Novel aggregated multiposition noncontact mapping of atrial tachycardia in humans: From computational modeling to clinical validation

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BACKGROUND A novel aggregated multiposition noncontact mapping (AMP-NCM) algorithm is proposed to diagnose cardiac arrhythmias.

OBJECTIVE The purpose of this study was to computationally determine an accuracy threshold and to compare the accuracy and clinical utility of AMP-NCM to gold standard contact mapping.

METHODS In a cellular automata model, the number of catheter positions and chamber coverage were varied to establish accuracy requirements for clinically relevant AMP-NCM. This guided the clinical study protocol. In a prospective cohort of patients with atrial tachycardia (AT), noncontact mapping (NCM) recordings from a single position (SP) and multiple positions were compared to contact mapping with a high-density multipolar catheter using morphology and timing differences of reconstructed signals. Identification of AT mechanisms and ablation targets using both AMP-NCM and contact mapping were randomly evaluated by 5 blinded reviewers.

RESULTS AMP-NCM accuracy was asymptotic at 60 catheter positions in computational modeling. Twenty patients (age 65 ± 13 years; 19 male) with 26 ATs (5 focal, 21 reentrant) were studied. Morphologic correlation of signals derived from AMP-NCM was significantly better than those from SP-NCM compared to contact signals (median 0.93 vs 0.76; \( P < .001 \)). AMP-NCM generated maps more rapidly than contact mapping (3 ± 1 minutes vs 13 ± 6 minutes; \( P < .001 \)) and correctly diagnosed AT mechanisms in 25 of 26 maps (96%). Overall, 80% of arrhythmia mechanisms were correctly identified using AMP-NCM by blinded reviewers.

CONCLUSION Once 60 catheter positions were achieved, AMP-NCM successfully diagnosed mechanisms of AT and identified treatment sites equal to gold standard contact mapping in 3 minutes of procedural time.

KEYWORDS Ablation; Atrial tachycardia; Charge-density mapping; High-density mapping; Noncontact mapping; Slow conduction

Introduction

Atrial tachycardias (ATs) frequently arise after catheter ablation of atrial fibrillation (AF) but also can occur de novo in patients with complex scar substrates after previous cardiac surgery or atrioventricular conduction. Since the seminal description of localizing AT sites of origin via p-wave morphology, the advent of high-density 3-dimensional mapping systems has aided in the diagnosis, mechanistic understanding, and treatment of these arrhythmias. However, successful treatment of these rhythms still can be challenging, as accurate diagnosis of the mechanism and identification of treatment sites requires adequate chamber and cycle length electroanatomic mapping coverage. Although

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high-density multielectrode catheters have improved both the accuracy and the speed of 3-dimensional contact mapping, dependence on sequential data collection leaves it susceptible to tachycardia cycle length changes and/or catheter stability. Minor fluctuations often require restarting the mapping protocol, which significantly lengthens the procedure.

A noncontact charge-density mapping system (AcQMap, Acutus Medical, Carlsbad, CA) was recently shown to identify putative AF “drivers,” which are an effective target for ablation in clinical trials (Supplemental Figure 1). Although the principles of noncontact electrogram (EGM) acquisition also may be applicable in stable ATs, there is a concern about the potential diagnostic error due to signal attenuation over distance from single-position noncontact mapping (SP-NCM). Hence, a novel aggregated multiposition noncontact mapping (AMP-NCM) algorithm was developed to address this concern. The algorithm aligns noncontact data from multiple catheter positions in close proximity to the cardiac chamber wall to create more accurate activation maps, and promising results have been obtained in a small early clinical series.

We hypothesized that AMP-NCM would require a minimum number of positions to accurately map ATs but would perform similarly to contact systems clinically. Our study aimed to (1) use a computational model to test the threshold for accurate AMP-NCM map generation; (2) apply the AMP-NCM algorithm in a clinical series of AT patients to validate mechanisms and guiding ablation in comparison to high-density contact mapping.

Methods

Computational model of AMP-NCM

A cellular automata model was used to simulate focal AT (N = 10) and reentrant AT (N = 2) from the left atrium (LA). Focal AT was simulated as isotropic conduction with constant velocity initiating from a single point. The 10 initiation sites were the inferoposterior wall, posterior roof, midseptum, 4 pulmonary veins (PVs), aortomitral continuity, LA appendage, and roof of the LA. Macoreentrant flutter was simulated by slowing down conduction velocity around the mitral annulus. Localized reentry near the right superior PV was simulated by discrete slowing of conduction velocity adjacent to the right superior PV. These modulations replicated each of the common mechanistic substrates for clinical AT. We also simulated focal and macroreentrant right ATs (for details see the Supplemental Methods).

