Assessment of Inter-operator Reproducibility of CardioInsight ECG-Imaging

Michele Orini[1,2], Peter H Waddingham[3], Adam Dennis[3], Jan O Mangual[3], Pier D Lambiase[2,3], Anthony WC Chow[3]
[1]MRC Unit for Lifelong Health and Aging, London, United Kingdom
[2] University College London, London, United Kingdom
3 Barts Heart Centre, Barts Health NHS, London, United Kingdom

Abstract

ECG Imaging (ECGI) provides non-invasive, single beat panoramic assessment of cardiac electrophysiological parameters, which makes it a promising tool in different clinical settings. This study aimed to assess ECGI reproducibility of ventricular epicardial mapping. Ten (n=10) patients underwent ECGI during left-ventricular epicardial pacing delivered from cardiac resynchronization therapy devices. Two experts performed ECGI (CardioInsight, Medtronic, MN), using the same cardiac computed tomography and body-surface ECG recordings, but they independently performed semi-automatic cardiac segmentation and identification of 252 body-surface electrodes. The closest epicardial sites on the two cardiac geometries were paired. Correlation coefficient (r) and absolute percentage difference (|Δ|) were used to assess agreement. N=1,791 (1710, 1860) (median [interquartile range]) nodes were paired per map with distance between paired ventricular nodes equal to 3.0 (2.1 – 4.5) mm. Reconstructed UEG were similar, with r_{UEG}= 0.993 (0.976 – 0.998) and absolute difference in the area under the unipolar electrogram of 10.8% (4.8 – 20.7)%. Local AT were also similar, with r_{AT} = 0.90 (0.83, 0.94) and $|\Delta AT|$ = 1.0 (0.0, 4.0) ms. However, 5% of paired cardiac sites showed $|\Delta AT| \geq 34$ ms. In conclusion, the morphology of UEGs and AT sequence were not significantly impacted by inter-operator variability in cardiac segmentation and electrode identification.

1. Introduction

ECG Imaging (ECGI) provides non-invasive, single beat panoramic assessment of cardiac electrophysiological parameters, which makes it a promising tool in different clinical settings, including mechanistic studies [1], [2], ablation for cardiac arrhythmias [3], [4] and scar imaging [5]. However, reproducibility, which is a key aspect for any methodology with potential for clinical translation, remains undetermined [6]. This study aimed to assess reproducibility of ventricular ECGI mapping.

2. Methods

Ten (n=10) patients underwent ECGI (CardioInsight, Medtronic, MN) during implantation of cardiac resynchronization therapy devices. Eight patients were men, and median age was 71 (interquartile range 64 - 74) years. Left ventricular ejection fraction was 28.5% (23% - 34%) and intrinsic QRS duration was 167 (159 – 186) ms.

Pacing was delivered from the left ventricle and one beat per patient was analyzed. Two expert operators performed all manual and semi-automatic steps of CardioInsight system and post-processing. These included: Segmentation of computed tomography data and localization of body surface electrodes, as well as manual revision of activation time annotation in a Matlab Graphical User Interphase developed in our groups and used in other studies [7]. Activation time was defined as the time of minimum first derivative of the reconstructed unipolar electrogram [8]. Comparison of ECGI data was performed as follows. First, each node of the ventricular mesh showing the least number of nodes was paired to the closest node of the other ventricular mesh. For a given electrophysiological index x_i^j, with $i = \{1,\ldots,n\}$ and $j = \{A,B\}$ representing a given cardiac site and a given operator, respectively, agreement was assessed using the correlation coefficient and percentage difference, i.e. $|x_i^A - x_i^B|/(x_i^A + x_i^B)$. Bland-Altman plots were used to visually inspect agreement, with limits of agreement measured as $m_E \pm 1.96 * \sigma_E$, where m_E and σ_E are the mean and standard deviation of the differences between measurements. Robust limits of agreement were measured as $m_E \pm 1.96 * \widetilde{\sigma_E}$, where $\widetilde{\sigma_E}$ is a robust estimate of σ_E measured as 1.482 times the median absolute deviation.

Results are reported as median (interquartile range).

3. Results

An example of AT map for the same patient and same paced beat obtained by two independent operators is shown in Figure 1. The two ventricular meshes are different, but the AT sequence is visually similar.

