce radiation exposure and physical stress to the operator and could theoretically enhance the safety and efficacy of the procedure due to the unrestricted and more precise catheter movement. The feasibility of remote magnetic catheter navigation (RMN) for mapping and ablation of different types of supra-ventricular tachycardia (SVT) has been demonstrated in non-randomized studies.\(^7-9\) In a more recent investigation, RMN reduced fluoroscopic times and radiofrequency lesion deliveries for SVT as compared to conventional manual catheter navigation (CON).\(^10\) However, this study only included patients with SVT other than AFL, and thus the value of RMN for CTI ablation remains poorly defined.\(^9\)

The aim of the present randomized controlled trial was to evaluate the efficacy of the RMN-system for mapping and ablation of CTI-dependent AFL. Furthermore, we attempted to relate ablation outcome with anatomical properties of the right atrium (RA) and the CTI as determined by right atrial angiography.
Methods

The protocol of this single-center, randomized controlled study was approved by the Institutional Ethics Committee of the University Göttingen.

Patients were eligible for enrollment if $\geq 1$ episode of AFL had been documented on a 12 lead surface ECG and if the atrial rate and flutter waves were suggestive of CTI dependent (common-type) AFL. Prior right atrial ablation and presence of an implanted device at risk for magnetic interference (e.g., pacemaker, ICD) were exclusion criteria.

Eligible subjects were enrolled after written informed consent and were randomized in blocks of 10 patients to CON- or RMN-guided CTI-ablation. Enrollment started June 2007 and ended December 2008. Prospectively defined primary endpoints of this study were radiofrequency (RF) current application duration and fluoroscopy time. Pre-specified secondary study endpoints were ablation time (defined as the time from the first to the last ablation), procedure duration (defined as the time from venous puncture until sheath withdrawal), acute success (defined as achievement of complete bidirectional CTI block), long-term success (defined as acute success and freedom from AFL recurrence during 6 months of follow-up), and the frequency of procedure-related complications.

Electrophysiological testing and ablation procedure

The procedure was carried out during analgo-sedation with spontaneous respiration using intravenous fentanyl and midazolam under continuous monitoring of blood pressure and oxygen saturation. In patients with persistent AFL, sufficient anticoagulation for $>3$ weeks or a transesophageal echocardiogram that excluded left atrial thrombus were prerequisites for the procedure.
Two catheters were introduced via the femoral vein: A 6F steerable decapolar catheter (Polaris X, Boston Scientific, San Jose, CA) was positioned in the coronary sinus, and the ablation catheter was placed in the RA. In the CON group, a conventional 8mm tip ablation catheter (Celsius, Biosense-Webster, Diamond Bar, CA) was introduced through a long 8F sheath (SR0 or SAFL, St. Jude Medical, Minnetonka, MN) to enhance catheter stability. In the RMN group, a magnetic 8mm tip ablation catheter (Celsius Navistar RMT DS, Biosense-Webster, Diamond Bar, CA) was introduced through a short 8F sheath to allow unrestricted remote catheter navigation.

The RMN system has been described in detail elsewhere. Briefly, the magnetic ablation catheter incorporates 4 magnets in the distal portion of the catheter, while the system utilizes two large permanent magnets located on either side of the procedure table to generate a magnetic field (0.08Tesla) within the patient for directional catheter orientation. If the operator changes the desired vector for catheter orientation on a computer screen, the system automatically alters the magnetic field accordingly. A joystick-controlled motor drive (Cardiodrive, Stereotaxis) allows catheter advancement and retraction in 1mm steps and thereby complete remote catheter navigation for mapping and ablation.

Prior to ablation, entrainment maneuvers were conducted in patients with persisting AFL to confirm CTI-dependent re-entry. In case of sinus rhythm, ablation was performed during pacing from the proximal coronary sinus at a cycle length of 600ms. Catheter navigation was performed under fluoroscopic and electrocardiographic guidance. No three-dimensional mapping system was used in either group.

