

# Utilization of Computed Tomography for Left Ventricular Lead Placement to Optimize Cardiac Resynchronization Therapy

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## Abstract

**Objective:** This study evaluates the possible utility of computed tomography angiography (CTA) to optimize planning and lead placement during cardiac resynchronization therapy (CRT). We sought to evaluate how often leads were suboptimally placed and determine if CTA could identify a more optimal lead placement.

**Background:** CRT has been shown to improve morbidity and mortality associated with systolic heart failure. Nevertheless, a significant proportion of patients remain CRT non-responders, which may be due to location of LV lead placement. Evaluation of patients with CTA before device implantation may aid clinicians by providing a roadmap for LV lead placement. Hence, CTA may aide to decrease the number of CRT non-responders.

**Methods:** CTAs of 39 post-CRT patients were reviewed to assess LV lead placement. LV lead vein position was identified as the anterior interventricular vein (AIV), coronary sinus (CS), or posterolateral vein (PLV). If placed in the AIV, PLV identification was attempted. Also, each CTA was assessed for the presence of myocardial scar in the distribution of the LV lead. Suboptimal placement was considered when the lead was in the AIV (in the presence of a large, >3 mm, PLV) or when scar tissue was present in the distribution of the lead.

**Results:** The LV lead was positioned in the AIV in 19 (48.7%) patients, PLV in 19 (48.7%) patients; CS in 1 (2.6%) patient. 16 (41%) patients with AIV lead placements had a more optimal PLV present. Myocardial scar tissue was in the immediate vicinity of the LV lead in 7 (17.9%) patients. Thus, a total of 14 of 39 (35.9%) patients had suboptimal lead placement.

**Conclusion:** CTA can be used to delineate the coronary venous anatomy to aid in LV lead placement for optimization of CRT.

**Keywords:** Cardiac computed tomography; Bi-Ventricular lead; Electrophysiology; Heart failure; Cardiac resynchronization therapy

## Abbreviations

CTA: Computed Tomography Angiography; CRT: Cardiac Resynchronization Therapy; LV: Left Ventricular; MRI: Magnetic Resonance Imaging; AIV: Anterior Interventricular Vein; CS: Coronary Sinus; GCV: Great Cardiac Vein; PLV: Posterolateral Vein; MCV: Middle Cardiac Vein; LAD: Left Anterior Descending

## Introduction

Cardiac resynchronization therapy (CRT) as an adjunct to maximal medical therapy has been utilized in patients with moderate to severe systolic heart failure and prolonged intraventricular conduction over the past decade. Several large randomized controlled trials have shown an improvement in symptoms, as well as decrease in hospitalizations and mortality [1-5].

The beneficial effects of CRT are derived from improvement in electromechanical ventricular dyssynchrony; hence, improving systolic function with reduced medical costs. It has also been theorized that CRT may improve functional mitral regurgitation, and have positive

remodeling effects on the heart with cardiac chamber size reduction. Nevertheless, despite the positive effects of CRT, certain patients continue to decompensate. Currently, it is thought that 20% to 30% of patients do not respond to this costly therapy [6,7]. Studies demonstrate that selective use of surgical lead placement when anatomy is suboptimal improves outcomes. Thus, defining anatomy with non-invasive imaging may have a well-defined role prior to CRT.

Presently, there are several studies with the specific goal of determining the etiology of CRT non-responders. Improper left ventricular (LV) lead placement leading to ineffective resynchronization is a likely culprit of CRT failure. Several early trials demonstrated lateral placement of the left ventricular lead via a lateral branch of the coronary sinus was deemed optimal compared to an anterior placement [8-11]. Moreover, placing a lead on the site of myocardial scar will likely negate the positive effects of CRT as these sites are not likely to respond to electrical activity [12]. Pre-procedural definition of coronary venous anatomy and myocardial scar tissue would likely improve response to CRT.

Several imaging modalities have been used to aid in identifying proper lead placement including echocardiography, magnetic resonance imaging (MRI) and computed tomography angiography (CTA). CTA has the ability to identify both venous anatomy and

myocardial scar [13,14]. Given that CTA can identify both sub optimally placed LV leads and myocardial scar, we hypothesize that CTA can facilitate planning the best potential approach to LV lead revision. Hence, CTA may have utility in isolating the non-responders of CRT and planning an optimal approach to CRT implantation.

