# Validation of Non-Invasive Electrophysiological Mapping Accuracy Using Endocardial Pacing With Three-Dimensional Non-Fluoroscopic Electroanatomical Mapping

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## Abstract

*Preoperative non-invasive diagnosis of ventricular arrhythmias allows to predict ablation effectiveness, reduces the operation and radiation exposure time. Previous studies based on comparison of the early activation zone with the anatomic location of the pacemaker's tip showed high accuracy of noninvasive mapping in cardiac regions of pacemaker implantation. However, understanding of ECG imaging precision in other anatomical areas is still limited. To determine the accuracy of non-invasive mapping and examine the reconstructed excitation patterns, endocardial ventricular pacing of different myocardium areas was conducted in combination with 3D Non-Fluoroscopic Electroanatomic Mapping. Results of invasive and non-invasive mappings were analyzed and qualitative comparison of pacing point locations was performed. Better results were obtained for free walls of ventricles and worse for septum, apical parts and outflow tracts.*

## 1. Introduction

Preoperative non-invasive electrophysiological topical diagnostics of ventricular arrhythmias (VA) allows to predict the effectiveness of ablation, reduces the operation time and radiation exposure time. In the previous studies [1-4], comparison of the early activation zone (EAZ) with the anatomic location of the pacemaker's tip showed a high accuracy of non-invasive mapping in the areas of pacemaker implantation.

Nevertheless, the ECG imaging accuracy of localizing ectopic sources coming from other anatomical areas is still unclear. Such a validation task is challenging due to its intrinsic difficulty and long time duration. In some cases, it can be difficult to access cardiac walls, in others – to achieve a stable position of the pacing catheter. Furthermore, high arrhythmogenicity of the ventricles can lead to life-threatening rhythm disorders. Pacing verification of different parts of ventricles can clarify the accuracy of non-invasive mapping and improve the topical diagnostic of VA.

## 2. Aim

To determine the non-invasive mapping accuracy and examine the excitation propagation resulted from endocardial ventricular pacing of different areas of myocardium with Three-Dimensional Non-Fluoroscopic Electroanatomic Mapping.

## 3. Methods

The study was performed in University Medical Centre Mannheim (Mannheim, Germany) and was approved by the local ethic committee.

A 27 years old male with ventricular tachycardia (VT) and indications for ablation has undergone non-invasive electrophysiological mapping before and during operation. Cardiac magnetic resonance imaging (MRI) was performed to reconstruct anatomical models of heart and torso. Unipolar surface electrograms were recorded at 216 ECG channels with non-invasive mapping system ("Amycard 01C" EP Solutions SA, Switzerland). Carto LAT (Biosense Webster, Inc., US) mapping for the left and right ventricles (LV and RV, respectively) was also conducted. During operation, 27 points of the ventricular endocardial surfaces (11 in the RV and 16 in the LV) were paced according to the standard scheme of anatomical segments. For this purpose, Carto ThermoCool SmartTouch catheter (Biosense Webster, Inc., US) was used. For each pacing point, the coordinates were determined and marked in the Carto 3 system. For the inverse reconstructions, two heart models were created for each patient: an epicardial polygonal model enclosing both ventricular cavities (epicardial project), and an epi-endocardial model taking the heart cavities into account (endocardial project). Epi- and endocardial isopotential

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and activation maps were created. The EAZ were determined for epicardial surfaces of the epi- and endocardial projects and for endocardial surfaces of the endocardial projects by visual analysis based on the following criteria: the appearance of an EAZ at the time of the first negative deflection of the electrogram, a typical QS form of electrogram, an eccentric spread of excitation from the ectopic focus.

Afterwards, results of invasive and non-invasive mappings were analyzed, and qualitative comparison of pacing points' localization was performed. The EAZ localization in the same anatomical segment was the criterion of matching for the invasive and non-invasive maps.

## 4. Results

The EAZ was located with sufficient accuracy. Maps were not completely identical but main activation patters were similar (Table 1, Table 2).

