Characterization of QRS Rotation Direction Changes in Frank Vectorcardiogram

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Abstract

This study aimed to describe beat-to-beat changes in QRS rotation direction observed in Frank vectorcardiograms (VCGs) from patients with advanced heart failure with preserved ejection fraction (HFpEF)—a condition marked by electrical and structural heterogeneity that complicates the vectorcardiographic analysis and challenges rotational pattern identification.

We analyzed 10-minute VCG recordings from 40 HFpEF patients using the ECGPC system (TEB, Brazil; 1200 Hz, Frank lead system). Each QRS complex was manually classified in the frontal and horizontal planes as showing clockwise, counterclockwise, or figure-of-eight rotation. The direction of rotation was assessed beat-by-beat to detect any changes relative to the previous cycle. Rotation changes occurred in 19 of the 40 recordings (121 beats), mostly involving transitions to or from figure-of-eight configurations, often misclassified by automated software, and two were associated with extrasystolic beats.

These findings highlight the frequency of electrical rotation variability in HFpEF patients and the limitations of automated classification tools in interpreting complex VCG morphologies. Standardized criteria for defining rotation direction are essential to improve diagnostic accuracy and reproducibility in VCG analysis, especially in populations with abnormal cardiac conduction.

1. Introduction

The vectorcardiogram (VCG) is a diagnostic tool that offers a spatial representation of the heart's electrical activity across three orthogonal planes: coronal (frontal), transverse (horizontal), and sagittal (vertical). It captures the magnitude and direction of electrical vectors during the cardiac cycle, providing a more comprehensive view of depolarization and repolarization patterns compared to the standard electrocardiogram (ECG). Among the key morphological features derived from VCG analysis are the amplitude, angular orientation, and rotational behavior of the QRS loop, which reflects ventricular depolarization.

In three-dimensional space, the QRS complex typically forms a loop whose rotation pattern—most notably in the transverse plane—can reveal important information about the directionality and distribution of ventricular activation. A normal heart exhibits counterclockwise rotation of the QRS loop in the horizontal plane, indicating a physiologically balanced sequence of ventricular depolarization [1].

Deviations from this pattern, such as clockwise or figure-of-eight rotations, may suggest conduction delays, structural abnormalities, or chamber overload. Rotation analysis has demonstrated clinical relevance in identifying pathologies such as right and left ventricular hypertrophy, fascicular blocks, and ischemic heart disease [2]. Specifically, clockwise rotation has been associated with conditions like right bundle branch block and chronic obstructive pulmonary disease, while exaggerated counterclockwise patterns may be observed in left ventricular hypertrophy and early myocardial infarction [1].

Recent findings also highlight that VCG rotational patterns not only assist in identifying present structural or conduction abnormalities, but also carry prognostic value. Clockwise rotation of the QRS transition zone has been linked to an elevated risk of heart failure and noncardiovascular mortality, whereas counterclockwise rotation has shown a protective association with reduced cardiovascular and all-cause mortality [1].

Additionally, abnormal QRS loop configurations—such as figure-of-eight or folding patterns—may indicate localized conduction delays or alterations in myocardial fiber orientation due to dilation, infarction, or fibrosis [3,4]. The planarity and rotational uniformity of the QRS loop, for instance, have been proposed as sensitive markers for distinguishing normal cardiac function from pathological deviations, particularly in myocardial infarction and ventricular tachycardia [5].

In this study, we focus specifically on analyzing intrapatient changes in the direction of QRS loop rotation in

the frontal and horizontal planes of the Frank vectorcardiogram (VCG). Our aim is to visualize and understand the origin of these variations—whether they reflect clinically meaningful electrical phenomena or are simply artifacts or inconsistencies introduced by the software's detection algorithm.

2. Methods

The data analyzed in this study were originally collected from patients at the Heart Failure with Preserved Ejection Fraction (HFpEF) outpatient clinic of the Instituto Dante Pazzanese de Cardiologia, São Paulo, Brazil. Each subject underwent a 10-minute recording of simultaneous electrocardiogram (ECG) and vectorcardiogram (VCG) signals using the ECGPC System (TEB, Brazil), with eight electrodes placed according to the Frank lead configuration. The recordings were sampled at 1.2 kHz, providing high-resolution data for beat-to-beat analysis.

