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Performance of 3D, Navigator-Echo Gated, Contrast-Enhanced, Magnetic Resonance Coronary Vein Imaging in Patients Undergoing CRT

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Abstract

Purpose—The aims of this study were to evaluate the ability of contrast-enhanced MRI to visualize the coronary veins with validation by the gold standard, X-ray venography, and to determine whether MRI can visualize the coronary vein branch used for LV lead implantation.

Materials and Methods—Nineteen (19) patients undergoing CRT received a cardiac MRI at 1.5T 1 week before treatment. Coronary vein images were acquired using a 3D, navigator- and ECG-gated, contrast-enhanced, inversion-recovery, fast low angle shot (FLASH) sequence. X-ray venography was performed during the CRT procedure to image the coronary venous anatomy and the LV lead location. MRI coronary vein images were graded on a 0 – 3 scale (0 = non-existent, 1 = poor, 2 = good, 3 = excellent). MRI and X-ray venogram images were also graded using a binary visible/not visible scheme to compare the visibility of the coronary veins.

Results—The mean visibility scores for the coronary sinus, the posterior interventricular, the posterior vein of the left ventricle, the left marginal vein, and the anterior interventricular were 3.0 ± 0.2, 2.3 ± 0.7, 1.6 ± 1.1, 1.9 ± 0.8 and 2.4 ± 0.9 respectively. When compared to X-ray venography, MRI was capable of visualizing 90% of veins and all of the veins used for LV lead implantation. The vein used for LV lead implantation had an average vein image quality score of 1.9 on MRI images.

Conclusions—Contrast-enhanced MRI was capable of visualizing 90% of the coronary venous anatomy and was able visualize the vein used for LV lead implantation in all patients.

Keywords

coronary vein; CRT; MRI; X-ray venography

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Introduction

Cardiac Resynchronization Therapy (CRT) uses a biventricular pacemaker to create synchronous contraction of the ventricles of the heart. The left ventricular (LV) pacing lead is typically implanted through the coronary venous system at an epicardial site along the lateral LV wall. Studies have shown that the location of LV pacing lead affects CRT response and the optimal lead location is in the latest contracting segment of the heart that is not primarily myocardial scar tissue[1, 2]. Since the coronary veins are only imaged during LV lead implantation by retrograde venography and X-ray fluoroscopy, there is no way to know *a priori* if the lead can be implanted at an optimal location. Additionally LV lead implantation has complication rates of 2-5%, which occasionally requires repeat invasive procedures [3, 4]. Therefore, pre-procedural knowledge of the coronary venous anatomy can help improve LV lead implantation success rates and determine whether the optimal lead implantation location has coronary vein access.

Studies using contrast-enhanced MRI for coronary vein imaging have shown that the technique is capable of visualizing the coronary venous vasculature [5, 6]. However, none of these studies have had corresponding X-ray venograms to validate the existence of the coronary veins visualized by MRI, and most studies have small sample sizes [7]. The small size and tortuous nature of the coronary vein tributaries leads to subjectivity when determining the existence of a vein, and hence validation of the veins imaged by MRI with a reference standard such as X-ray venography is necessary. The objective of this study is to determine the accuracy of contrast-enhanced coronary vein imaging for visualizing coronary venous anatomy as compared to X-ray venography, and to determine whether the vein that is ultimately used for lead implantation is identified by a pre-procedure MRI.

Methods

Patient Population

Patients (n=19, 9 male, age 70 ± 10 years) scheduled to undergo CRT from 01/2011 – 05/2013 at a single institution were included in this study. Patients received a cardiac MRI 6 hours to 1 week before X-ray venography, which occurred during the CRT procedure. The patients met current clinical criteria for CRT (EF < 35%, QRS duration > 120 ms, New York Heart Association Class III+, heart failure despite stable medication for 1 month) [8]. This study was approved by the Institutional Review Board (IRB) and HIPAA compliant, and all patients gave written informed consent.