## Methods

### CTA acquisition

**CTA studies:** CT studies were performed initially using an Imatron C-150XLP CT scanner (GE-Imatron, San Francisco, CA), and subsequently a 64 detector Lightspeed VCT multi-detector computed tomography (MDCT) (GE, Milwaukee, WI). In order to optimize contrast enhancement in all studies, a single-level flow study was performed using 20 ml of Iopamidol (370 mg Iodine/ml) at 4 ml/sec to evaluate the contrast-agent circulation time required to opacify the ascending aorta. Contrast was administered through an antecubital vein. Average doses of contrast for the cohort were  $94 \pm 12$  cc.

**Electron beam computed tomography (EBCT) methodology:** A 50-70 axial slice CTA imaging sequence was obtained cranio-caudally using 1.5 mm slices and 1.5 mm/slice table incrementation during a single breath hold. A total of 100-140 ml of contrast agent was administered at a rate of 3.5- 4 ml/sec, based on patient weight and heart rate. Electrocardiographic triggering was employed utilizing the trigger method described by Mao et al. in which a heart rate-dependent delay is used to trigger image acquisition at the end of systole, minimizing coronary motion artifact [15]. The image acquisition time was 100 msec per image and the total scan time was 50 seconds. A  $512 \times 512$  matrix with a 15 or 18 cm of field-of view was employed. In order to decrease study and breath holding time, up to 1.2 mg atropine was administered intravenously (in 0.4 mg doses) just prior to image acquisition to ensure heart rates of  $>60$  beats per minute.

**64 MDCT methodology:** CTA images were acquired using 64-multi-detector row Lightspeed VCT scanner (GE Healthcare, Milwaukee, Wisconsin). The details of the image acquisition, published elsewhere, were typical of CTA for coronary assessment [16]. Using this protocol, both coronary arteries and veins were available for interpretation. All patients undergoing CTA had non-contrast studies as a part of the protocol for CAC score measurement. The scan parameters were  $64 \times 0.625$  mm collimation, tube voltage 120 mV, and effective mA 350 to 780 mA. Radiation reduction algorithms using electrocardiography modulations were used. This reduced the radiation exposure during systole and end-diastole. Beta blockers were used as needed intravenously (metoprolol) to slow the heart rate, without issue in this cohort. After the scans were completed, multiphase reconstruction of the CTA scans was performed. The images were reconstructed from 70% to 80% phase by 5% increments and 5% to 95% phase by 10% increments. All CTA images were transferred to a reading center at Los Angeles Biomedical Research Institute at Harbor-UCLA for 3-dimensional image analysis using the GE Advantage Workstation.

Contrast administration was determined by the time to cover the intended scan length. Thus, the length of the heart in the z-axis was the primary measure to determine contrast administration. Target heart rate aimed with use of beta-blockade was  $<65$  bpm for MDCT scans.

**Patient detection and data acquisition:** A database of approximately 20,000 patients who underwent cardiac CTA at our institution from

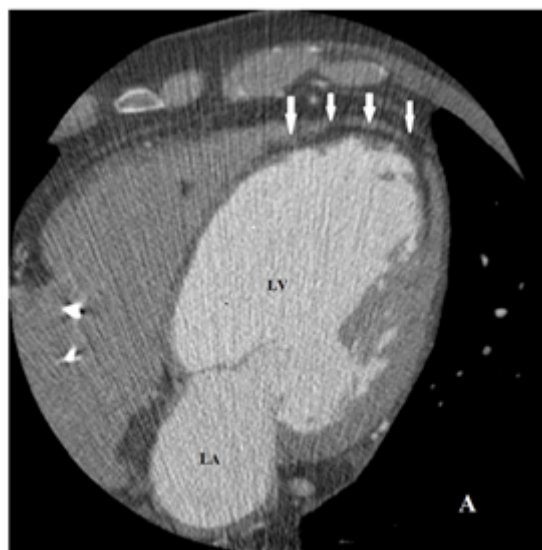
year 2000 to 2010 was searched to identify patients who had CRT devices present. This retrospective study used Digital Imaging and Communications in Medicine standard (DICOM) data from the patients selected. The DICOM images were obtained via an electron EBCT or with MDCT for various clinical indications including congestive heart failure, abnormal stress test results, chest pain, dyspnea or failed CRT implantation. All of the CTA images were of good quality and sufficient to evaluate lead placement and coronary veins. CRT was placed for either ischemic or non-ischemic cardiomyopathy with a QRS  $>120$  milliseconds and Ejection fraction  $<35\%$ . 39% of the patients enrolled had a LBBB pattern.

