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# Left ventricular orientation and position in an advanced heart failure population

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ABSTRACT

*Introduction:* Previous canine and *in silico* studies indicate that left ventricular (LV) orientation and position have clinically significant effects on standard ECG elements, which are particularly relevant in an advanced heart failure (HF) population. Our objectives were to investigate the real-world implications of these previous results by describing for the first time the range of LV orientations and positions in HF patients, identifying clinical predictors of orientation and position, and investigating how thoracic geometry may affect orientation and position.

*Materials and methods:* Cardiac MRIs were used to measure LV orientation angles, LV position, chest dimensions, and the ratio of LV volume to thoracic area (LVTR). Multivariate regression analyses were used to identify significant predictors of orientation and position.

*Results:* The mean frontal plane LV orientation angle was 31 ± 11° (range, 0°–47°) and fell within the ranges used in previous studies of orientation effects. Orientation in the transverse plane, the effects of which have not been simulated, averaged 48 ± 10° (range, 21°–71°). The ranges of LV positions in the frontal and transverse planes (7.9 and 5.6 cm, respectively) are similar to or greater than those used *in silico*. Orientation and position were weakly correlated with multiple significant predictors, and the relationship between HF progression and LV orientation and position could not be determined.

*Conclusion:* Variation in LV orientation and position in advanced HF patients is large and cannot be readily predicted using the standard clinical variables or additional thoracic geometry measures used in this study. These findings may have significant clinical implications because of the possible effects of orientation and position on key ECG features. New tools and additional studies are needed before LV orientation or position data can be incorporated into clinical ECG interpretation.

## 1. Introduction

Previous canine and *in silico* studies have shown that alterations in left ventricular (LV) orientation and LV position significantly alter the main diagnostic elements of the 12-lead ECG, including QRS duration (QRSd) and morphology [1–7]. Those studies used ranges of orientations and positions based on limited, healthy-patient data [6,7]. In addition, population studies documenting LV orientation or position have focused on patients without cardiovascular disease [8–11]. The single identified study that reported LV orientation ranges in a heart failure (HF) population included only 13 HF patients out of a total cohort of 77 [12]. The relationship between LV orientation, LV position, and thoracic geometry has not been reported previously. We hypothesized that LV orientation and position would correlate strongly with thoracic geometry and LV size and that such relationships could help identify patients predisposed to unusual LV orientation or position and to subsequent confounding effects on the interpretation of their ECGs.

The potential effects of LV orientation and position on ECG features are particularly relevant for the heart failure (HF) population. ECG elements such as QRSd, QRS waveform components (i.e., R- and S-wave patterns and notching), and the QRS axis are relied upon for diagnosing underlying conduction abnormalities and previous myocardial infarctions [13–17]. The same features are used to determine if a patient is a candidate for treatments such as cardiac resynchronization therapy (CRT) [18–20]. Although many studies have investigated the effects of body habitus, age, gender, and LV anatomy on ECG results [3,21–23], efforts to adjust ECG measures and lead positioning to account for cardiac orientation or position have failed [6,7,11].

Our primary study goal was to investigate the real-world

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**Abbreviations**

| | |
|---|---|
| HF | heart failure |
| LV | left ventricle |
| QRSd | QRS duration |
| CRT | cardiac resynchronization therapy |
| UHVC | United Heart and Vascular Clinic |
| EF | ejection fraction |
| CW | chest width |
| CD | chest depth |
| AP | anterior-posterior |
| ML | medial-lateral |
| EDV | end-diastolic volume |
| LVTR | LVEDV thoracic ratio |
| $AP_{REL}$ | relative AP position |
| $ML_{REL}$ | relative ML position |

implications of previous simulation studies by describing for the first time LV orientations and positions in a large advanced systolic HF patient population. We also aimed to identify any relationships between LV orientation and position and standard clinical variables, such as age, BMI, LV volume, QRSd, and thoracic geometry measures (e.g., chest depth and width). Such information constitutes the first step in determining the potential impact of LV orientation and position variation in a clinical setting, in identifying patients that are likely to have unusual LV orientations or positions, and in defining the need for new technologies or strategies to address this issue.

## 2. Materials and methods

### 2.1. Study design and data collection

This was a retrospective study of advanced systolic HF patients at United Heart and Vascular Clinic (UHVC) in St. Paul, MN, who participated in a study of patients with new CRT implants between 2013 and 2015. Written informed consent was obtained from all patients, and the study protocol was approved by an IRB. Inclusion criteria for the current analyses were clinical HF and a viable MRI less than 2 years prior to CRT implant. Patients were excluded if they had atrial fibrillation, previous right ventricular pacing, or complete heart block.