For CTI ablation, the ablation catheter was advanced through the tricuspid valve and then pulled back through the annulus at a 6 o'clock position in the left
anterior oblique view until a stable atrial signal became visible at the tip electrode electrogram. After each ablation application the catheter was withdrawn in a stepwise manner until the absence of a local atrial electrogram on the proximal electrode indicated that the catheter had reached the inferior vena cava (IVC). In the RMN-group, the magnetic field vector was usually oriented inferiorly and sometimes even slightly posteriorly in the anterior and in the middle part of the CTI to optimize electrode contact and stability, whereas in the posterior CTI (close to the IVC) the vector was usually oriented more anteriorly.

RF current was delivered in a temperature-controlled mode using a standard generator (Cordis-Stockert RF generator, Cordis-Webster, Miami, FL) with a target temperature of 60°C, a nominal power limit of 70W, and a maximum duration of 60s.

The end point of the ablation procedure was achievement of complete bidirectional CTI block persisting for a waiting period of 30 minutes. Assessment for CTI block was performed during pacing (cycle length 600ms) from the proximal coronary sinus or, after repositioning of the decapolar catheter, from the low lateral RA, and was based on point to point activation mapping a) along the entire ablation line and b) at the lateral right atrium and the atrial septum. CTI block was diagnosed if the interval between the split atrial components of the isthmus electrogram was ≥110ms or ≥90ms with ≤15ms variation along the line, and if a cranial-to-caudal activation sequence was documented at the lateral right atrium during proximal coronary sinus stimulation and at the atrial septum during pacing from the lower lateral right atrium.

If complete CTI block was not achieved with the first ablation drag the line was mapped for conducting gaps where local ablation was repeated. If conduction persisted thereafter, additional ablation lines were created just lateral and (if
conduction still persisted) medial to the initial 6 o’clock line. If CTI conduction still persisted the procedure was classified as ablation failure.

**Right atrial angiography**

RA angiography was acquired after ablation and prior to sheath removal by positioning a 5-F pigtail catheter in the IVC, just below the RA. Contrast solution (50 cm$^3$) was injected during 3-5s, and a 25° right anterior oblique (RAO) view of the RA was acquired and stored digitally. Inter-electrode spaces of the ablation catheter, which was positioned perpendicular to the RAO projection along the CTI, were used as a reference for later measurements. The latest atrial diastolic frame just prior to the opening of the tricuspid valve was utilized for all measurements. RA diameter was defined as the maximum distance between the lateral atrial wall and the tricuspid valve annulus. CTI length and morphology were determined and categorized as described earlier.$^{2,3,14}$ CTI length was categorized into short (≤32mm) or long (>32mm)$^{14}$ and CTI morphology was sub-divided into straight (CTI depth ≤2mm), concave, or presence of a pouch-like recess. CTI angulation was quantified as described by others,$^2$ measuring the angle between a line that connects the IVC and the lower hinge point of the tricuspid valve and a line parallel to the ablation catheter in the terminal IVC. A representative example for image analysis is given in Figure 1.

Angiogram analysis was performed by an independent operator that was blinded for ablation outcome.

**Follow-up**

All patients were monitored in the hospital overnight. Echocardiography was performed after the procedure to rule out pericardial effusion. On the next day, the venous puncture site was inspected for significant local hemorrhage, and a 12-lead surface ECG was acquired to confirm normal sinus rhythm and rule out new cardiac
conduction disturbances. Patients were then discharged and followed after 3 and 6 months. At each visit, subjects were asked for arrhythmia recurrences, ECG documentations, and current medication. An echocardiogram was acquired to assess left atrial diameter and left ventricular ejection fraction, and ambulatory holter monitoring was performed for 7 days at each follow-up to diagnose possible arrhythmia recurrences. Long-term ablation success was defined as achievement of CTI block and absence of AFL recurrence during follow-up.