MRI Protocol

All cardiac magnetic resonance (CMR) exams were performed on a 1.5T MRI (Avanto or Espree, Siemens Medical Systems) system using a six-element phased-array cardiac coil. Short and long axis cine images of the left ventricle were acquired. The cine vertical long axis (VLA) was used to find the resting period of the coronary sinus [9]. The coronary venous anatomy was imaged using a 3D whole-heart, navigator and EKG-gated, inversion-recovery FLASH sequence with a centric k-space trajectory. A double dose of gadobenate dimeglumine at 0.2 mmol/kg (MultiHance, Bracco Diagnostics Inc, NJ, USA) was slowly infused at a rate of 0.3 mL/s, followed by an equal amount of saline. Acquisition started ~ 45 seconds after the start of contrast injection to ensure contrast was present in the coronary veins [10]. The sequence parameters were: TR = 3.3 ms, TE = 1.49 ms, flip angle = 15°, inversion time = 200 ms, readout bandwidth = 610 Hz/pixel, and number of segments per heartbeat = 47. 70 – 100 partitions with voxel size 1.3 × 1.3 × 1.5 mm^3 were acquired and interpolated to 140 – 200 partitions with 0.64 x 0.64 x 0.75 mm^3 voxel size. The generalized autocalibrating partially parallel acquisitions (GRAPPA) technique was used for parallel imaging with an acceleration factor of 2. The total scan time was 4.19 minutes assuming 100% navigator efficiency with a heart rate of 71 bpm.

X-ray Venography

Catheter-based X-ray venography was performed during the CRT procedure, immediately before pacemaker lead implantation by an experienced cardiac electrophysiologist (M.L. or M.H.) to visualize the coronary venous system. The coronary sinus (CS) was cannulated with an introducer sheath and a balloon catheter was inflated to occlude the coronary sinus. An iodinated contrast agent was injected retrograde through the coronary sinus to visualize the venous system. Cine images at 30° left anterior oblique (LAO) and right anterior oblique (RAO) were acquired during contrast injection and were used as a reference for LV lead positioning[11]. LAO and RAO single frame views were taken after LV lead implantation and were used along with the cine images to determine the vein segment in which the lead was implanted.

MR Coronary Vein Image Grading

MR coronary vein images were graded for visibility based on the following segments: coronary sinus (CS), posterior and anterior interventricular (PIV/AIV), posterior vein of the left ventricle (PVLV) and left marginal vein (LMV), Figure 1. MRI images were graded on a scale of 0-3 (3 = sharp borders, high contrast between vessel lumen and myocardium, 2 = fair lumen/myocardium contrast with slightly blurred edges, 1 = noisy lumen, poor contrast with myocardium with blurred edges, 0 = not visible/non-existent; Figure 2 and Supplementary Video 1). Images were evaluated independently by an MRI scientist and a cardiac electrophysiologist (A.L.,L.V.).

MRI to X-ray Venogram Visibility

Coronary veins were also given a binary classification on MRI of ‘visible’ or ‘not visible’. A vein needed to have an average score of ≥ 1 between readers in order for the vein to be considered ‘visible’ by MRI. Vein segments on X-ray venograms were graded as visible or not visible by a cardiac electrophysiologist and used as a gold standard for visibility comparison. Only veins visible by X-ray venography were considered in the analysis.

Results

X-ray Venography

X-ray venography was successfully performed in all 19 patients. Three X-ray venograms were of non-interpretable quality due to insufficient balloon occlusion of the coronary sinus as determined by the grading electrophysiologist and excluded in the X-ray venogram to

MRI concordance comparisons (Supplementary Video 2). Therefore, final comparisons were done in 16 subjects.

MR Coronary Vein Image Grading

The coronary veins were successfully imaged by MR in all 19 patients. Acquisition time of the whole-heart MR sequence was 9.8 ± 2.5 min with navigator efficiency of 48 ± 15%. MR coronary vein image quality scores are shown in Table 1. The CS was observed in all patients (19/19) and had an average image quality score of 3.0. The PIV and AIV were observed in all but one patient (18/19) and had slightly lower image quality scores, 2.3 and 2.4 respectively. The PVLV was observed in 15/19 patients and the LMV was observed in 17/19 patients and had the lowest image quality scores, 1.6 and 1.9 respectively.