The number of catheter positions was varied from 1 to 187 positions (1, 10, 20, 40, 60, 80, 105, 125, 166, and 187 positions). The center point of the catheter was repositioned uniformly throughout the chamber and randomly sampled 20 times. Root mean square error (RMSE) of local activation times (LATs) from AMP-NCM was compared with the “actual” simulated LATs to assess the optimal number of catheter positions needed to achieve the best mapping accuracy. This was the minimum number whereby no significant further decrease of RMSE occurred with increasing number of positions.

We then simulated varying coverage of anatomic sampling throughout the atrial chamber to assess its impact on the accuracy of AMP-NCM. Starting with SP-NCM from the first simulations, the percent-of-chamber coverage was systematically varied. We used a distance cutoff of 10 mm between the anatomic mesh and closest electrode, as it reproduces local contact recordings with high accuracy. Noncontact mapping was applied to reconstruct charge density and estimate LAT on the atrial surface. The noncontact EGMs were forwardly computed on the anatomic surface from the reconstructed surface charge density and compared to the simulated surface voltages (“ground-truth” EGMs), using cross-correlation of morphology (CC) and time lag to the maximum cross-correlation (CC-Lag).

AMP-NCM

The details of charge-density mapping have been previously described. The AMP-NCM algorithm uses the same principles as a single catheter position. In contrast to noncontact recording of AF in which a static central catheter position is used, AMP-NCM roves the mapping catheter throughout the chamber during repetitive atrial rhythms, acquiring noncontact EGMs close to the chamber wall (Figure 1). Data collection is guided by visual feedback of surface illumination when the noncontact electrodes are within a distance of 10 mm. To avoid overlap between noncontact and contact signals, data from electrodes within 5 mm of the reconstructed anatomic surface were not included for inverse calculation of signals and maps. Thousands of measurements were aggregated from multiple beats and multiple catheter positions to reconstruct charge density on the endocardial surface. LAT of charge density is determined by considering both zero-crossing and maximum negative temporal derivatives. LATs are displayed as propagation activation history maps with user-defined time windows (Figure 1) (for details see the Supplemental Methods).

Prospective clinical study in human AT

Study population

Twenty consecutive patients referred with symptomatic drug-refractory AT for catheter ablation at the Royal Brompton Hospital were recruited. To ensure the integrity of the ATs compared during noncontact mapping and contact mapping, only those with constant cycle length and coronary sinus (CS) activation pattern were included. Exclusion criteria were patients with LA thrombus detected by transesophageal echocardiography, contraindication to anticoagulation, recent myocardial infarction, or unmappable AT during the procedure. Informed written consent was obtained from all patients before the procedure, and the study was approved by the national ethics committee (NHS Health Research Authority). The research reported here adhered to Consolidated Standards of Reporting Trial (CONSORT) guidelines.
Noncontact data acquisition and contact AT mapping

A standard decapolar catheter was placed in the CS, and a quadripolar catheter was placed in the inferior vena cava below the level of the diaphragm, with 1 electrode used as a unipolar electrical reference. This was closely monitored to ensure the same tachycardia persisted during the procedure. Access to the LA was gained via double transseptal puncture. Heparin was administered by intravenous bolus to maintain an activated clotting time $\geq 350$ seconds to prevent thrombus formation. All patients underwent single-position (catheter optimally positioned at the center of cardiac chamber of interest) and multiple-position noncontact acquisition of electrical activation with the AcQMap catheter (Acutus Medical). This was followed by high-density contact mapping using the HD Grid catheter (EnSite Precision, Abbott Laboratories, Minnesota, MN). The noncontact and contact data were processed offline using a MATLAB script to reconstruct location and propagation data. In both Precision mapping and AMP-NCM, geometric calculations were performed after removing inert structures such as the mitral valve and PV ostia.

