# Minimum Time Duration for Detecting Phase Singularities in Human Persistent Atrial Fibrillation

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## Abstract

*Atrial fibrillation (AF) is a leading cause of cardiovascular morbidity, affecting millions globally[1], Phase singularity density maps play a crucial role in cardiac electrophysiology by identifying arrhythmogenic substrates. However, the ideal duration for capturing reliable phase singularity data remains uncertain. This study examines the correlation between phase singularity density maps generated from different durations and a 3-minute gold standard. Electrophysiological data from 10 patients were analyzed using MATLAB, with maps computed for time frames ranging from 5 to 180 seconds. The results show a strong correlation (average coefficient > 0.85) for durations longer than 60 seconds, indicating that shorter acquisition times may be sufficient for accurate analysis. These findings could help optimize clinical workflows in cardiac electrophysiology.*

## 1. Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia encountered in clinical practice, affecting 1-2% of the general population[2]. Cardiac arrhythmias like atrial fibrillation involve intricate electrophysiological processes, including phase singularities[3]. These singularities indicate rotational activations in cardiac tissue and serve as crucial markers for detecting arrhythmogenic substrates[4]. Accurate identification and analysis of phase singularities are vital for guiding ablation therapy and enhancing patient outcomes[5]. Although phase singularity density maps are commonly used in both research and clinical practice, the ideal duration for acquiring reliable data remains unclear[6]. Extended data collection may be impractical in clinical settings, highlighting the need to balance data quality with acquisition efficiency[7]. This study investigates the relationship between phase singularity density maps generated from shorter time frames and a 3-minute gold standard, aiming to determine the shortest duration needed for reliable analysis. A *gold standard* is the initial 180 seconds of data which was utilized.

## 2. Materials and Methods

### 2.1. Electrophysiological study

Our study comprised ten patients with persistent atrial fibrillation (persAF) who were receiving their initial left atrial (LA) catheter ablation procedure[8]. To direct the ablation procedure towards the rotors, we obtained up to 300 seconds of noncontact electrogram (EGM) data from the left atrium (LA) using the (Ensite Array system from St Jude Medical)[9]. The generated data was then analysed using the Matlab software. As stated before, phase density zones were identified in the LA. 40% of the patients had their atrial fibrillation (AF) terminated, with 30% experiencing atrial flutter and 10% returning to normal sinus rhythm, by rotor ablation before undergoing pulmonary vein isolation (PVI). All 10 patients experienced no negative outcomes[10].

**Table 1**. Clinical Characteristics of the Patients

| | Median | Min | Max |
|---|---|---|---|
| **Male (n)** | 10 | - | - |
| **On amiodarone (n)** | 2 | - | - |
| **Age (years)** | 57.8 | 36.1 | 76.4 |
| **Days in AF pre-procedure** | 219 | 132 | 848 |

## 2.2. AF EGM Pre-processing

We examined 2048-channel virtual EGMs (EnSite Array, Abbott; 5 min). The electrocardiogram (EGM) recordings, which lasted for 5 minutes, were initially sampled at a rate of 2034.5 Hz[11]. To reduce processing time and storage requirements, the recordings were subsequently re-sampled to a rate of 512 Hz using the cubic interpolation method. To improve the accuracy of rotor identification, we conducted QRST subtraction, because ventricular far field activity in EGMs can occasionally be misleading, showing up as frequency components within the atrial frequency spectrum, affecting PS identification accuracy, therefore QRST subtraction was conducted[12]. After subtracting QRST, the EGMs were subjected to spectrum analysis using fast Fourier transform (FFT) with 4-second sliding windows and a 2-second overlap. During the FFT computation, a zero-padding factor of 5 was employed, which led to a frequency increment of 0.05 Hz. By employing a Hamming window, the amplitude of the side lobes encircling the rotor peak in the power spectrum was diminished. The rotor was defined as the frequency of the peak in the power spectrum within the physiological range of 4-10 Hz.

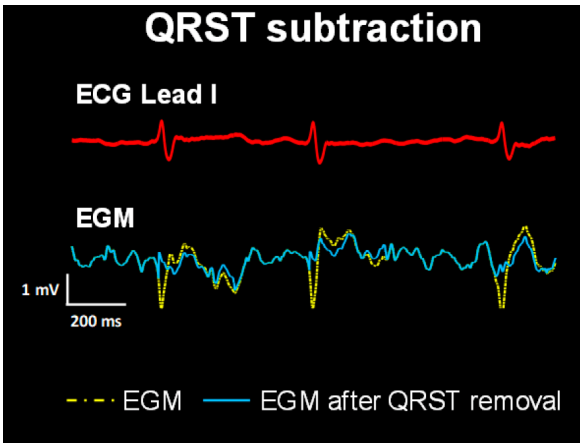


**Figure 1**. Illustration of QRST complex removal in non-contact electrograms (EGMs)[13].

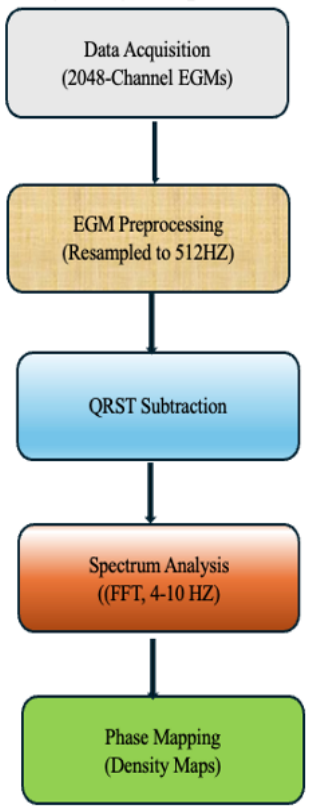


**Figure 2**: Phase Singularity Analysis Pipeline Schematic, illustrating data acquisition, preprocessing, QRST subtraction, spectrum analysis, and phase mapping.