**Statistical analysis**

Continuous variables are expressed as mean ± standard deviation or as median with inter-quartile range if appropriate. Normally distributed data were compared using the independent Student’s \( t \)-test. Otherwise, comparisons between groups were performed using the Mann-Whitney \( U \)-test. Categorical values are stated as absolute and relative frequencies and were compared using Fisher’s exact test. Time to AFL recurrence was estimated with the use of the Kaplan–Meier method and compared by the log-rank test. Estimates of treatment effect (e. g., differences between means) are presented along with the 95% confidence interval (CI) if applicable. Bonferroni correction was used to adjust alpha of the analysis of the two primary endpoints for multiple comparisons. All other parameters were described by exploratory data analysis. All tests are two-tailed. \( P<.05 \) is considered statistically significant.

We expected an average fluoroscopy time of 15±5 minutes and an average RF application duration of 600±100 seconds.\(^{15}\) Based on these assumptions we calculated that a sample size of 45 patients per group would detect a 20% difference in fluoroscopy time (3 minutes) and 10% difference in RF application duration (60 seconds) with at least 80% power and a 2-tailed alpha of 5%.
Results

One hundred patients were eligible; ninety-four subjects signed the written informed consent and were enrolled. Four patients were excluded after enrollment and randomization to CON (n=2) and RMN (n=2) because electrophysiological testing revealed atypical atrial flutter. Baseline characteristics of the remaining 90 patients (CON n=45, RMN n=45) are given in Table 1.

Acute ablation efficacy

The outcome of the primary study endpoints is illustrated in Figures 2 and 3. The procedural end point (complete bidirectional CTI block) was achieved in 41/45 patients (91%) in the CON group and in 38/45 cases (84%) in the RMN group (p=.52). Ablation details are summarized in Table 2. RF current application duration was significantly longer in the RMN group than in the CON group (see also Figure 2). Furthermore, RMN was associated with significantly more RF applications and longer ablation times (Table 2).

Termination of persisting AFL during ablation was observed in 40 patients 6±5min (CON, n=23) and 16±14min (RMN, n=17), respectively, after ablation start (difference between means 10 min, 95% CI 4 to 16, p=.0024), and following 5±4 (CON) and 9±6 (RMN) RF applications (difference between means 4, 95% CI 1 to 7, p=.012). After complete block was initially obtained, recurrent CTI conduction during the subsequent 30 minute waiting period occurred in 15% (CON) and 28% (RMN) of the cases (p=.18) after a median of 13 (7 to 26) min (CON) and 2 (1 to 20) min (RMN) (p=.21).

During ablation, char formation at the ablation electrode tip occurred in 91% of the cases in the RMN group as compared to 22% in the CON group (p<.0001).
Multiple (>1x) charring events were observed in 52% (RMN) and 10% (CON) of these cases, respectively.

In cases of ablation failure (inability to achieve complete bidirectional CTI block), an alternative ablation approach was attempted, with catheter selection at the discretion of the operator. In the RMN group, conventional manual ablation with an 8mm (n=4) or an open irrigated 4 mm (n=3) tip catheter was used as a second-line approach, and CTI block was achieved in all 7 cases. In the CON group, a manually guided irrigated 4 mm tip catheter was used as a secondary approach in all 4 unsuccessful cases, and CTI block was achieved in 3 of these patients.

Total procedure duration was significantly longer in the RMN as compared to the CON group (113.5±34.8 and 77.2±24.1 min; difference between means -36.3 min, 95% CI 23.7 to 48.9, p<.0001). Procedure duration in the RMN group did not decrease significantly with time (cases 1-22: 120.2±35.1min, cases 23-45: 107.2±34.0min, difference between means -13.0 min, 95% CI -7.8 to 33.8, p=.21). The difference in preparation time (duration from venous puncture to first ablation) between groups was small (CON: 18.7±6.1min, RMN: 21.6±7.1min, difference between means 2.9 min, 95% CI 0.1 to 5.7) but statistically significant (p=.048).

