# Noninvasive localization of premature ventricular complexes

## A research-community-based approach

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### Background

Noninvasive localization of premature ventricular complexes (PVCs) to guide ablation therapy is one of the emerging applications of electrocardiographic imaging (ECGI). Many implementations of ECGI exist, and one example is shown in **Figure 1**. Recent validation studies of ECGI show a range of accuracy in localizing PVCs or paced beats, see **Table 1**. Because of its increasing clinical use, it is essential to compare the many implementations of ECGI to understand the specific characteristics of each approach.

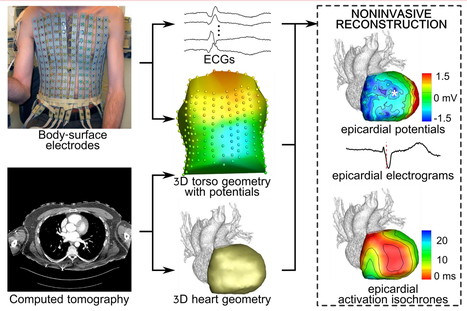



**Figure 1**: Electrocardiographic imaging (ECGI) as developed in Maastricht is only one of many of current ECGI implementations.

| Medium & method | Nmb of subjects | Nmb of beats | Mean electrogram correlation | Mean pacing localization error (cm) | Ref |
|---|---|---|---|---|---|
| **Torso tank** | | | | | |
| Single site epicardial pacing in torso tank | - | - | - | < 1.0 | 1 |
| Single and dual site epicardial pacing in torso tank | - | 4 | 0.81 | 0.2 | 2 |
| **Humans** | | | | | |
| Intraoperative mapping in patients while pacing (nonsimultaneous recording, open chest) | 3 | 5 | 0.72 ± 0.25* | ~ 1.0 | 3 |
| Ventricular pacing by implanted pacemaker | 4 | 6 | - | 0.5 | 1 |
| Endocardial atrial pacing in AF patients | 6 | 37 | - | 0.6±0.4 | 4 |
| Epicardial ventricular pacing | 4 | 79 | - | 1.3±0.9 | 5 |
| Pacemaker atrial/ventricular pacing | 29 | 456† | - | 0.9±0.6 | 6 |
| Endocardial atrial/ventricular pacing | 5 | 412† | - | 0.7±0.2 | 6 |
| **Canines** | | | | | |
| Epicardial and endocardial ventricular pacing | 4 | 93 | 0.71 [0.36-0.86]‡ | 1.0 [0.7-1.7]‡ | 7 |

**Table 1:** Overview of recent *in vivo* validation studies of the potential-based problem of ECGI. Only studies providing quantitative data (i.e., pacing location mismatch or invasive electrogram comparison) on ECGI validation were included.
* Determined by allowing a time-shift (cross-correlation); † Includes beats paced from identical locations (non-unique morphology); ‡ (median [IQR]); Qal: Qualitative comparison, no quantitative comparison.

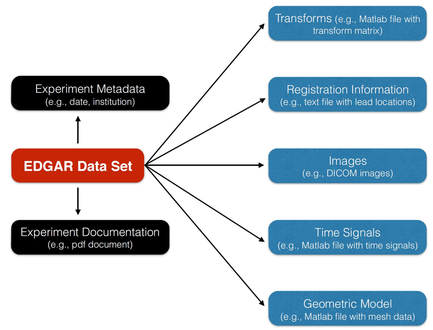
### Objective

The Consortium of ECG Imaging (CEI, see ecg-imaging.org) is a community of researchers aiming to collaborate in the field of ECGI, and to objectively compare and improve methods. Here, we will specifically compare methods to localize the origin of PVCs with ECGI.

### Methods

Our consortium hosts a repository of ECGI data on its website, **Figure 3**. For the current study, participants analysed simulated electrocardiograms from premature beats, freely available on that website. These PVCs were simulated to originate from eight ventricular locations and the resulting body-surface potentials were computed, **Figure 4**. These body-surface electrocardiograms (and the torso-heart geometry) were then provided to the study participants to apply their ECGI algorithms to determine the origin of the PVCs. Participants could choose freely among four different source models, i.e., representations of the bioelectric fields reconstructed from ECGI: 1) epicardial potentials ($POT_{epi}$), 2) epicardial & endocardial potentials ($POT_{epi\&endo}$), 3) transmembrane potentials on the endocardium and epicardium ($TMP_{epi\&endo}$) and 4) transmembrame potentials throughout the myocardium ($TMP_{myo}$). Participants were free to employ any software implementation of ECGI and were blinded to the ground truth data.