MRI to X-ray Venogram Visibility

Concordance comparisons were successfully performed between MR images and X-ray venograms in 16 patients (Figure 3). X-ray venography imaged the CS in 100% (16/16) of patients, the PIV in 70% (13/16) of patients, the PVLV in 60% (11/16) of patients, the LMV in 85% (15/16) of patients, and the AIV in 75% (15/16) of patients. Of these vein segments seen by X-ray venography, MRI was capable of resolving all of the CS segments, 12/13 of the PIV segments, 8/11 of the PVLV segments, 13/15 of the LMV segments, and 15/16 of the AIV segments. In total, MRI visualized 90% (64/71) vein segments, Table 2.

Coronary Vein LV Lead Placement

The coronary vein branch used for LV lead placement was imaged by X-ray venography in 14/16 patients. Lead placement could not be determined by X-ray venogram images because the final lead position was not imaged in one case and because of multiple LV lead implantation attempts in different branches in the other case. The most common vein used for LV lead placement was the LMV, which was used in 10 patients. The lead was placed in a PVLV in 3 patients and in the AIV in one patient. The vein used for LV lead placement was visible by MR images in all patients and had an average MR visibility score of 1.9.

Discussion

The major findings of this study were: 1) MRI was able to visualize 90% of the coronary venous anatomy when compared to the gold standard, retrograde X-ray venography and 2) MRI was able to visualize the vein used for LV lead implantation for all patients. These results show that MRI can be used as a tool for pre-procedural planning for patients undergoing CRT.

There were cases in which MR was not able to resolve particular coronary veins as seen by X-ray venography. These cases most commonly occurred in the lateral branches, such as the PVLV and LMV, and this is reflected by their slightly lower image quality scores. The lower scores are expected due to the vein's small size and in-plane orientation, which leads to decreased contrast between the vessel and myocardium and partial volume effects. A short-axis imaging orientation may help remedy partial volume effects, but this imaging orientation obscures branch take-off points, which are important to help estimate the direction of the branch and requires more slices for whole heart imaging, lengthening the acquisition time. Although MRI may not be able to resolve all of the smaller branches, these branches may not be clinically relevant. Smaller coronary vein branches are typically more difficult to cannulate and may have a greater risk of dissection or perforation. A higher vein quality score of the vein used for LV lead implantation demonstrates that MRI is capable of sufficiently resolving all clinically relevant veins.

There were multiple cases in which a vein was visible on the MR images but not on the venogram images. This occurred with 5 PIVs and 6 PVLVs. Since this study uses X-ray venography as the gold standard for coronary vein imaging, all veins identified by MRI but not by X-ray venography could be considered false positives by MRI. However, the balloon used in X-ray venography is inflated in the coronary sinus and can also block contrast from flowing down the PIV and occasionally the PVLV. Therefore, veins may be identified using MRI but not by X-ray venography. A method which eliminates potential issues with blocking the PVLV or PIV with the balloon is necessary to discern whether the veins that were solely visible by MRI are “false positives” or are veins that are present but not seen by X-ray venography.

There were multiple cases with low quality X-ray venograms, including three cases in which insufficient balloon occlusion of the coronary sinus resulted in limited opacification of the coronary vein anatomy and two cases in which the vein used for LV lead implantation was not visible by venography. However, based on prior experience, electrophysiologists are capable of estimating the general position and angle of a missing branch to guide the LV lead wire down a coronary vein not visible on the X-ray venograms. This is non-ideal, as the placement of the lead in an optimal location for these cases relies on physician experience and skill to move the guide wire into a branch that cannot be seen. Pre-procedural coronary vein imaging by MRI would eliminate these cases, allowing physiologists to more accurately estimate the location and angle of the desired implanting coronary vein branch before attempting lead implantation.

Recently, multislice spiral computed tomography (MSCT) has also been used for non-invasive coronary vein imaging [12, 13]. This method is capable of acquiring the coronary venous anatomy with greater SNR, at higher resolution, and with faster speeds than MRI. However, pre-procedural determination of optimal LV lead placement often necessitates knowledge of the latest contracting region and the extent of myocardial scar in addition to coronary venous anatomy. Cardiac MRI is the currently only imaging modality that is capable of determining all three factors. As a result, MRI is currently the best option for pre-procedural LV lead planning in patients undergoing CRT.