Fluoroscopy time (RMN: 10.6 (7.6 to 19.9) min, CON: 15.0 (11.5 to 23.1) min, Figure 3) and patient x-ray exposure (RMN: 3274 (2045 to 5025) μGy m², CON: 4304 (3435 to 5862) μGy m²) were significantly lower in the RMN than in the CON group (p=.043 and p=.032, respectively).
Follow-up

Patients were followed 1 day, 91±19 days and 189±35 days after the procedure. There was no difference in follow-up duration between groups. One patient (CON group) relocated after hospital discharge and was lost to follow-up. One patient in the CON group developed significant local hemorrhage after the ablation procedure. No other procedure-related complications were observed.

Recurrence of common-type AFL after initial achievement of CTI block occurred in 2% (CON group, 1/41) and 13% (RMN group, 5/38) of the cases (p=.073). A second procedure that confirmed recurrence of CTI-dependent AFL was conducted in 4 of these patients. As illustrated in Figure 4, the long-term success-rate of the initial ablation procedure (achievement of CTI block and no AFL recurrence during follow-up) was lower in the RMN (73%, 33/45) than in the CON (89%, 40/45) group (p=.063).

Use of anti-arrhythmic medication did not change significantly during follow-up. The proportion of patients with documented paroxysmal or persistent atrial fibrillation increased from 40% at baseline to 62% after 6 months. Five subjects underwent circumferential pulmonary vein isolation for symptomatic AF within this time period. Left atrial diameter was 47±7 mm and 47±6 mm and left ventricular ejection fraction 53±7% and 55±5% at 3 and 6 months, respectively.

Anatomical properties of the CTI

RA angiograms were obtained from 37 (82%) and 39 (87%) of the patients in the CON and RMN group, respectively. No angiogram was acquired in cases with a history of allergic reactions against contrast medium, significantly impaired renal function, or hyperthyroidism.
RA diameter, as determined by angiographic analysis, was 64±9mm in the total study population. Overall CTI length was 26±7mm, with 66 (87%) classified as short (≤32 mm) and 10 (13%) as long CTI. CTI morphology was straight in 10 (13%), concave in 23 (30%), and with a pouch-like recess in 43 (57%) cases. Mean pouch depth was 8±4mm. The average angle between CTI and VCI was 103±19°. No significant difference existed between the two treatment groups in terms of RA diameter or CTI length, morphology, and angulation.

Relationship between anatomical properties and ablation efficacy

Within each treatment group, angiographic parameters were compared between ablation procedures classified as easy (ablation time ≤20min) or difficult (ablation time >20min) and between procedures with or without long-term success.

As illustrated in Table 3, none of the anatomical parameters was significantly predictive for difficult or unsuccessful ablation. In the RMN group, there was a non-significant trend of RA diameter to be larger in ablation failures.

Discussion

The main finding of this prospective randomized study is that the use of RMN for CTI ablation (8-mm tip catheter) decreases fluoroscopy time but prolongs RF current application, ablation and procedure times as compared to the CON approach. While the acute success-rate (achievement of CTI block) is similar with both techniques, the use of RMN is associated with a lower rate of long-term success (defined by achievement of CTI block and freedom from AFL recurrence) as compared to a CON approach.

Conventional RF ablation of the CTI in patients with common-type AFL has emerged as a standard therapy with high success and low complication rates.¹
Nevertheless, recent advances in ablation technology aim to reduce x-ray exposure to patients and physicians while maintaining or improving patient safety, procedure times and ablation success-rates.

In the present study, the use of RMN was associated with a significant reduction in fluoroscopy time and x-ray exposure. This reduction, which becomes remarkable when considering the prolonged ablation times in the RMN group, was also noted in other studies of RMN-guided ablation.\textsuperscript{9,10,16} This uniform finding can be explained by the fact that the risk of cardiac perforation appears low when the flexible magnetic catheter in navigated within the cardiac chambers. The maximal force that is exerted by the magnetic vector to the tip is limited, which makes trauma to cardiovascular structures unlikely. Thus, large catheter movements can safely be made with minimal fluoroscopy. In contrast, the stiffness of the conventional ablation catheter mandates constant visualization of the catheter tip during manipulation.

