A detailed assessment of the human coronary venous system using contrast computed tomography of perfusion-fixed specimens

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BACKGROUND Access to the coronary venous system is required for the delivery of several cardiac therapies including cardiac resynchronization therapy, coronary sinus ablation, and coronary drug delivery. Therefore, characterization of the coronary venous anatomy will provide insights to gain improved access to these vessels and subsequently improved therapies. For example, cardiac resynchronization therapy has a 30% nonresponder rate, partially due to suboptimal lead placement within the coronary veins.

OBJECTIVE To understand the implications of coronary venous anatomy for the development of devices deployed within these vessels.

METHODS We cannulated the coronary sinus of 121 perfusion-fixed human hearts with a venogram balloon catheter and injected contrast into the venous system while obtaining computed tomographic images. For each major coronary vein, distance to the coronary sinus, branching angle, arc length, tortuosity, number of branches, and ostial diameter were assessed from the reconstructed anatomy.

RESULTS Twenty-nine percent (35/121) specimens did not have a venous branch overlying the inferolateral side of the heart large enough to fit a 5F pacing lead. No significant differences in anatomy were found between subgroups with varying cardiac medical histories.

CONCLUSION The anatomical approach employed in this study has allowed for the development of a unique database of human coronary venous anatomy that can be used for the optimization of design and delivery of cardiac devices.

KEYWORDS Coronary; Cardiac; Vein; Pacing; Anatomy

ABBREVIATIONS CHF = chronic heart failure; **CRT** = cardiac resynchronization therapy; **CT** = computed tomography

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Introduction

Understanding the coronary venous system is critical for the development and deployment of therapies and devices that use these vessels. Current devices include cardiac resynchronization therapy (CRT),[1] coronary sinus ablation,[2,3] coronary artery bypass,[4] mitral valve annuloplasty devices,[5] defibrillation,[6] and cell therapy.[7,8]

CRT is currently one of the most common clinical applications that require access to the coronary venous system. During CRT, a pacing lead is placed in a coronary vein to pace the left ventricle, ideally at the latest site of activation to improve delayed conduction.[9–14] For many patients, this delay occurs on the inferolateral side of the heart.[15] Several clinical trials have demonstrated that CRT is an effective therapy for moderate to severe heart failure.[16–19] However, 30% of the patients do not respond to the treatment. One of the predictors for nonresponders is suboptimal lead placement.[20] A better understanding of the coronary venous anatomy is essential for improving suboptimal lead placements.

The coronary veins are referred to by several different nomenclatures in the literature. We chose to use attitudinally correct nomenclature consistent with our previous publications.[21,22] In this study, we further classified the lateral veins into 3 subgroups: (1) inferolateral veins, (2) left lateral veins, and (3) anterolateral veins. The anatomy of the inferolateral veins is of particular relevance to the development of CRT delivery devices.[15]

In this study, images obtained from computed tomography (CT) scans are used to construct 3-dimensional models of the coronary venous system. These models are used to evaluate the venous anatomy in order to provide inputs for the design of devices deployed into these vessels. In addition, the results of this study can provide electrophysiologists with a further understanding of the range of venous anatomy that can be expected during procedures that require access to the veins. Specifically, the study aims to identify the major coronary veins on the inferolateral side of the heart for the application of CRT. In addition, the information will be used to evaluate anatomical differences and their relation to varying diseased states. The conditions of interest for this study include heart failure, hypertension, atrial fibrillation,

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and coronary artery disease. Specimens from patients with a history of these disorders were evaluated.

Methods

Study population

We assessed the coronary venous system of 121 freshly obtained human hearts. These specimens were obtained through LifeSource Inc (Organ and Tissue Donation, St Paul, MN) or the University of Minnesota Anatomy Bequest Program (Minneapolis, MN). The participants or their family members provided consent to use these hearts for research. The hearts were perfusion fixed using 10% formalin. The superior vena cava, pulmonary trunk, 1 pulmonary vein, and the aorta of each specimen were cannulated and connected to an upper container filled with formalin. The specimens were submerged in formalin in a lower container, while formalin was continuously pumped to the upper chamber to maintain a pressure head of 40–50 mm Hg. This method fixes the specimens in their approximate end-diastolic shape.[23]

Detailed medical histories were available for 114 of 121 (94%) specimens, and those are summarized in Table 1. We compared anatomical parameters between 5 subgroups on the basis of the reported cardiac history: (1) no history of cardiac disease, 2) heart failure, 3) hypertension, 4) atrial fibrillation, and 5) coronary artery disease. Table 2 presents the mean and SD of the patient weight and age for the study population and each subgroup.