For morphology and timing correlation between noncontact and contact EGMs, the HD Grid catheter was connected to the Acutus system and placed in a fixed location on the endocardium to directly record unipolar contact EGMs while the noncontact catheter was roved throughout the chamber. EGM morphology and LAT were compared between paired EGMs using morphology correlation (CC) and time-lag (CC-Lag) as previously described.$^5$

Figure 1  Workflow of aggregated multiposition noncontact mapping. Data Acquisition: Intracavity potentials were recorded by a noncontact catheter while roving inside the cardiac chamber. CS signals were recorded simultaneously as a reference. Reference Annotation and Segmentation: Activation timings were automatically annotated on CS signals. The timing reference channel was selected based on cycle length stability and amplitude. Window of interest was placed around the time reference (active time annotated on the reference channel) to concatenate all data into segments. Morphology Feature Recognition: Wavelet decomposition was applied to all CS channels to analyze wave morphologies across multiple scales. Two scales are provided as examples. Feature clustering algorithm was applied to cluster the segments. Beat Grouping: Segments were binned to groups and noncontact measurements were sorted into each group. Mapping: An individual map was created for each group. CS = coronary sinus; EGM = electrogram.
The accuracy of AMP-NCM in diagnosing the tachycardia mechanism and successful identification of the critical target ablation site were determined by programmed electrical stimulation maneuvers, such as entrainment, and termination of tachycardia during radiofrequency delivery at the target site (Figure 2). Surface electrocardiograms and bipolar intracardiac EGMs were continuously monitored using the LabSystem PRO recording system (Boston Scientific, Marlborough, MA). Signals were sampled at 1 kHz and filtered at 0.1 to 50 Hz for surface electrocardiograms and 30 to 250 Hz for intracardiac signals.

Catheter ablation
Catheter ablation was performed using an irrigated-tip radiofrequency ablation catheter (TactiCath, Abbott Medical, St. Paul, MN). Power delivery ranged from 30 to 50 W (depending on ablation site), and irrigation flow rate was 15–30 mL/min with target temperature <45°C. The endpoint was termination of AT. AT was reintroduced after termination, remapped, and reablated until AT was no longer inducible. If linear ablation lesions were necessary, bidirectional block across the lines was confirmed by activation mapping and differential pacing.

Interpreting AMP-NCM activation map by blinded reviewers
Activation maps derived from AMP-NCM and contact mapping were retrospectively assessed by 5 reviewers who were blinded to the ablation outcome. In total, 50 anonymized activation maps (25 AMP-NCM, 25 contact) in 2 views were superimposed on grids and the order randomized when shown to each reviewer who was not able to rotate the geometry and change windows of isochronal maps or the propagation playback speeds when reviewing the maps. Diagnostic score was assigned for the correct identification of the arrhythmia mechanism(s) (focal/macroreentrant) and anatomic location of the earliest activation/dependent isthmus (perimitral, roof-dependent, left PVs, right PVs, appendage/ligament of Marshall, posterior wall, anterior wall, cavotricuspid isthmus). Scores were compared within groups (intraobserver) and between groups (interobserver) to assess reproducibility and compared to the diagnosis reached in the case.

Figure 2  Electroanatomic and electrogram data for a perimitral atrial tachycardia post atrial fibrillation ablation in a 72-year-old man. A: Precision map showing earliest meets latest at mitral annulus, with HD Grid contact catheter spanning the area (left) and electrograms (right) spanning >75% of the tachycardia cycle length (290 ms). B: Corresponding aggregated multiposition noncontact map (AMP-NCM) from same patient showing same earliest meets latest activation wavefronts suggesting macroreentry around mitral annulus. C: Entrainment at 260 ms from ablation catheter at the location marked with the asterisk in A showed concealment with postpacing interval tachycardia cycle length (PPI-TCL) = 6 ms. D: First radiofrequency application in the same location terminated the tachycardia within 2.7 seconds. LIPV = left inferior pulmonary vein; MA = mitral annulus.
Figure 3  Summary of computational data for the 3 modeled mechanisms of atrial tachycardia. **A:** Example of focal activation, with accuracy condition reached within 10 catheter positions. **B:** Example of macroreentry with accuracy condition reached within 60 catheter positions. **C:** Example of localized reentry, with an optimum of 60 catheter positions. Note in **C** that increasing catheter positions does not lead to any further increase in accuracy of local activation time assignment (see text for details). RMSE = root mean square error.
Statistical analysis
Continuous and normally distributed data are given as mean ± SD, and non-normally distributed data are given as median (interquartile range [IQR]). Categorical data are reported as percentage. The computational model was statistically assessed using the unpaired Student t test, using significant differences in RMSE to determine when a threshold effect occurred. Comparison of contact and noncontact EGM was statistically assessed using the Mann-Whitney U test or Wilcoxon signed-rank test. Interobserver variability during blinded scoring was calculated using the Cohen kappa coefficient. P < .05 was considered significant. All statistical analysis was performed using SPSS Version 22.0 (SPSS, Chicago, IL).