Acute CTI block was achieved in our study in 91\% (CON) and 84\% (RMN) of the cases. Prior investigations that used conventional 8-mm or irrigated 4-mm ablation catheters demonstrated achievement of complete CTI block in ~90\% of the cases, varying from 80\% to 100\% between studies and with the type of ablation catheter.\textsuperscript{11,15} Thus, our acute success-rates are within the range reported in the current literature.

During follow-up, however, the rate of AFL recurrences in the RMN group (13\%) tended to be higher than in our control (CON) group (2\%) and possibly higher than the rate reported for conventional CTI ablation in prior reports (~10\%, ranging from 2-13\% with the mode and duration of follow-up \textsuperscript{11,15}). Limited data exist to date on the use of RMN for ablation of SVT,\textsuperscript{7-10,16-18} and, in particular, of common-type AFL.\textsuperscript{9} Of note, only one of these investigations was a randomized controlled trial.\textsuperscript{10} This study by Wood et al. compared RMN and conventional catheter navigation for
slow pathway, accessory pathway or AV junctional ablation. As in our study, the use of RMN was associated with reduced fluoroscopy time and similar acute success rates as compared to the conventional approach. Contrary to our findings, however, Wood and colleagues observed a lower number of RF lesions and comparable procedure times in the RMN group. Arya et al. recently reported their experience with RMN-guided CTI-ablation in 26 patients with common-type AFL. In this study, complete CTI-block was achieved with a magnetic 8 mm tip ablation catheter in 96% of the cases. The median ablation time was 25 (12 to 78) minutes, procedure duration was 53 (30-130) minutes and fluoroscopy time 7.2 (3.2 to 12.2) minutes. The comparability of these findings to our results, however, is limited by the fact that Arya et al. used a 3D mapping system (CARTO) which has been shown to impact procedural parameters. In recent preliminary reports from other groups, RMN-guided CTI-ablation with an 8 mm magnetic tip catheter resulted in complete CTI block in only 89% (8/9), 59% (10/17) and 54% (15/28) of the cases. Of note, these investigations also noted prolonged ablation and procedure times, a high incidence of char formation at tip the catheter tip and an elevated rate of AFL recurrences (12%) during follow-up.

The observation that RMN-guided CTI ablation requires more RF current application and results in lower overall success-rates suggests that lesions produced with an 8 mm magnetic catheter are less effective than those applied conventionally. Other studies evaluated RMN for slow pathway or accessory pathway ablation and found lesions produced with a 4 mm magnetic tip catheter equally or even more effective than with the conventional approach. In contrast, Di Biase et al. were unable to produce effective lesions with the same catheter and the RMN system in their study of circumferential pulmonary vein isolation. Thus, the ability to achieve effective ablation lesions with the RMN system appears to vary with the anatomical
region, the ablation electrode, and the type of desired lesion (focal versus linear, sub-
endocardial versus transmural).

Successful CTI ablation requires a continuous transmural linear lesion. Specific anatomical characteristics, such as a long or concave CTI, prominent pectinate muscles, existence of a sub-Eustachian pouch or presence of a rectangular orientation of the CTI with respect to the IVC may hamper the application of effective ablation lesions. In the present study, the distribution of these anatomical properties did not differ significantly between the 2 treatment groups. Furthermore, we were not able to relate specific anatomical characteristics to ablation outcome in either of the 2 groups, although the sample size may have been not sufficiently sized for this sub-analysis. Prior studies showed that use of an 8-mm tip catheter can overcome some of the ablation difficulties related to CTI morphology. It is well appreciated, however, that adequate lesion formation with large ablation electrodes requires a sufficient electrode to tissue surface area of contact. In consideration of the anatomical complexity of the CTI, significant force often has to be exerted to the catheter tip to embed the ablation electrode parallel oriented within the tissue and to thereby increase the area of contact for energy transfer. Earlier studies demonstrated that the maximal endocardial force that is exerted by the RMN-assisted magnetic catheter is generally lower than that applied by CON-controlled ablation catheters. Furthermore, 3 of the 4 magnetic components of the Navistar RMT DS 8mm ablation catheter are located proximal to the electrode ring, away from the tip. This distribution may further reduce the force exerted to the electrode tip if the catheter is advanced over a convex contour, as is the case when passing from the VCI onto the CTI.