Table 1. EAZ matching of pacing points in RV obtained by invasive and non-invasive method

| Pacing site (anatomical segment) | EAZ matching for invasive and non-invasive maps | |
|---|---|---|
| | Epicardial project | Endocardial project |
| RVOT septal | yes | yes |
| RVOT lateral | no | no |
| RVOT anterior | yes | yes |
| RV apex | yes | yes |
| RV anterior | yes | yes |
| RV inferior | yes | yes |
| RV septal-basal | no | no |
| RV septal-middle | no | yes* |
| RV lateral-basal | yes | yes |
| RV His | no | no |
| RV lateral-middle | no | no |
| Total number of matches in the RV | 55%(6/11) | 64%(7/11) |

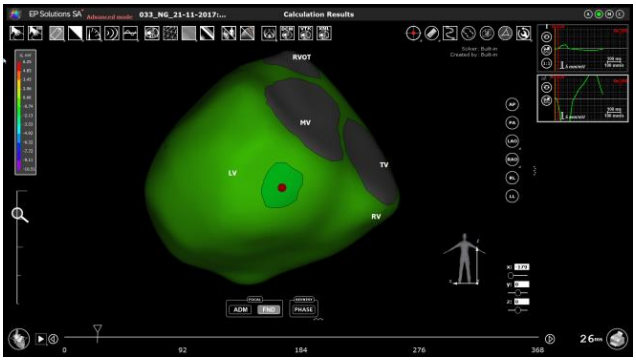
*Matching after RV removing

Table 2. EAZ matching of pacing points in LV obtained by invasive and non-invasive method

| Pacing site (anatomical segment) | EAZ matching for invasive and non-invasive maps | |
|---|---|---|
| | Epicardial project | Endocardial project |
| LV apex | no | no |
| LV anterior-middle | yes | yes |
| LV anterior-apical | no | no |
| LV anterior-basal | yes** | yes** |
| LV inferior-basal | yes | yes |
| LV inferior-apical | yes | yes |
| LV septal-basal | yes | no |
| LV lateral-basal | yes | yes |
| LV lateral-middle | yes | yes |
| LV lateral-apical | no | no |
| LV septal-apical | no | no |
| LV septal-middle | yes* | yes* |
| Left aortic cusp | no | no |
| Right aortic cusp | yes | no |
| LV His | yes | no |
| LV inferior-lateral | yes | yes |
| Total number of matches in the LV | 69%(11/16) | 50%(8/16) |

*Matching after RV removing
**Matching after RVOT removing

For the epicardial project and RV pacings, a good match between paced and reconstructed areas was obtained for septal and anterior parts of the right ventricular outflow tract (RVOT), anterior, inferior, lateral-basal walls of the RV, and the RV apex. In the LV epicardial project, a good qualitative agreement was found for anterior-middle, inferior-apical, inferior-basal, inferior-lateral, septal-basal, lateral-basal, lateral-mid walls, right aortic cusp, and LV His system. In Figures 1, 2, 3, we show some exemplary non-invasively generated isopotential maps for distinct pacing locations.




A

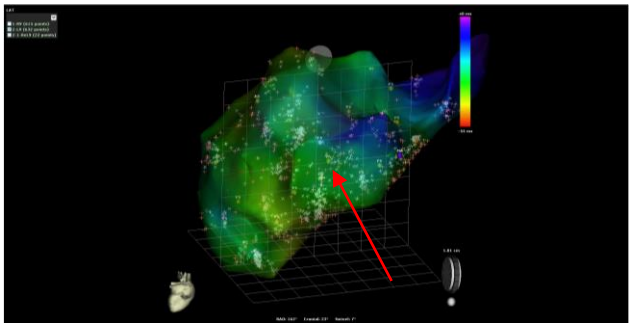


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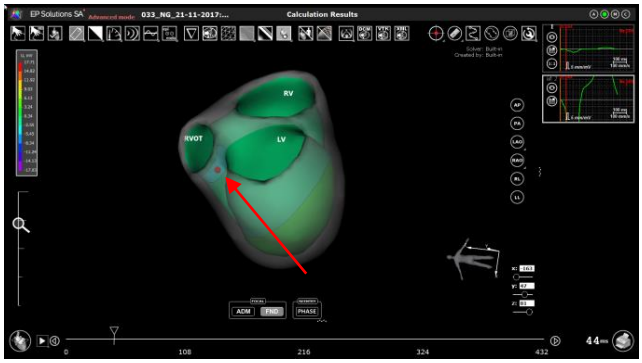
Figure 1. A. Epicardial project. Isopotential map of the LV inferior-basal pacing point. B. Carto polygon model. The arrow indicates the pacing point of inferior-basal segment of the LV.