Contrast CT

The specimens were scanned by using a 64 multidetector CT scanner (Sensation 64, Siemens, Munich, Germany) at the University of Minnesota Fairview Health Services. To prepare for CT scans, the coronary sinus of each specimen was cannulated with a venogram balloon catheter and the specimen was placed in its attitudinally correct position within the scanner. Contrast was injected into the venous system at 5 mL/s for 8 seconds, and the CT scan was obtained. After the contrast injection, the catheter and venous system were flushed with saline to remove the remaining contrast. The resulting scans provided 512 × 512 resolution images with 0.6-mm slice thickness.[23]

Model generation and anatomical assessment

The CT scans were uploaded into Mimics software (Materialise, Leuven, Belgium), and the coronary venous system of each specimen was reconstructed into a 3-dimensional model. Centerlines were generated for the resulting 3-dimensional model as displayed in Figure 1. The prevalence of major veins as well as the prevalence of any major vein on the basal inferolateral side was recorded.

Table 1 Summary of the study population's medical history

Medical history	Sample size
Total study population	121
Healthy	34
Heart failure	11
Hypertension	45
Atrial fibrillation	14
Coronary artery disease	11
Other cardiac history	29
No data available	7

Table 2 Mean and SD of the patient weight and age for the study population and subgroups

Study population	Patient weight (kg)	Patient age (y)
All hearts (n = 121)	79.9 ± 19.8	58.0 ± 15.9
Healthy (n = 34)	77.3 ± 21.3	52.6 ± 18.3
Heart failure (n = 11)	81.0 ± 21.1	66.6 ± 16.7
Hypertension (n = 45)	82.3 ± 19.4	63.1 ± 12.3
Atrial fibrillation (n = 14)	77.3 ± 22.5	72.1 ± 12.1
Coronary artery disease (n = 11)	85.0 ± 21.6	62.0 ± 11.8

Anatomical parameters were then assessed for each primary vein greater than 20 mm in arc length by using Mimics and 3-Matic Software (Materialise). Veins less than 20 mm in arc length were considered not clinically relevant and therefore were not assessed. The arc length of each major vein was measured by using the generated centerlines from the start to the end of the vein. Tortuosity was assessed as the ratio of the arc length to the linear distance from the start to the end of the vein. The proximal branching angle to the coronary sinus was determined as well as the distance from each vein's ostium to the coronary sinus ostium. The long and short axis of each vein's ostium was measured by reslicing the CT images so that the ostium was in plane, as displayed in Figure 2. For the inferolateral veins or veins with branches on the inferolateral wall, the CT images were resliced along the centerline of the vein. The minimum venous diameter was measured 40 mm from the venous ostium. It was recorded if this diameter was less than 1.6 mm, which indicated the vessel was too small to implant a 5-F lead. The number of secondary branches for each primary vein was recorded as well.

Statistical analysis

Anatomical parameters are presented as mean ± SD. For each parameter, normal and nonparametric tolerance intervals were calculated for 90% of the population with 95% confidence by using Minitab software (Minitab Inc, State College, PA). This generates a range that includes 90% of the population with 95% certainty. In other words, it provides the upper and lower extremes for each parameter in the population. Anderson-Darling statistical analyses were performed for each data set to determine whether the data distributions were normal or nonparametric. Data sets resulting in a P value less than .05 were considered nonparametric. Wilcoxon rank sum tests were performed to compare anatomies between specimens with no history of cardiac disease and specimens with a history of (1) heart failure, (2) hypertension, (3) atrial fibrillation, and (4) coronary artery disease.

Results

Table 3 summarizes the prevalence of major veins. Only 14 of 121 (12%) specimens had a visible small cardiac vein greater