**Figure 3**: The EDGAR data repository stores simualted and experimental data sets for validation of ECGI approaches and techniques. These data are contributed by members of the Consortium for ECG Imaging. The data are freely available to all on ecg-imaging.org and the consortium welcomes contributions of additional examples. The data are all structured similarly to support data usage.



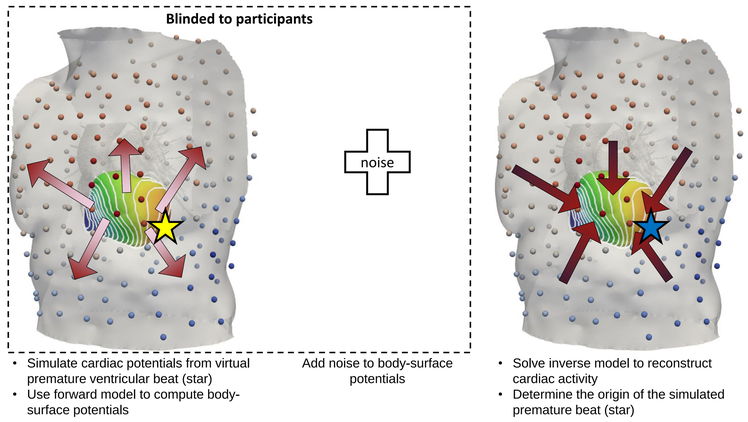




**Figure 4**: Potentials on the myocardium are simulated from a virtual origin. The resulting body-surface potentials are calculated by solving the forward problem, and noise is added for realism. The torso-heart geometry and body-surface potentials are then provided to the participants (blinded to the cardiac activity and source), who then solve the inverse problem to determine the origin of the simulated beat.

### Results

Four research groups submitted 11 entries for this study. **Figure 5** shows the localization error between the known and reconstructed origin of each PVC for each submission, categorized per source model. Each colour represents one research group and some groups submitted results using different approaches. These results demonstrate that the variation of accuracy was larger among research groups than among the source models. Most submissions achieved an error below 2 cm, but none performed with a consistent sub-centimetre accuracy.

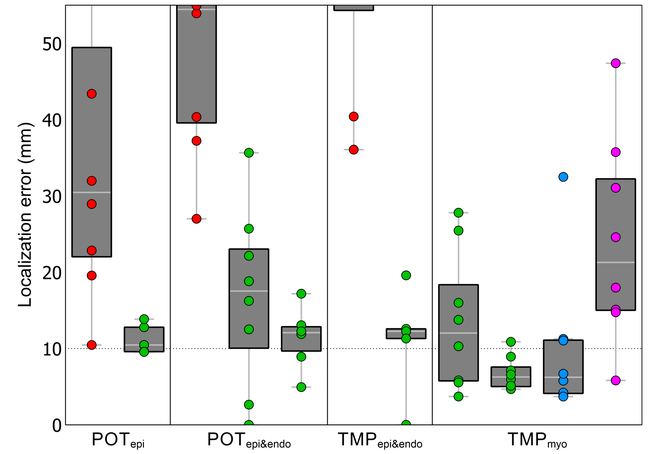



**Figure 5**: Localization error between the known origin and reconstructed origin of each reconstructed beat (circles), with boxplots summarizing the data per research group and cardiac source. Colors are unique for each participating research group.

### Conclusion

This study demonstrates a successful community-based approach to study different ECGI methods for PVC localization. The goal was not to rank research groups but to compare both source models and numerical implementations. PVC localization with these methods was not as dependent on the source representation as it was on the implementation of ECGI. Consequently, ECGI validation should not be performed on generic methods, but should be specifically performed for each lab's implementation. The novelty of this study is that it achieves this in the first open, international comparison of approaches using a common set of gold standards. Continued collaborative validation is essential to understand the effect of implementation differences, in order to reach significant improvements and arrive at clinically-relevant sub-centimetre accuracy of PVC localization.

**References**

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**Disclosures**: Matthijs Cluitmans is supported by the Hein Wellens Fonds, and part-time employed by Philips (Eindhoven, the Netherlands).