**Coronary venous anatomy and data analysis:** The CTA images were then viewed and assessed on the Advantage Workstation (General Electric, Milwaukee, WI). The 3-D images of the coronary arteries and veins were obtained using the workstation's volume-rendering program. At a threshold of 80-100 Hounsfield units, transverse, sagittal and coronal images were generated. The course of the coronary venous system was identified using axial data, volume rendering, curved multiplanar reformatting, and maximal intensity projections.

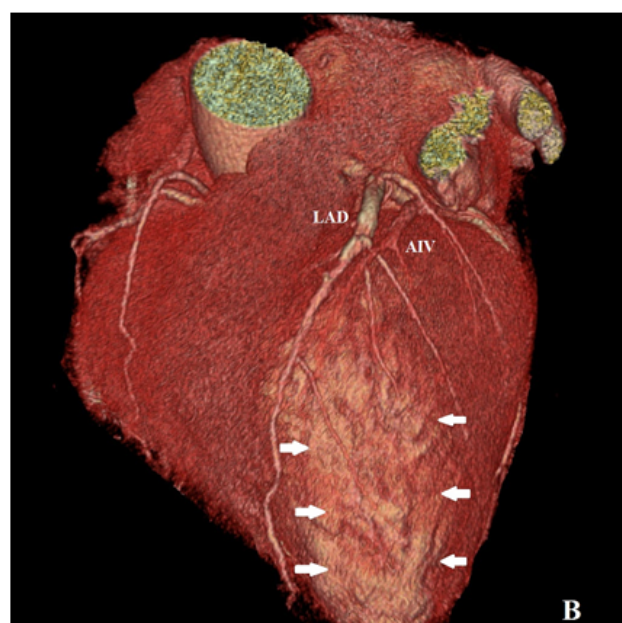
The images of the coronary venous anatomy were analyzed with branch identification and description of the spatial relationship to specific reference points and are described below. Atrial and ventricular chambers, atrioventricular groove, interventricular sulcus, and coronary arteries were used as reference points.

The coronary sinus (CS) ostium was branches off the posteroseptal region of the right atrium. The great cardiac vein (GCV) merges with the coronary sinus and runs along the posterolateral part of the atrioventricular groove. The posterolateral vein (PLV) is the dominant vein along the posterolateral aspect of the left ventricle and feeds into the GCV. The anterior interventricular vein (AIV) courses through the anteroventricular groove towards the apex of the heart and parallel to the left anterior descending (LAD) coronary artery. The middle cardiac vein (MCV) runs parallel to the posterior descending artery along the posterior septum of the heart.

The imaging data was analyzed for CRT left ventricular lead placement and coronary venous anatomy. The left ventricular lead tip was identified in the AIV, PLV or CS. The location of the lead tip in the heart was also described as either anterior, posterior or lateral. If the lead was found in the AIV, a posterolateral vein was searched for and measured. The proximal diameter of the veins was expressed as the mean  $\pm$  standard deviation. The presence of myocardial scar adjacent to the lead was identified. Myocardial scar was defined as a localized area of myocardial thinning, hypo-attenuation, and in rare cases, calcification as shown in Figures 1A-1C. For all patients, the structure, segmental location, and lowest Hounsfield units in the regions involved was assessed.



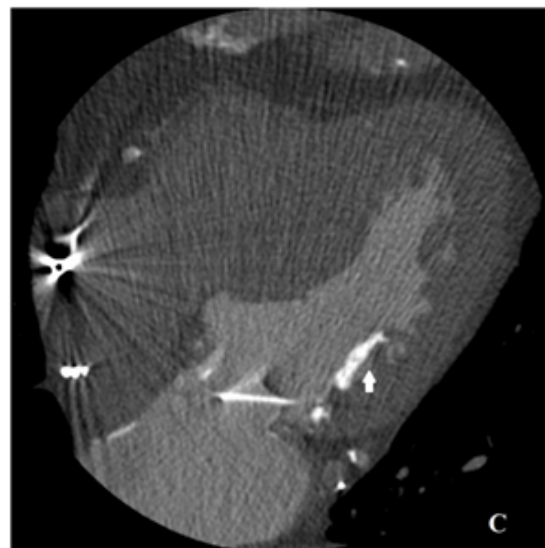
**Figure 1A:** Axial image showing myocardial scar as an area of hypoattenuation and myocardial thinning at the apex and septum (indicated by arrows).



**Figure 1B:** Volume rendered 3-dimensional reconstruction of the same patient showing myocardial scar. White arrows indicating scar.

Patients with suboptimal lead placements were identified. They were defined as left ventricular lead placement in the AIV with a PLV

identified >3 mm or the left ventricular lead placed in the distribution of myocardial scar or placed in the main body of the coronary sinus. Patients with inadequate coronary venous anatomy were defined as patients with AIV LV lead placement without an adequate PLV (<3 mm) and LV lead placement in scar, as these patients may benefit from epicardial LV lead placements.