There were limitations to this study. This was a retrospective study and only enough contrast was injected retrograde into the coronary sinus for X-ray venography as deemed necessary by the performing electrophysiologist. This led to cases with low quality X-ray venograms and balloon occlusion at the PIV/PVLV. Coronary vein imaging by balloon occlusion also created some non-physiologic distortion of the coronary venous anatomy, and several of the coronary veins did appear larger on venography than on MRI. However, as quantitative coronary angiography (QCA) was not available, specific quantitative comparisons could not be made to characterize the degree of distortion. Since both X-ray venograms and MR coronary vein images were graded by users, there is subjectivity in determining the existence of a vein. A larger sample size would also help strengthen the capability of MRI to resolve the coronary venous anatomy. Lastly, these studies were done at 1.5T using a 6-channel coil. Studies have shown that image quality can be improved by performing studies on a 3T MRI with a 32 channel coil for maximum SNR [6]. However, most CMR studies are still performed at 1.5T because of better consistency of SSFP imaging at 1.5T [14].

Conclusion

In this study, MRI was capable of visualizing 90% of the coronary veins seen by X-ray venography. All veins used for LV lead placement in CRT were seen in the pre-procedure MRI. MRI may serve as a suitable imaging modality for pre-procedural planning of LV lead implantation.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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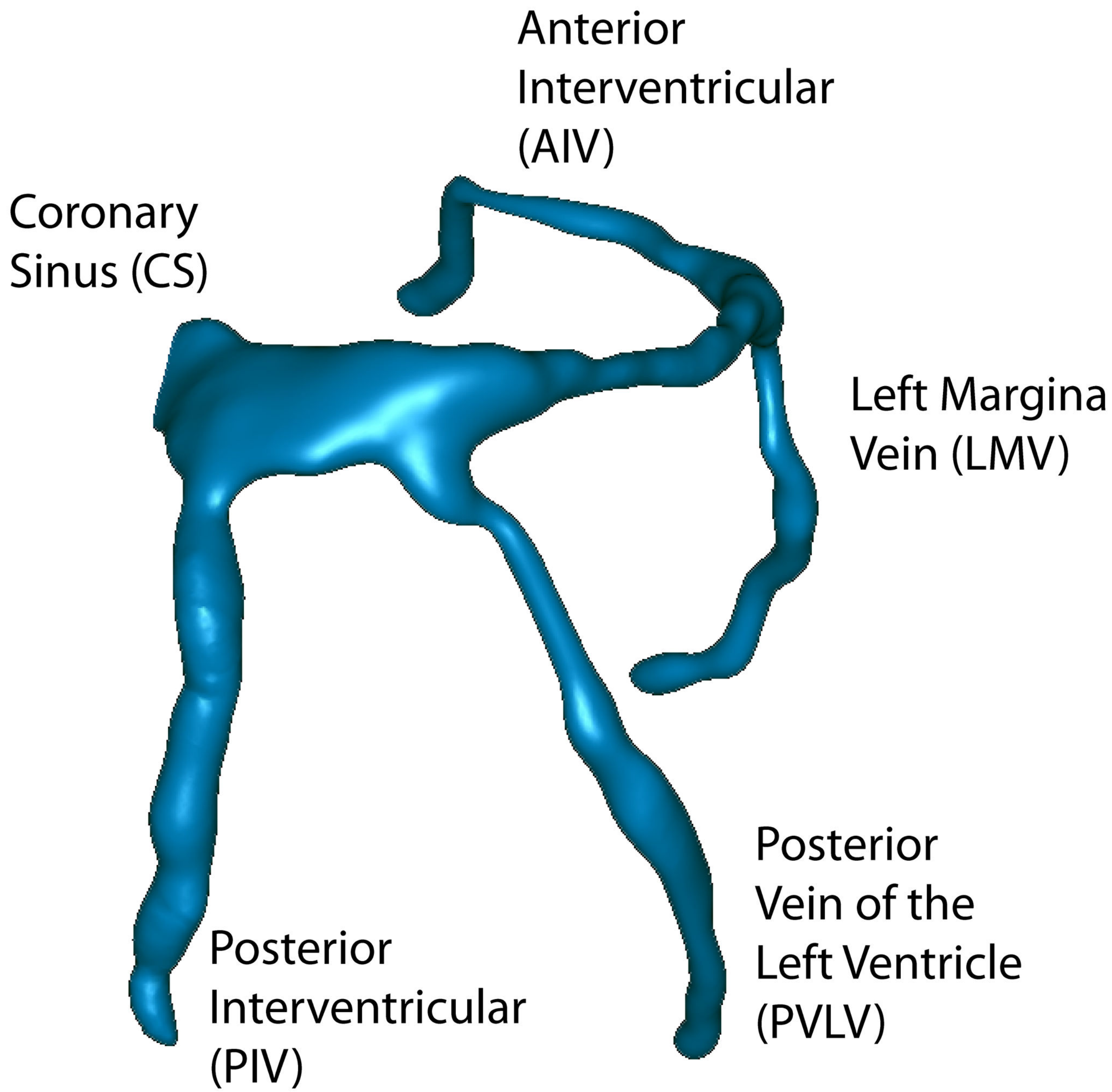