Results
Computational modeling
Impact of number of NCM positions on LAT
The optimal threshold for the number of catheter positions that reach no further significant decrease in LAT RMSE was 60 positions for all 3 rhythms (focal reentry, macroreentry, and localized reentry). Examples of LATs generated by a different number of catheter positions and corresponding RMSE are shown in Figure 3. At the optimal minimum number of catheter positions, the mean and standard RMSE values for simulated LAT were 3.65, 12.60, and 9.94 ms for focal reentry, macroreentry, and localized reentry, respectively. Supplemental Figure 2 shows RMSE scatter graphs as a function of the number of catheter positions divided by AT mechanism.

Impact of chamber coverage on LAT
The percentage of chamber endocardial surface coverage with electrodes within 10 mm increased from 2% (single position), 56% (10 positions), 73% (20 positions) to >80% (40, 60, 80, 105, 125, 166, and 187 positions) (Supplemental Figure 3). Supplemental Figure 4 shows the plots of RMSE as a function of surface coverage, which showed that when surface coverage was >80%, RMSE has less variance and lower RMSE values, with results split among the 3 AT mechanisms.

Impact of number of NCM positions on EGM morphology simulations showed increasing CC and CC-Lag accuracy as the number of catheter positions increased (P < .001). At 60 catheter positions, median CC was >0.9 and median CC-Lag was <1.0 ms, also confirming 60 positions as a threshold for high accuracy of AMP-NCM signal recording (Supplemental Figure 5). Right atrial simulation data are shown in Supplemental Figures 6 and 7.

Clinical validation study
The modeling data suggested that the AMP-NCM algorithm required continuous roving of the noncontact mapping catheter for 1–3 minutes to obtain 60 separate catheter positions and ~80% chamber coverage to achieve the best mapping accuracy. This was adopted as the basis of the noncontact mapping protocol during the clinical study.

Patient characteristics
Twenty patients (age 65 ± 12 years; 19 male) with 26 ATs were studied. Baseline clinical characteristics are given in Table 1.

Clinical study
EGM morphology comparisons
All patients had SP-NCM and AMP-NCM data acquired using the noncontact mapping catheter before HD Grid contact mapping. Maximum CC and CC-Lag values of 19,292 paired noncontact and contact EGMs were analyzed for 26 AMP-NCM maps (10 LA, 7 right atrium, 7 biatrial, 2 with two separate ATs). Figure 4 shows the comparison of AMP-NCM and contact propagation maps between an LA macroreentrant tachycardia and a left focal AT.

The noncontact EGMs from AMP-NCM showed significantly better morphology correlation to contact EGMs than those from SP-NCM (median CC 0.93 vs 0.76; P < .001). AMP-NCM showed a significantly smaller CC-Lag of noncontact EGMs (median CC-Lag 1.28 ms; 90% confidence interval [CI] 1.28–1.28 ms) than SP-NCM (median CC-Lag 4.80 ms; 90% CI 4.80–5.12 ms) (P < .001) compared to contact EGM. Similarly, for HD Grid contact EGMs (n = 4135), median maximum CC values (0.880; 90% CI 0.876–0.884) and median CC-Lag value (5.12; 90% CI 4.8–5.4 ms) were significantly better than median CC values (0.735; 90% CI 0.727–0.742) and median CC-Lag value (7.68; 90% CI 7.04–8.32 ms) of SP-NCM noncontact EGMs (P < .001). Overall, the results showed