**Figure 1C:** Axial image showing calcification along the base of the lateral wall in a location with myocardial scar

## Results

We identified 39 consecutive patients with prior CRT device implantations who had CTA performed. The baseline characteristics of these patients were collected from the respective charts and are listed in Table 1. The mean age was  $59 \pm 10$  years and 74% of patients were male. There were no complications of the CTA in this study population (contrast induced nephropathy, anaphylactoid reactions, hypotension).

Age	$58 \pm 10$
Male	74%
Diabetes mellitus	17%
Hypertension	33%
Hyperlipidemia	50%

**Table 1:** Baseline Characteristics

The results were listed in Table 2. There were an equal number of LV lead placements in the AIV (n = 19, 48.7%) and PLV (n = 19, 48.7%). One patient had LV lead placed in the coronary sinus. 16 of the 19 patients with AIV lead placements had a more optimal PLV that was visible with cardiac CTA (Table 2). The average PLV size of all patients with AIV LV lead placement was  $3.3 \pm 0.86$  mm. Of the 16 identified with a more optimal PLV, 12 patients had a PLV that measured greater than 3 mm proximally. The average PLV size in this group was  $3.7 \pm$



0.44 mm. Figure 2 demonstrates a PLV that was identified in a patient who had a suboptimal LV lead placement in the AIV.

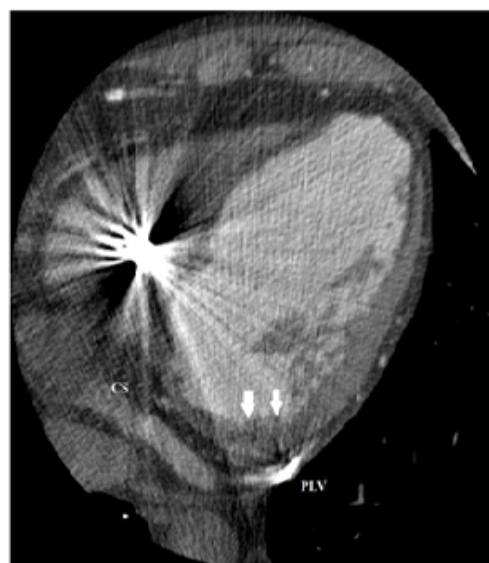
LV Lead Placement	
AIV	19 (48.7%)
Lateral	19 (48.7%)
CS	1 (2.6%)
LV lead in scar	8 (21 %)
PLV identified	16 (84%)*
PLV >3 mm	12 (63%)*
Average diameter of all PLV identified	3.3 ± 0.86 mm
PLV >3 mm	3.7 ± 0.44 mm
Suboptimal Lead Placement	12 (41%)

**Table 2:** Results



**Figure 2:** Multiplanar view demonstrating the coronary veins including the coronary sinus (CS), great cardiac vein (GCV) and posterolateral vein (PLV). The PLV was found in a patient with the LV lead placed in the AIV.

The LV lead was placed in a region of myocardial scar in 7 (17.9%) of the 39 patients as demonstrated in Figure 3. The total number of suboptimal lead placements included 14 (35.9%) patients. In addition, the number of patients with inadequate venous anatomy defined as alternate adequate size PLV (<3 mm) or with a PLV LV lead placement in scar tissue was 6 (15.3%).



**Figure 3:** Axial image of LV lead placed in posterolateral vein (PLV) adjacent to lateral scar.

Also of significance, there were certain anatomical variations that were identified with CTA that affected LV lead placement. There were two patients who had their LV lead placed in the AIV. Two patients had LV lead placements placed immediately adjacent to the RV lead. In another patient, a LV lead was placed in myocardial scar along the lateral wall. However, the PLV extended past the scar. Theoretically, the tip of the LV lead could have been placed farther into the PLV and beyond the scar tissue (Figure 4).

## Discussion

This is the first study to demonstrate simultaneous visualization of myocardial scar and coronary venous anatomy using CTA in CRT patients. We identified 35.9% of patients had suboptimal placement of their LV lead in the AIV when a PLV was present. Also, 17.9% of patients with CRT had LV lead placement in a region of myocardial scar.