Figure 1. Coronary venous anatomy

Coronary vein anatomy segmented from MRI coronary vein images using Segment (Medviso AB; Lund, Sweden [15]) and smoothed using Geomagic (Raleigh, NC)

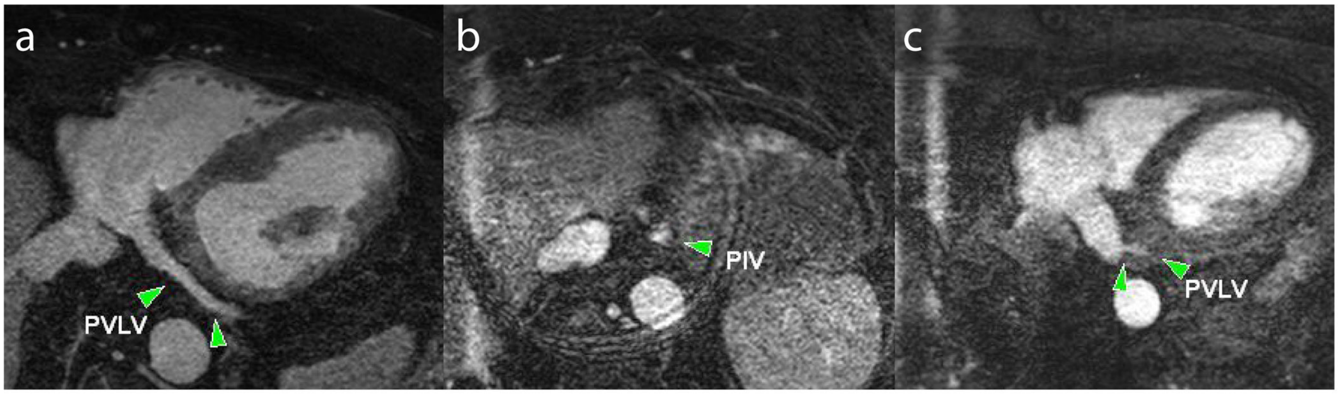

Figure 2. Coronary vein image quality

Sample coronary veins imaged by MRI with different image quality grades are shown. a) PVLV with a coronary vein grade of 3, b) PIV with coronary vein grade of 2, and c) PVLV with coronary vein grade of 1.