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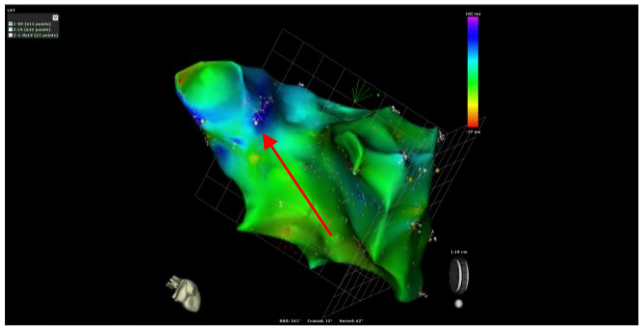

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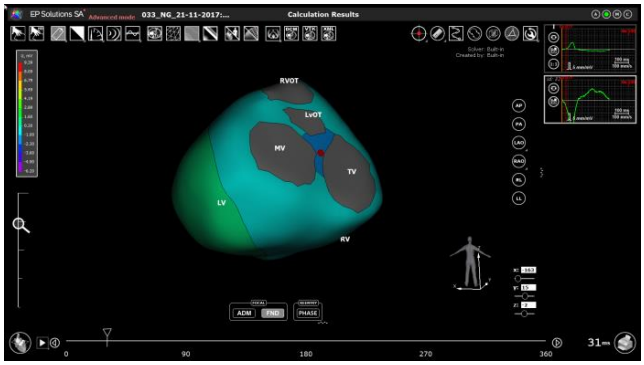
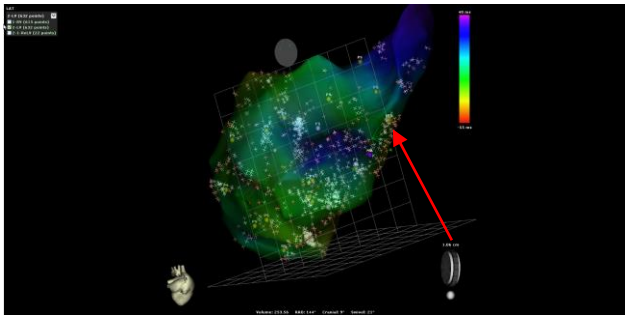
Figure 2. A. Isopotential map of the RVOT septal pacing point indicated by arrow on the endocardial surface. B. Carto polygon model of the RV. The arrow indicates the stimulation point.




A



B

Figure 3. His system pacing point from the LV. A. Epicardial project. Non-invasive isopotential map with red point in the interseptum corresponding to the stimulus location. B. Carto polygon model of the LV. The arrow indicates the excitation onset.

Lower accuracy results were obtained for the septal ventricular regions (basal, middle parts of the RV and apical part of septum of the LV). It might have been caused by the absence of septum within the epicardial project. To give an example, the septal-middle pacing resulted in a hardly defined excitation area for the "full" epicardial project. After the RV removing, however, we could clearly see the EAZ in the middle of LV septum, though the electrogram at this point was atypical and had a RBBB form (Figure 4).

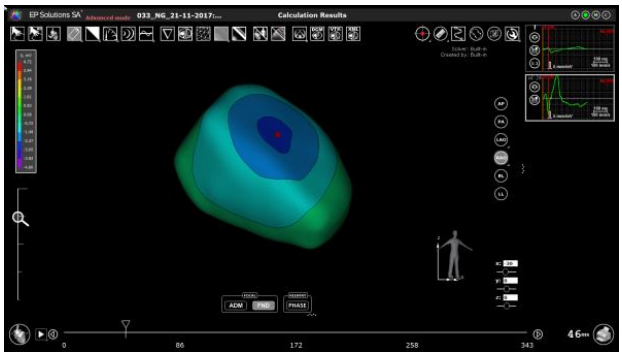


Figure 4. Epicardial project. Isopotential map of LV septal-middle point after RV removing.

Furthermore, there was no complete match for the apical LV regions (LV apex - LV anterior-apical, LV lateral-apical). The corresponding non-invasively obtained areas were side -shifted by approximately one anatomical segment. Some other pacing points resulted in shifted solution too, but were closer to the real pacing catheter positions. For the left aortic cusp, the EAZ was in right aortic cusp region. The RVOT lateral pacing point was "moved" to the septal part of the RVOT. The RV lateral-middle pacing point was shown in the lateral part of the RVOT. The pacing of the His system from the RV side resulted in the EAZ in the RVOT septal part.