CRT has become a mainstay in heart failure therapy for patients deemed optimal candidates by improving ventricular mechanical dyssynchrony. The most conventional placement of the left ventricular lead has been through a transvenous approach via the coronary sinus. To achieve the clinical benefits of CRT, the correct positioning of the LV lead is crucial. It can also be fraught with obstacles given the complexity and variability of the coronary venous anatomy. In a study by Gilard et al. [17] while the middle and great cardiac veins were visualized with angiography in all patients, visualization of the left posterior branch was variable. Pre-procedural visualization of the coronary venous system aids in the optimization of CRT. While the dose of CTA in this study was 7.8 mSv (which can be reduced by 80% by use of prospective triggering) [18], we have previously demonstrated that use of CTA can reduce radiation exposure in the cath lab, offsetting most of the dose given to perform the CTA. Girsky et al. [19] performed a prospective, randomized CT trial of patients undergoing CRT. They demonstrated that pre-procedure review of CT

coronary venous anatomy led to significantly decreased procedure times and utilization of contrast, fluoroscopy and guide catheters.



**Figure 4:** Volume rendered 3-dimensional reconstruction showing LV lead placed in the AIV which eventually lead into lateral area of the LV.

Currently, coronary venous anatomy is most often visualized with retrograde coronary venography (RCV). This procedure entails catheterization of the coronary sinus and injection of contrast while occluding the coronary os with a balloon. Disadvantages of this procedure include its invasiveness, the possibility of suboptimal visualization of the coronary venous system, as well as a small but measurable risk of balloon inflation. Retrograde coronary venography is also limited to a 2-dimensional view of the coronary venous system. In addition, RCV may require more contrast and radiation as multiple views are required [20].

CTA allows a three dimensional view of the coronary venous system in relation to the coronary arteries and other pertinent structures. CTA has been demonstrated to be able to identify anomalous structures potentially affecting the implant including a valve covering the coronary sinus ostium, coronary sinus diverticula, and left superior vena cava connection to the coronary sinus. [21,22] Recently, visualization of the relationship between the phrenic nerve and coronary veins has been demonstrated which is of potential importance in avoiding diaphragmatic pacing. [23] Finally, visualization of scar tissue and its relationship to the coronary venous system has been reported with CT angiography, providing a significant advantage over echocardiographic guidance [24].

In this study, we also elucidated individual variations that have potential clinical implications. In two of the patients with LV leads positioned in the AIV, the AIV had an unusual course which led to final placement in a high lateral position of the left ventricle. This anatomical variation may explain certain studies showing that a lateral vein of the coronary venous system may not necessarily be the most optimal [25]. Another patient with AIV placement had a PLV identified. However, placement of the LV lead in this PLV would likely not have led to clinical benefit since the lead would have been placed in

scar tissue. This exemplifies the use of cardiac CTA to easily identify individual variations in anatomy and potentially improve response to CRT.

CTA allows for comprehensive assessment of cardiovascular structure and function through non-invasive simultaneous 3-D visualization of cardiac chambers, coronary vessels, and thoracic vasculature. This enables assessment of structures particularly germane to electrophysiology studies including: the coronary veins, pulmonary veins, and left atrium. In contradistinction to CMR imaging, patients with pacemakers and claustrophobia can be studied and the entire course of the coronary anatomy can be discerned [26]. Our study suggests that CTA may be used as a roadmap for lead placement during CRT, which may reduce failure and complication rates. CTA may also have the application to elevate non responders to responders by guiding lead revision. Additionally, a pre-procedure CTA can inform the clinician that a LV lead placed through the coronary sinus may not be favorable because of a lack of a large enough PLV or scar tissue in the lateral part of the LV. In these cases, an epicardial lead through a surgical approach may be advantageous [27,28].

### Study limitations

Given that this was a retrospective study, selection bias may skew the percentage of patients with suboptimal placement. The study is also limited by having several heterogeneous variables. There were different types of CTA used, including EBCT and MDCT, depending on when the images were acquired. Also, most of the images were obtained for coronary artery visualization and not for venous anatomy. The study population was small and did not have a comparison group. Furthermore, we did not have data on clinical CRT non-responders, nor information regarding lead revisions based on the CCTA data. That will require a prospective evaluation.

### Conclusion

Our study indicates that CTA can provide an accurate roadmap for optimal lead placement for CRT, can improve the capacity for adequate therapy, and has the potential for reducing the rate of CRT failure. In our study, not only were we able to identify the possible etiology for non-responders, but also demonstrate a potential for revision. The prospective evaluation of CT angiography in this setting is warranted and large scale trials evaluating the potential clinical benefit of CT procedural guidance should be undertaken.

### Conflicts of interest

Dr. Budoff receives grant support from General Electric, no other author has any conflicts. This study was Unfunded.

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