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Baseline patient clinical characteristics (N = 20)</th>
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<tbody>
<tr>
<td>Age (y)</td>
<td>65 ± 12</td>
</tr>
<tr>
<td>Male</td>
<td>19 (95)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>9 (45)</td>
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<tr>
<td>Diabetes mellitus</td>
<td>3 (15)</td>
</tr>
<tr>
<td>Cerebrovascular accident</td>
<td>2 (10)</td>
</tr>
<tr>
<td>Structural heart disease</td>
<td>7 (35)</td>
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<tr>
<td>Heart failure (NYHA functional class ≥2)</td>
<td>7 (35)</td>
</tr>
<tr>
<td>Previous failed DCCV</td>
<td>12 (60)</td>
</tr>
<tr>
<td>Antiarrhythmic drugs attempted (per patient)</td>
<td>1.3 ± 1</td>
</tr>
<tr>
<td>Previous AF ablation</td>
<td>12 (60)</td>
</tr>
<tr>
<td>Previous AT ablation</td>
<td>12 (60)</td>
</tr>
<tr>
<td>Previous linear ablation in LA</td>
<td>12 (60)</td>
</tr>
<tr>
<td>Previous cardiac surgery</td>
<td>7 (35)</td>
</tr>
<tr>
<td>Mean BMI (kg/m²)</td>
<td>27 ± 11</td>
</tr>
<tr>
<td>LA diameter (mm)</td>
<td>44 ± 3</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>51 ± 13</td>
</tr>
<tr>
<td>AT CL (ms)</td>
<td>313 ± 91</td>
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</tbody>
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Values are given as mean ± SD or n (%). AF = atrial fibrillation; AT = atrial tachycardia; BMI = body mass index; CL = cycle length; DCCV = direct current cardioversion; LA = left atrium; LVEF = left ventricular ejection fraction; NYHA = New York Heart Association.
excellent correlation between AMP-NCM and contact HD Grid EGMs (Figure 5). Examples of contact and noncontact EGMs pairs with different cross-correlation are shown in Supplemental Figure 8.

Arrhythmia diagnosis and target ablation site identification

Noncontact mapping was performed before contact mapping. Mean time to complete electroanatomic mapping of each AT was 3 ± 1 minutes using AMP-NCM noncontact mapping.
Interpreting AMP-NCM activation map by blinded reviewers
Five reviewers blinded to the ablation outcomes assessed both sets of noncontact and contact maps from the 20-patient series. Overall, 80% of arrhythmia mechanisms were correctly identified using AMP-NCM compared to 100% for the contact maps (P = .01). In 100% of AMP-NCM and contact maps, at least 3 reviewers were concordant with the correct mechanism (P = NS).

The reviewers correctly identified the site of AT termination in 76% of cases from the AMP-NCM activation maps and 78% cases from the contact maps (P = NS). In terms of interobserver concordance, at least 3 reviewers agreed on the same mechanism in 91% of AMP-NCM maps and 87% of contact maps (P = NS). Diagnostic accuracy categorized by termination site and tachycardia mechanism is given in Supplemental Table 2. Interobserver agreement was highest for cavotricuspid isthmus-dependent AT (Fleiss kappa 0.76 for AMP-NCM and 0.74 for contact), followed by roof-dependent AT (Fleiss kappa 0.62 for AMP-NCM and 0.76 for contact).

Discussion
Main findings
This is the first study to systematically compare features of both SP-NCM and AMP-NCM methods for contact mapping using a prospective combined computational and clinical approach. Our main findings are as follows. (1) A minimum of 60 catheter positions and ~80% mapping chamber coverage are required in computational studies for AMP-NCM, which are easily achievable within 3 minutes of catheter roving. (2) AMP-NCM improves on the accuracy of SP-NCM signal recordings. (3) AMP-NCM has similar accuracy and signal characteristics to high-density contact mapping. (4) AMP-NCM can successfully guide AT ablation, and successful sites of AT termination are reproducible when scored by blinded reviewers.

SP-NCM vs AMP-NCM
AMP-NCM overcomes the signal attenuation with increasing distance from the atrial wall, which affects SP-NCM. Previous studies have found signal morphology to be inaccurate, and we recently showed that 40 mm (from the center of the NCM catheter to the chamber wall) represents an accuracy threshold for SP-NCM in both sinus rhythm and AF. In that study, >80% of EGMs fell within the 40-mm radius; however, the remaining 20% would still have an impact on mapping results in complex substrates. By roving the noncontact catheter throughout the atrium, the maximum distance from the catheter to the atrial wall is dynamically decreased. Our results demonstrate the AMP-NCM method is superior to SP-NCM and comparable to high-density contact mapping in stable coherent rhythms, in which significant changes in mechanisms would not be expected during catheter roving. It represents an adjunctive approach between contact and noncontact methodologies.

