To the Editor-Interpretation of electrograms is key to understand the clinical potential of ECGI

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Reply to the Editor—Performance and limitations of noninvasive cardiac activation mapping

We thank Dr Rudy for his remarkable contribution to the development of noninvasive electrocardiographic (ECG) mapping and for his interest in our work.[1] The term ECGi was used in reference to an epicardial potential formulation using the method of fundamental solutions, as termed in previous publications. This method is used in the commercial system we evaluated. Historical validation of ECGi was performed by studying animal hearts placed in a tank filled with conductive saline, which we believe may overestimate the accuracy of the reconstruction. Our goal was to evaluate ECGi under clinical conditions.

Contact unipolar maps were annotated using a maximal –dV/dT approach, identical to ECGi. Example maps constructed from unipolar contact signals are available in the Supplemental Material, and readers will observe that the differences with bipolar maps are minor. We have also compared contact bipolar- to unipolar-based annotation in other patients (Rhythmia system) and observed little change in activation.

Breakthrough sites were defined using activation mapping—the focus of this work—similar to other studies.[2] This approach has the advantage of being unambiguous and automatic. In contrast, the "center of earliest persistent minimum" lacks a precise definition and, in our opinion, requires further studies.

Repolarization times were not evaluated because they cannot be reliably acquired using a point-by-point methodology. We have implied that repolarization mapping should be subject to caution because they are based on the same reconstruction scheme as activation mapping. The studies referenced by Dr Rudy as validation have not compared noninvasive and invasive repolarization measurements.

Lines of block are mostly due to structural anomalies and are fixed at stable physiological rates. Using invasive mapping as the gold standard, our findings provide unequivocal evidence that those imaged by ECGi were artificial.

In summary, we want to emphasize that ECGi activation mapping is relatively accurate for single-site breakthroughs (pacing or ectopy) but insufficient for this use during sinus rhythm (multiple breakthroughs). We do not believe that expert editing is a sufficient answer to these shortcomings. Among other options, artificial intelligence may help improve noninvasive mapping, but probably in inverse reconstruction itself rather than in postprocessing. Whatever the proposed solutions, this work highlights the necessity of their clinical validation.

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To the Editor— Interpretation of electrograms is key to understand the clinical potential of ECGI

With great interest we read the article of Duchateau et al[1] on clinical validation of noninvasive electrical activation mapping by comparing electrocardiographic imaging (ECGI) with epicardial invasive contact mapping. We commend the authors for performing this much-needed study, which helps to further define the value of ECGI in the cardiology clinic. Overall, we find the approach of these investigators sound, but we also consider that the study falls short of explaining the reported discrepancies.

Interpretation of the underlying recorded and reconstructed electrograms is key to the results. However, electrogram morphology was not systematically assessed. In our in vivo animal validation study, we recorded epicardial electrograms with implanted electrodes, simultaneous to ECGI.[2] We concluded that a spatial shift (due to cardiac motion or geometrical inaccuracies) of the recorded vs reconstructed electrograms results in low correlations. Compensating for these spatial mismatches improved the correlations.[2]

In addition, we found most low correlations in myocardial regions of gradual change in electrogram morphology (eg, polarity switch). During the electrographic transition in these regions, multiple deflections were present, and selecting the right "activation time" is not trivial. We demonstrated that activation time accuracy improved when not only temporal but also spatial characteristics of the activation wavefront were taken into account.[2] The influence of the postprocessing algorithm used to determine the activation time from the electrogram, although emphasized by the authors previously,[3] is not assessed in the present study. Overall, these various aspects may also explain the apparently lower resolution of

ECGI activation maps compared to the authors' previous publications.

We agree that the current performance of ECGI is likely lower than that of invasive (high-density) contact mapping, but without the possibility to analyze local electrograms and the effect of postprocessing algorithms, the authors' value judgment of ECGI in patients and its perspectives may be more negative than warranted.

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Reply to the Editor—Interpretation of electrograms is key to understand the clinical potential of ECGi

We thank Cluitmans et al for their interest in our work and for pinpointing some of the key challenges in electrocardiographic imaging.

Postprocessing of electrograms (EGMs) is a nontrivial task, and questions as to whether this step had an influence on the final results warrant our interest. Our correspondents suggest that a spatiotemporal approach may substantially improve the reconstruction.

In a previous work, we have indeed observed an improvement in the quality of activation maps with the use of a spatiotemporal approach,[1] but this improvement was minimal and cannot explain the significant differences between epicardial and body surface recordings. In addition, –dV/dT is the most widely used approach for unipolar EGM annotation, both for invasive and for noninvasive unipolar signals; and contact maps annotated using bipolar signals (analog to a spatial derivative) were highly correlated with contact unipolar maps (see the Online Supplement[2]), which suggests that their combination in a "spatiotemporal approach" would not substantially modify the results. These observations indicate that the main map discrepancies come from the EGMs themselves and not the annotation scheme.

In a previous study, our correspondents have shown that cardiac motion may degrade reconstructions and propose to time-shift recorded EGMs as a correction, which is an interesting point.[3] In our study, it is important to note that map correlation was poorest in patients with narrow QRS morphology, for which cardiac motion during ventricular activation is minimal, as compared to cardiac pacing.

The divergence between our study and previous publications can be explained by different factors.[2] We have highlighted differences between experimental and clinical conditions, and between paced and conducted QRS. Furthermore, our analysis was focused on individual map pair comparison, a metric we believe to have more clinical meaning than global correlation across subjects.

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