In the present study we found that significantly more power was delivered during RMN- than during CON-guided ablation to reach comparable target temperatures. This finding suggests that a larger proportion of the magnetic catheter
electrode tip surface was exposed to the blood flow, resulting in enhanced electrode cooling and dissipation of ablation energy into the circulating blood pool. This also supports the hypothesis that a smaller area of electrode to tissue contact accounts for insufficient CTI ablation lesions in the RMN group.

To enhance tissue contact, a long sheath is routinely utilized for CTI ablation at our institution and was therefore used in the CON group of the present study. We limited the use of a long sheath to the CON group because its utilization in the RMN group would have significantly restricted the process of remote navigation. We cannot exclude that this discrepancy between the study groups influenced our results, although others demonstrated that CTI ablation with a conventional 8mm tip catheter is highly effective even without the use of a long sheath.3,14

Last, it appears notable that char formation at the ablation electrode tip was observed in 91% of the cases in the RMN group (as compared to 22% in the CON group). It remains speculative whether a reduced tip to tissue surface area of contact may underlie the high incidence of char formation in the RMN group. Of note, other investigators have also expressed concern about a higher incidence of char formation during RMN-guided ablation.16 Irrigated magnetic catheters have recently become available and may reduce the risk of char formation on the one hand but also increase lesion efficacy during RMN-guided ablation.20

**Conclusion**

RMN-guided CTI-ablation is associated with reduced radiation exposure but prolonged ablation and procedure times as compared to conventional catheter navigation. Furthermore, the use of the RMN-system resulted in a lower overall success rate (failure to achieve CTI block or AFL recurrence during follow-up).
Our findings suggest that ablation lesions produced with an RMN-guided 8mm catheter are less effective, irrespective of the CTI anatomy, and potentially related to a reduced tip to tissue surface area of contact.

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**Conflict of Interest Disclosures**

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L. L., J. S. and G. H.: None.
References


### Tables

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<tr>
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<th>CON (n=45)</th>
<th>RMN (n=45)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male gender</td>
<td>33 (73%)</td>
<td>36 (80%)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>68 ± 9</td>
<td>69 ± 8</td>
</tr>
<tr>
<td>Hypertension</td>
<td>35 (78%)</td>
<td>33 (73%)</td>
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<tr>
<td>Coronary artery disease</td>
<td>23 (51%)</td>
<td>18 (40%)</td>
</tr>
<tr>
<td>Valve disease</td>
<td>11 (24%)</td>
<td>8 (18%)</td>
</tr>
<tr>
<td>Other CV disease</td>
<td>4 (9%)</td>
<td>4 (9%)</td>
</tr>
<tr>
<td>‘lone’ atrial flutter</td>
<td>4 (9%)</td>
<td>7 (16%)</td>
</tr>
<tr>
<td>COPD</td>
<td>3 (7%)</td>
<td>5 (11%)</td>
</tr>
<tr>
<td>Left atrial diameter (mm)</td>
<td>46 ± 7</td>
<td>46 ± 6</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>52 ± 6</td>
<td>51 ± 10</td>
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<tr>
<td>Paroxysmal atrial flutter</td>
<td>12 (27%)</td>
<td>10 (22%)</td>
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<tr>
<td>Persistent atrial flutter</td>
<td>33 (73%)</td>
<td>35 (78%)</td>
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<tr>
<td>History of atrial fibrillation</td>
<td>17 (38%)</td>
<td>19 (42%)</td>
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<td>Treatment with AA drugs</td>
<td>9 (20%)</td>
<td>13 (29%)</td>
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<tr>
<td>Amiodarone</td>
<td>2 (4%)</td>
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<tr>
<td>Sotalol</td>
<td>3 (7%)</td>
<td>2 (4%)</td>
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<tr>
<td>Flecaainde</td>
<td>4 (9%)</td>
<td>5 (11%)</td>
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<tr>
<td>Betablocker</td>
<td>35 (78%)</td>
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<tr>
<td>Digitalis</td>
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<tr>
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<td>32 (71%)</td>
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<tr>
<td>Diuretic</td>
<td>22 (49%)</td>
<td>23 (51%)</td>
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<tr>
<td>Statin</td>
<td>21 (47%)</td>
<td>15 (33%)</td>
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</table>