Accuracy as a function of AMP-NCM catheter positions
Our computational results confirmed our hypothesis that diagnostic accuracy is improved by acquiring data from multiple catheter positions. However, if mapping started near a critical isthmus, initial positions may yield sufficient data to reduce this “threshold value.” This is akin to starting off a study at the site of the longest signal deflection or border zone area on voltage, suggestive of a potential critical isthmus. The 60 positions required for optimal accuracy using AMP-NCM is easily obtainable within the 3-minute roving protocol and will be further reduced by transitioning from research to clinical workflows.

Contact vs noncontact EGM morphology
The study data are consistent with our recent series of AF and sinus rhythm EGM pairings. The fidelity of AMP-NCM signals was significantly superior to that of SP-NCM, and the maximum CC-Lag of over 5 ms allows stable maps to be generated. The SP-NCM data in our study improves on previous similar technologies, suggesting intrinsic catheter performance also contributed to achieving equivalence with contact EGMs from a high-density catheter. Variabilities in electrode type and size of any 2 catheters, such as HD Grid and AcQMap, will always lead to slightly different signal morphology, which could explain the CC difference between contact and noncontact EGMs in our study, but these did not have any clinical impact.

Mapping performance of AMP-NCM vs contact maps
Overall, AMP-NCM matched contact mapping in diagnostic accuracy and clinical utility, and required significantly less time. The clinical cases were guided by the contact system, but the AMP-NCM data agreed with the final choice of mechanism and ablation target. Five blinded reviewers with varying clinical experience found the AMP-NCM data to be clinically comparable to contact mapping data and agreed...
with the clinical case in an equal number of cases when using contact and AMP-NCM maps. The ablation strategy they chose was similar in both paired maps, targeting critical isthmuses that resulted in termination during the procedures. These data suggest that AMP-NCM could be used alone for mapping and ablation of stable ATs. As with any new technology, interpretation of AMP-NCM maps will improve with experience.

Anatomic considerations between AMP-NCM and contact mapping
Our data reveal subtle differences between AMP-NCM and contact mapping. One area is in resolving focal mechanisms, which may reflect lower amplitude of focal origins on AMP-NCM maps, together with small artifacts that may precede the “qs” signal. These may result in annotation errors of the earliest site.\(^1\)\(^3\) The 100% accuracy of AMP-NCM in roof-dependent, cavotrnicuspid isthmus and posterior wall macroreentry suggests high capability for detecting large planar propagating wavefronts that typically occur through these regions. In regions with greater potential for low-amplitude or far-field components to cause reduced signal accuracy, such as peri-PV reentry, scar-related, or partial epicardial circuits (ligament of Marshall), contact mapping still resolves these more accurately than AMP-NCM. Areas that physically limit roving of the catheter (eg, PV carina, coumadin ridge, CS) also remain an issue.

Study limitations
These data are from a small, single-center series and need validation in a randomized multicenter setting. Nonuniform anisotropic conduction or fixed confluent scar barriers were not incorporated in the simulation study, and only localized slowing to create the heterogeneous conditions for reentry was required in the cellular automata model used. A preoperative computed tomographic map was not performed as a standard for noncontact and contact mapping geometric comparison. Although the noncontact system displays all catheters, using contact force requires a separate system and may limit the applicability of these findings until contact force ablation data can be displayed on the noncontact system. Truly simultaneous EGM comparisons were not possible, as maps were made sequentially; however, by choosing to use stable AT patients, these effects were minimized.

Clinical perspectives
A new noncontact mapping method that can integrate data sampled from multiple positions within the chamber (≥60 positions) is comparable to gold standard contact mapping for complex AT diagnosis and ablative therapy guidance. This technique may improve the speed of mapping in patients who present with both de novo and postablation arrhythmias, without compromising accuracy.

Conclusion
Our computational clinical study demonstrates that AMP-NCM can rapidly acquire noncontact data in stable rhythms, with at least 60 catheter positions required for optimal accuracy. In clinical practice, AMP-NCM acquired better signals than SP-NCM, achieving more rapid diagnosis and identification of critical ablation sites corresponding to AT termination.

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Appendix
Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrthm.2021.09.025.

References