## 3. Results

The density map for each shorter duration was compared to the three-minute baseline map for individual patients. After analyzing each patient separately, an average correlation across all patients was calculated for each time duration to identify overall trends.

For each time interval, phase singularities were identified and mapped, potentially highlighting regions of interest, such as sources of atrial fibrillation.

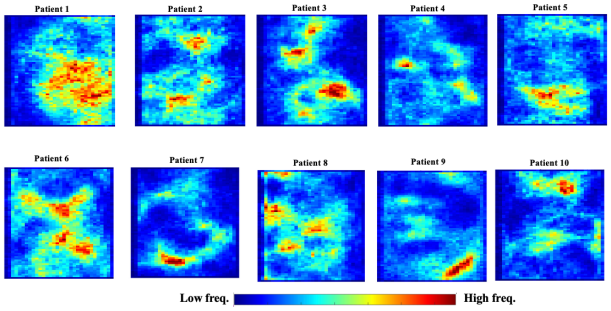


**Figure 3**. Phase Singularity density maps for all patients (for 3 mins each)

Each shorter-duration density map was compared to the 3-minute baseline map for each individual patient to assess correlation. After evaluating each patient separately, the average correlation for each time duration was computed across all patients to identify overall patterns.

The correlation between phase singularity density maps and the gold standard improved as duration increased, stabilizing around 120 seconds. For durations longer than 60 seconds, the average correlation coefficient across patients reached **0.85**.

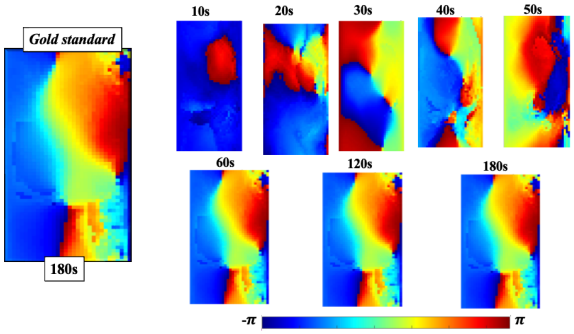


**Figure 4**. Phase per frame (-pi to pi) for 1 patient

Although the correlation increases with duration for all patients, there is clear variation in how quickly everyone's correlation levels off. In the results, some patients achieve a correlation of 0.9 with the gold standard sooner than others, suggesting person-specific differences in phase singularity patterns or signal characteristics.

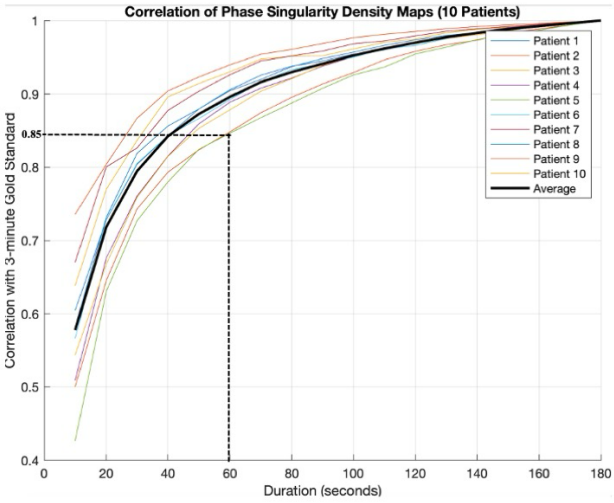


**Figure 5**. The plot of the Results illustrates the relationship between observation duration and correlation with a gold standard as well as the average of the correlation between the 10 patients.

The black line, indicating the average correlation, shows that for most patients, durations of approximately 90 seconds or longer yield a strong correlation near or above 0.9 with the 3-minute reference standard.

## 4. Discussion and Conclusions

Our findings indicate that phase singularity density maps derived from shorter durations (≥60 seconds) maintain a strong correlation with the 3-minute gold standard. This implies that accurate phase singularity analysis can be achieved with much shorter data collection periods, which is particularly beneficial in time-sensitive clinical environments. Previous studies have confirmed the reliable detection of phase singularities in shorter datasets, aligning with our results. However, our study builds on this by quantifying the correlation between shorter durations and the gold standard, offering a stronger foundation for clinical decision-making.

This study shows that phase singularity density maps derived from as little as 60 seconds of data strongly correlate with the 3-minute gold standard. These results indicate that shorter data collection periods for around 90 seconds or more might be nearly as reliable as 3-minute recordings for accurate phase singularity analysis, potentially improving efficiency in clinical cardiac electrophysiology. Differences between patients suggest that a fixed duration may not be suitable for everyone, as some individuals might need extended monitoring to obtain dependable results. For most

patients, the correlation appears to level off around 90 seconds, suggesting that extending observation beyond this point offers minimal additional benefit. Future research should confirm these findings in larger and more diverse patient groups.

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