Across the 10 patients, the median number of nodes per

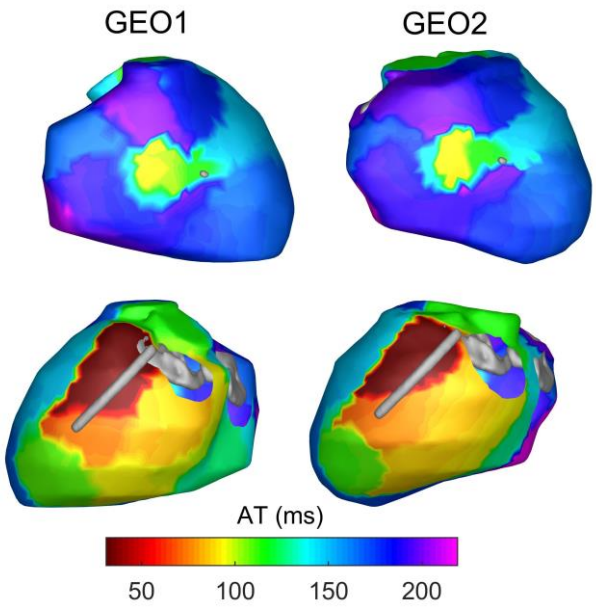

Figure 1. Local activation time (AT) map in a representative patient. Data analyzed by the first and second operators are shown on the left and right, respectively. Top and bottom panels represent different anatomical view of the same heart.

ventricular mesh was 1791 (1710 – 1860). The pairwise distance between all paired ventricular nodes (N=17,865) was 3.0 (2.1 – 4.5) mm, with about 5% of paired nodes showing a distance ≥ 10 mm. The Pearson's correlation coefficient between unipolar electrograms reconstructed by the two operators across all paired ventricular nodes, i.e. a measure of their morphological similarity, was 0.993 (0.976 – 0.998). Only 0.6% of cardiac showed a correlation coefficient <0.50. The relative difference in the area under the reconstructed unipolar electrograms obtained by the first versus the second operator was 10.8% (4.8 – 20.7)%.

The local AT across all ventricular nodes was also similar for the two independent operators, with median absolute difference equal to 1 (0, 4) ms. The distribution of absolute differences between AT showed a long tail, with 90th and 95th percentile equal to 12 and 34 ms, respectively. This is also highlighted in the Bland Altman plot shown in Figure 2. While classical limits of agreement (LoA) based on the standard deviation of AT error were (-29.5, 30.2) ms (dashed red line), robust LoA measured approximating the standard deviation with the median absolute deviation were much lower at (-2.6 3.2) ms.

The AT pattern across each map was similar, with median Spearman's correlation coefficient equal to 0.90 (0.83, 0.94).

4. Discussion

This study assessed reproducibility of ECGI performed using the CardioInsight system. Segmentation of cardiac computed tomography resulted in relatively similar ventricular meshes, with nodes that after pairwise pairing were located at median distance of 3 mm and from each other. The morphology of the reconstructed unipolar electrograms at paired ventricular nodes was very similar, as demonstrated by very high correlation coefficient. A median absolute difference in the area under the reconstructed unipolar electrogram of about 10% demonstrates that the amplitude of the unipolar electrograms reconstructed at paired ventricular nodes was also similar. Activation time maps were similar, with 50% of paired cardiac sites showing an absolute difference in AT ≤ 4 ms and 10% of cardiac sites showing an absolute difference in AT ≥ 12 ms. Despite this, most of cardiac sites show very similar AT, and median correlation of AT sequence across maps was 0.90, a small number (≤5%) of cardiac sites show large differences in cardiac AT. This had an impact on the limit of agreement shown in the Bland Altman plot, which was relatively high, from -29 to 30 ms. These results demonstrate overall good reproducibility of ECGI performed using the CardioInsight system, but suggest that in a small number of cases, small differences in the morphology of unipolar electrograms can translate into large differences in AT.

Future studies should investigate reproducibility of other ECGI features, such as earliest and latest sites of activation, repolarization and activation recovery intervals, as well as advanced indices such as those proposed to guide programming of devices for cardiac resynchronization therapy. Furthermore, in this study independent operators analyzed the same data, and a test-retest (or scan-rescan) strategy should also be implemented in future study. One possible explanation for the high reproducibility of ECGI demonstrated in this study is that segmentation of cardiac computed tomography performed by independent operators resulted in similar epicardial meshes. This is likely due to the high resolution of computed tomography and future studies are needed to assess reproducibility of MRI-based ECGI [1], [2] .