For the endocardial project, a good match between paced and reconstructed areas was obtained for anterior and septal RVOT walls, anterior, inferior, lateral-basal walls of the RV, and RV apex. Concerning the LV pacings, a good agreement was found for the following areas: anterior-middle, inferior-apical, inferior-basal, lateral-basal, lateral-middle, inferior-lateral walls.

Same as for the epicardial project, lower results were obtained in septal regions (septal-basal and septal-middle of the RV, septal-basal, septal-middle septal-apical segments of the LV), RV lateral middle, RVOT lateral walls and pacing of His system from right side. Similar to the previously shown example, some results were improved removing the RV from the anatomical model used for inverse calculations. For instance, after RV removal the RV septal-middle pacing point's EAZ

matched very well with the invasive measurements, with the respective non-invasively imaged electrogram being typical. Furthermore, there was also little correspondence for the apical LV regions (anterior-apical, lateral-apical walls, apex), left ventricular outflow tract (LVOT) (left and right aortic cusp), pacing of His system. Some pacing points resulted in isochronal maps difficult for visual inspection. For example, for a LV anterior-basal pacing point on the epicardial and endocardial projects, the EAZ was detected on the RVOT anterior wall, but the RVOT slightly covered the LV anterior wall. After removing the tract, the EAZ area was clearly visible on the LV anterior-basal wall (Figure 5,6).

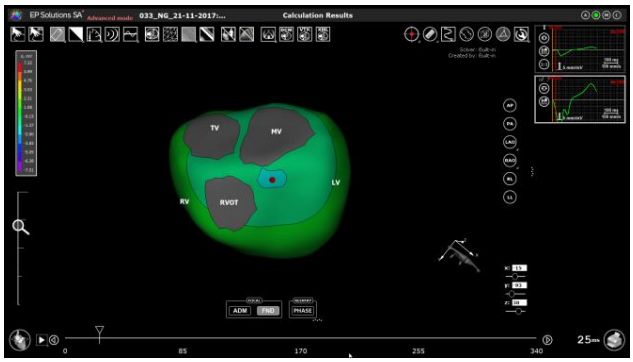


Figure 5. Epicardial project. Isopotential map of a pacing point from the LV anterior-basal segment.

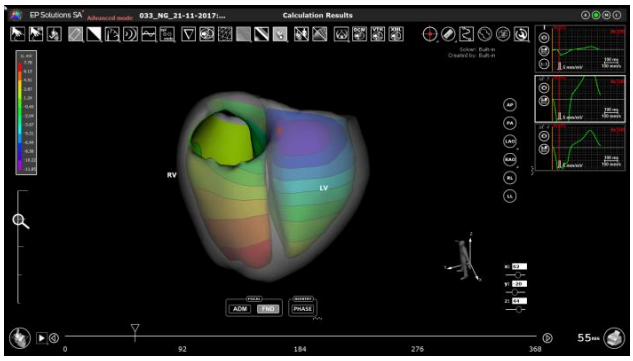


Figure 6. Endocardial project. Isopotential map of the pacing point from the LV anterior-basal segment after RVOT removal from the anatomical model.

## 5. Discussion

Summing up, better reconstruction results were obtained for free ventricular walls, as opposed to the non-invasive reconstructions of pacings coming from the septum, apical parts and outflow tracts. Lower results for pacing from left and right outflow tracts might be connected with the short distance between them. In some cases, removing parts of the ventricles could improve results due to decreasing influence of neighboring anatomical structures. On this basis the results of right determined EAZ may be associated with the polygonal model shape. Therefore, identify the optimal form of the segmented heart model can improve the ECGI accuracy.

Artificial induction of premature ectopic activity is a useful validation tool for evaluating the accuracy of non-invasive mapping and excitation patterns in the heart including patients with scars and fibrosis in combination with MRI. Moreover, comparison of real endocardial and reconstructed electrograms of each pacing point can help improve inverse ECG problem, create database for further modeling studies and improve topical diagnosis of PVCs.

## 6. Conclusions

Thus, the results of comparison EAZ location obtained by invasive and non-invasive method have shown a good agreement. Further quantitative analysis of the data and larger patients number are needed for supporting the presented observations.

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