This work builds upon the master's thesis by Barros [6], which focused on comparing the direction of QRS loop rotation between Frank VCGs and VCGs derived via the Kors transformation matrix applied to the standard 12-lead ECG. That previous analysis was performed entirely by automated software without manual validation of the output, classifying the rotation in each beat as clockwise (CW), counterclockwise (CCW), or figure-of-eight (E) across the frontal, horizontal, and sagittal planes.

The present study aims to manually verify the rotation direction changes reported by the software, as such variations are not typically expected unless an ectopic or premature beat is present. The goal is to assess the reliability of the software's automated classification and to describe the observed rotation changes in detail.

For this purpose, the data used in Barros's study were reexamined. Each patient's 10-minute VCG recording was segmented, and the first 11.04 seconds of each minute were selected for detailed analysis. The rotation classification for each beat—originally provided automatically by the ECGPC software—was reviewed manually using visual inspection of the QRS loop morphology in each plane. In Table 1 an example is shown of the manual analysis.

The ECGPC System enables visualization of individual cardiac cycles and provides quantitative measurements such as vector magnitude, angle, and direction of rotation. After extracting both the numerical data and associated images from the software, individual summary tables were created to document intra-patient variations in QRS rotation. These summaries were then consolidated to quantify the frequency and types of rotation changes observed across the study population.

This validation process allowed for the identification of potential misclassifications by the automated system and offered a more accurate characterization of unexpected QRS rotation changes, contributing to the refinement of vectorcardiographic analysis protocols.

Table 1: Beat-by-Beat Rotation Changes

Beat	Frontal	Horizontal
1	CCW	CW
2	CCW	CW
3	CCW	CW
4	CCW	CW
5	CCW	8*
6	CW*	CCW*
7	CCW*	CW*
8	CCW	CW
9	CCW	CW
10	CCW	8*
11	CCW	CW*
12	CCW	CW
Total	**2 changes**	**5 changes**

Legend:
CCW – Counterclockwise Rotation
CW – Clockwise Rotation
8 – Figure-of-Eight Rotation
* – Indicates a change compared to the previous beat

3. Results

The table above summarizes the frequency of intra-patient changes in QRS rotation direction observed across the frontal and horizontal planes. Overall, rotation changes were more prevalent in the frontal plane, with a total of 63 transitions compared to 25 in the horizontal plane. The most frequent type of variation in the frontal plane was from counterclockwise (CCW) to figure-of-eight (E) rotation, observed in 17 instances, followed by transitions from figure-of-eight to counterclockwise (15 cases) and from figure-of-eight to clockwise (13 cases). These findings suggest that figure-of-eight configurations are highly unstable or transitional and may shift between dominant directional components across consecutive beats.

In the horizontal plane, the most frequent transitions were from clockwise (CW) to counterclockwise (8 cases) and from figure-of-eight to either CW or CCW (5 cases each). Less frequent were direct reversals between CW and CCW or vice versa. These patterns highlight the dynamic nature of QRS loop morphology, especially in patients with HFpEF, and reinforce the notion that subtle variations in loop shape—though potentially physiological—can challenge the robustness of automated rotation classification. Some examples of the QRS Loop changes are shown in Figure 1 and Figure 2.

Table 2: Correspondence between the direction of rotation and each spatial plane.

Direction Change	Frontal	Horizontal
CW to CCW	10	8
CW to E	5	1
CCW to CW	3	1
CCW to E	17	5
E to CW	13	5
E to CCW	15	5