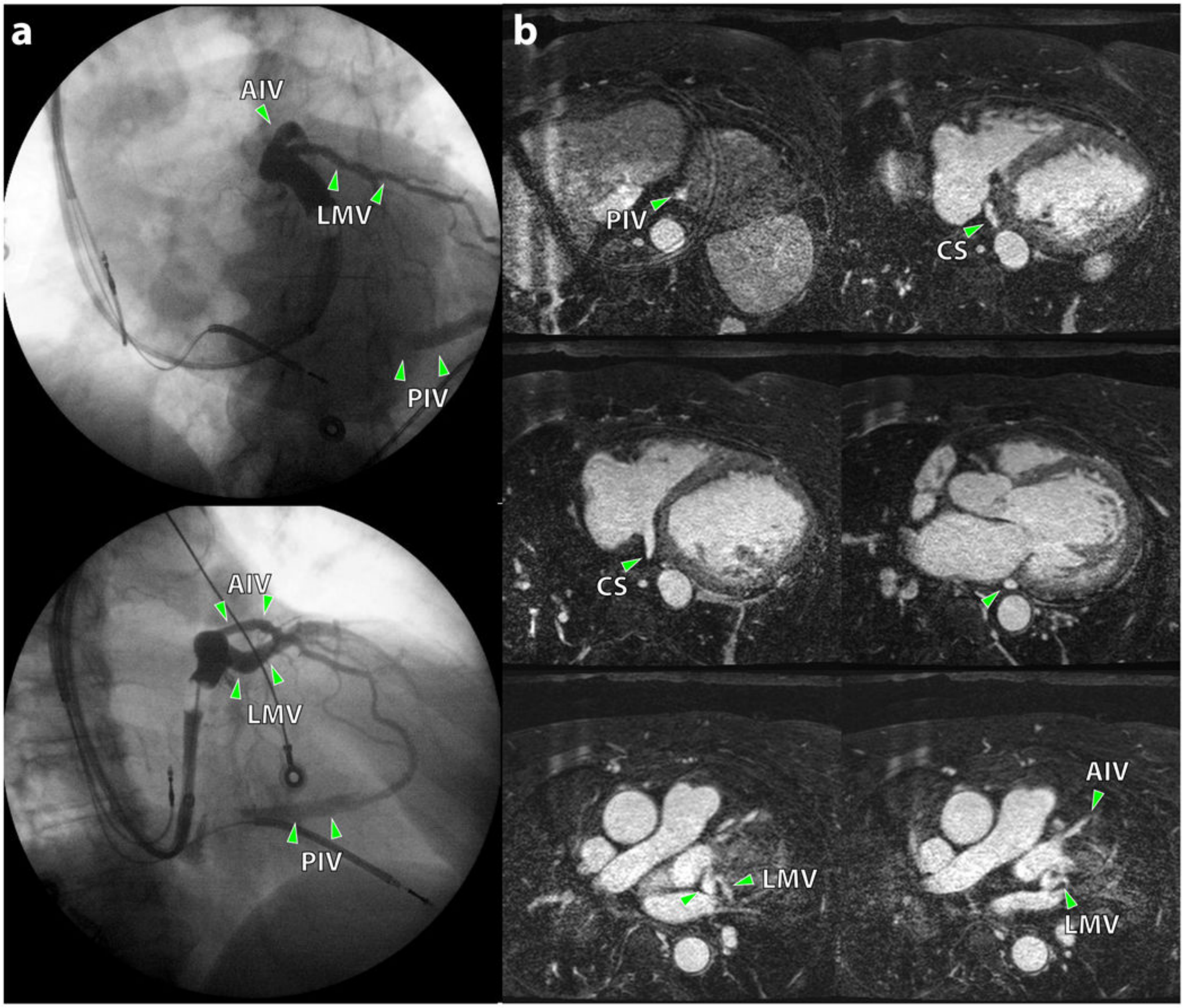

Figure 3. Coronary vein image comparison

Coronary venous anatomy imaged by X-ray venography and the corresponding MRI for a patient are shown above. Coronary veins are indicated by the green arrows. a) X-ray venography images showing LAO (top) and RAO (bottom) projections. b) Six slices from a MR coronary vein image stack.

Table 1

Coronary Vein Images Evaluated by MRI

	CS	PIV	PVLV	LMV	AIV
MR Visibility Score	19 (100%)	18 (95%)	15 (79%)	17 (89%)	18 (95%)
Average Vein Score	3.0 ± 0.2	2.3 ± 0.7	1.6 ± 1.1	1.9 ± 0.8	2.4 ± 0.9

MR visibility score and the average vein score among all patients are shown above. Values are averaged between two graders and veins were excluded and considered nonexistent if the average vein score was less than 1.

Table 2

Coronary Vein Concordance: X-ray Venography vs MRI

	CS	PIV	PVLV	LMV	AIV
Venogram Visibility (n = 16)	16	13	11	15	16
MR Visibility	16 (100%)	12 (92%)	8 (73%)	13 (87%)	15 (94%)
MR Image Quality Score	2.9 ± 0.3	2.0 ± 0.8	1.4 ± 1.1	1.7 ± 0.9	2.2 ± 1.1

X-ray venogram and MR visibility for the coronary veins are shown above. Coronary veins were excluded from the MR image quality score calculation if the vein was not visible by x-ray venography.