Conclusions

This study shows that ECGI based on the CardioInsight system has high inter-operator reproducibility.

Acknowledgements

MO is supported by a BHF accelerator award AA/18/6/34223.

References

[1] M. Orini *et al.*, "Noninvasive mapping of the electrophysiological substrate in cardiac amyloidosis and its relationship to structural abnormalities," *J. Am. Heart Assoc.*, vol. 8, no. 18, Sep. 2019, doi: 10.1161/JAHA.119.012097.

[2] C. M. Andrews *et al.*, "Electrical and Structural Substrate of Arrhythmogenic Right Ventricular Cardiomyopathy Determined Using Noninvasive Electrocardiographic Imaging and Late Gadolinium Magnetic Resonance Imaging," *Circ. Arrhythmia Electrophysiol.*, vol. 10, no. 7, Jul. 2017, doi: 10.1161/CIRCEP.116.005105.

[3] A. J. Graham *et al.*, "Simultaneous Comparison of Electrocardiographic Imaging and Epicardial Contact Mapping in Structural Heart Disease," *Circ. Arrhythmia Electrophysiol.*, vol. 12, no. 4, p. e007120, Apr. 2019, doi: 10.1161/CIRCEP.118.007120.

[4] A. J. Graham *et al.*, "Evaluation of ECG Imaging to Map Haemodynamically Stable and Unstable Ventricular Arrhythmias," *Circ. Arrhythmia Electrophysiol.*, Jan. 2020, doi: 10.1161/circep.119.007377.

[5] A. J. Graham *et al.*, "Assessing Noninvasive Delineation of Low-Voltage Zones Using ECG Imaging in Patients With Structural Heart Disease," *JACC Clin. Electrophysiol.*, vol. 8, no. 4, pp. 426–436, Apr. 2022, doi: 10.1016/j.jacep.2021.11.011.

[6] M. Cluitmans *et al.*, "Validation and opportunities of electrocardiographic imaging: From technical achievements to clinical applications," *Front. Physiol.*, vol. 9, no. SEP, p. 1305, Sep. 2018, doi: 10.3389/fphys.2018.01305.

[7] M. Orini *et al.*, "Evaluation of the reentry vulnerability index to predict ventricular tachycardia circuits using high-density contact mapping," *Heart Rhythm*, vol. 17, no. 4, pp. 576–583, Apr. 2020, doi: 10.1016/j.hrthm.2019.11.013.

[8] M. Orini, N. Srinivasan, A. J. Graham, P. Taggart, and P. D. Lambiase, "Further Evidence on How to Measure Local Repolarization Time Using Intracardiac Unipolar Electrograms in the Intact Human Heart," *Circ. Arrhythmia Electrophysiol.*, vol. 12, no. 11, Nov. 2019, doi: 10.1161/CIRCEP.119.007733.

Address for correspondence: m.orini@ucl.ac.uk; Michele Orini, 1-19 Torrington Place, London, United Kingdom.

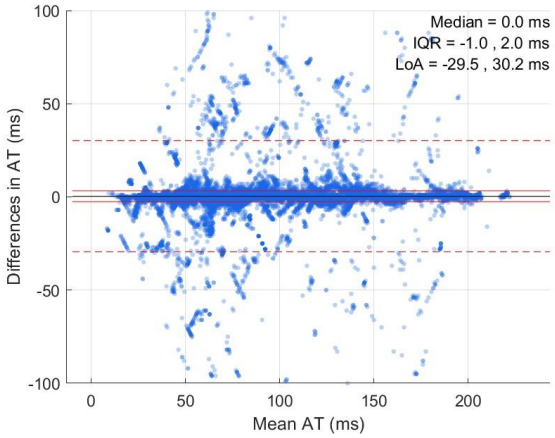

Figure 2. Bland-Altman plot showing the agreement in activation time (AT) across all paired ventricular nodes pooled together (N=17,875). The black line represents the mean difference, while the dashed and continuous red lines represent the standard and