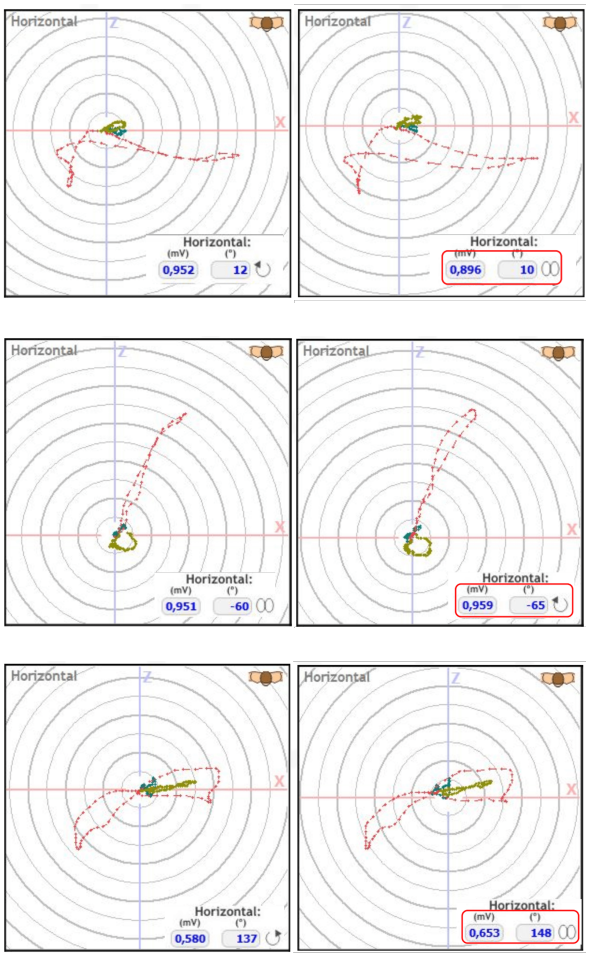


Figure 1: Example of change in rotation detected by the software and the corresponding QRS loop

4. Conclusion

The majority of rotation changes were observed in the frontal plane, with figure-of-eight patterns being the most frequently detected. These morphologies often appeared

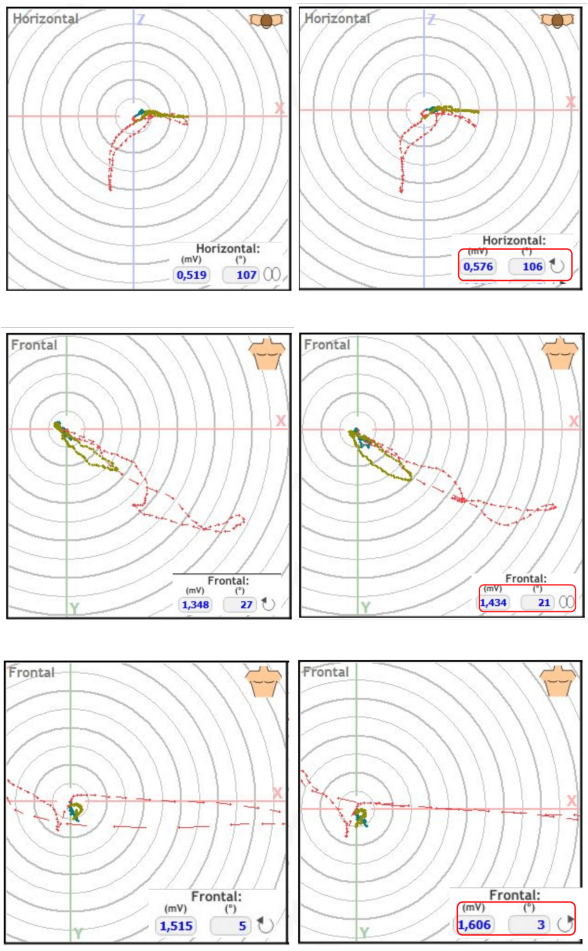


Figure 2: Example of change in rotation detected by the software and the correspondind QRS loop

transitional, with overlapping features of both clockwise and counterclockwise loops, making consistent classification challenging for the automated system. In several recordings, small variations in QRS loop shape between consecutive beats led the software to assign different rotation labels—despite visual similarities—highlighting the sensitivity of the algorithm to minor morphological changes.

This classification variability is particularly relevant in studies involving abnormal ECGs, such as those from patients with advanced HFpEF. In these cases, intrinsic electrical heterogeneity can introduce subtle beat-to-beat differences that may not reflect true physiological shifts, but still influence automated interpretations. If unaccounted for, such variability may affect the reliability of VCG-derived parameters used in longitudinal monitoring, risk stratification, or algorithm training, potentially leading to overinterpretation of noise as meaningful change.

These findings suggest that refining how rotation direction is defined and detected—especially in borderline or complex patterns—could benefit future research. While formal standardization may not be immediately necessary, clearer methodological criteria and improved algorithmic tolerance to variability would support greater consistency across studies and enhance the interpretability of VCG-based analyses in diverse clinical populations.

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