**Table 1** Patient baseline characteristics

AA = anti-arrhythmic, ACEI = angiotensin converting enzyme inhibitor, AT = angiotensin blocker, CV = cardiovascular, COPD = chronic obstructive pulmonary disease, LVEF = left ventricular ejection fraction.
<table>
<thead>
<tr>
<th></th>
<th>CON</th>
<th>RMN</th>
<th>Difference between means (95% CI)</th>
<th>P</th>
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<tr>
<td>RF application duration (minutes)</td>
<td>7.5 (3.6 to 10.9)</td>
<td>17.1 (8.6 to 25.1)</td>
<td>-</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>No. of RF applications</td>
<td>9 (6 to 16)</td>
<td>22 (10 to 30)</td>
<td>-</td>
<td>&lt;.0001</td>
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<td>Ablation time (minutes)</td>
<td>17 (7 to 31)</td>
<td>55 (28 to 76)</td>
<td>-</td>
<td>&lt;.0001</td>
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<td>Applied energy (Watt)</td>
<td>54 ± 10</td>
<td>59 ± 11</td>
<td>4 (0 to 9)</td>
<td>.047</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>51 ± 4</td>
<td>50 ± 4</td>
<td>-1 (-2 to 1)</td>
<td>.38</td>
</tr>
<tr>
<td>Impedance (Ohm)</td>
<td>93 ± 15</td>
<td>92 ± 12</td>
<td>-2 (-7 to 4)</td>
<td>.58</td>
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</table>

**Table 2** Ablation data
Table 3  Within both treatment groups, comparison of anatomical properties of the right atrium (RA) and the cavotricuspid isthmus (CTI) revealed no significant difference between easy (ablation time ≤20 minutes) and difficult (ablation time >20 minutes) ablation and between procedures with or without long-term success (defined by achievement of complete CTI block and absence of AFL recurrence during follow-up). Δ means = difference between means.
Figure Legends

Figure 1 Right atrial (RA) angiogram (right anterior oblique projection) illustrating the anatomical parameters analyzed for the present study. Note that the ablation catheter was positioned perpendicular to the projection to serve as a scaling reference.

Figure 2 Radiofrequency (RF) ablation application duration (*primary endpoint*) was significantly longer in procedures utilizing remote magnetic navigation (RMN) as compared to the conventional approach (CON).

Figure 3 Reduction of fluoroscopy time (*primary endpoint*) by the use of remote magnetic navigation (RMN), despite longer ablation times in the RMN-group as compared to conventional catheter manipulation (CON).

Figure 4 Lower rate of long-term success (achievement of CTI block and freedom from AFL recurrence during follow-up) using RMN-guided versus CON ablation of the CTI with an 8mm tip catheter (*p*=.063).
RF application duration (minutes)

p < .0001

CON

RMN
Remote Magnetic Catheter Navigation for Cavotricuspid Isthmus Ablation in Patients with Common-Type Atrial Flutter
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