MRIs were acquired using a Siemens MAGNETOM Avanto 1.5T system (Siemens, Erlangen, Germany). Patients were imaged in the supine position. Images from axial and coronal plane TrueFISP sequences without breath hold were used in this analysis. For each patient, a frontal plane image was selected such that the aortic valve, outflow tract, and pulmonary artery were visible in addition to the LV. A four-chamber transverse plane image was selected such that the interventricular septum could be clearly visualized.

### 2.2. Determination of orientation, position, and thoracic geometry measures

For each patient, the two MRI images were used to measure frontal and transverse plane LV long axis orientation angles, chest depth, chest width, and anterior-posterior and medial-lateral LV position in the transverse plane.

The method for LV orientation angle determination was based on that of Foster et al., who showed that the resulting measurements were not affected by respiration or the cardiac cycle [12]. Fig. 1 demonstrates the coordinate systems for frontal (panel A) and transverse plane (panel B) LV orientation angles, which are the same as those used by Foster et al. [12]. Frontal plane (Fig. 2A) and transverse (Fig. 2B) LV orientation angles were determined by drawing a line tangent to the LV apex, measuring the perpendicular to the apex tangent, and then measuring the angle between that perpendicular and the horizontal.

Using the selected four-chamber view, chest depth (Fig. 2C) was measured using the vertical from the center of the visible spine to the level of the sternum, while chest width was measured using the maximum transverse internal thoracic diameter. Anterior-posterior LV position was measured using the vertical beginning at the mid-point of the line across the mitral valve plane and terminating at the level of the visible spine. Medial-lateral LV position was measured as the distance between the vertical used for the chest depth measurement and the vertical from the mid-point of the line across the mitral valve plane.

The ratio of LV end-diastolic volume (EDV) to thoracic cross-sectional area (LVEDV thoracic ratio, LVTR), which was approximated as an ellipse using chest depth and width, was used to broadly examine the relationship between LV orientation, LV size, and thoracic area. Last, anterior-posterior and medial-lateral LV positions relative to chest depth and width, respectively, were also calculated. Relative positions were defined from −50% (the right lateral or the posterior aspect) to +50% (the left lateral or the anterior aspect), i.e., with the center of the chest at 0% medial-lateral and 0% anterior-posterior. While the LV position ranges are of significance for simulation studies, relative position data was considered to be easier for clinicians to interpret than raw position data. Regression analyses between LV position and other measures were therefore performed using the relative position data.

MRI analysis was performed in ImageJ [24] and cvi[42] (cvi[42] 2015, Circle Cardiovascular Imaging, Inc., Calgary, Canada). Native QRSd was determined using an ECG collected at 1-week post-implant follow-up device check (with CRT turned off) or using the ECG recorded immediately before CRT implant. Baseline LVEDV and EF were calculated from echocardiograms using the biplane Simpson's method by a single reviewer blinded to knowledge of MRI characteristics.

### 2.3. Statistics

Data are expressed as means ± standard deviations, unless otherwise indicated. Student's unpaired *t*-test was used to analyze unpaired

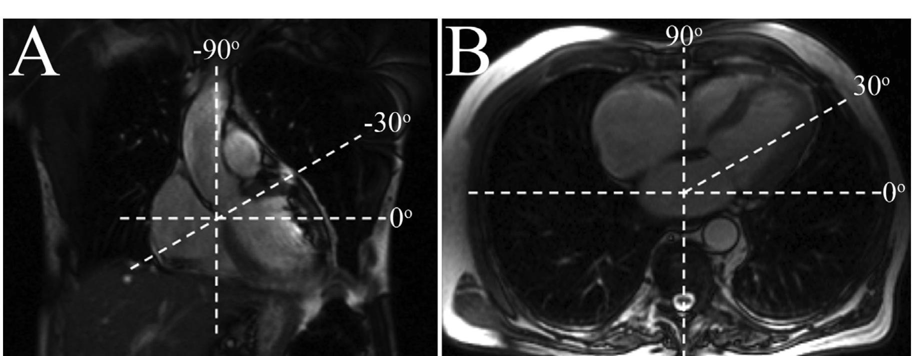


**Fig. 1.** Frontal and transverse plane LV orientation angles. Coordinate systems for frontal (A) and transverse (B) plane LV orientation angles.