Multimodality Imaging of Anatomy and Function in Coronary Artery Disease

Schuijf, J.D.

Chapter 24

Non-Invasive Visualization of the Cardiac Venous System in Coronary Artery Disease Patients using 64-slice Computed Tomography

Nico R. Van de Veire, Joanne D. Schuijf, Johan De Sutter, Dan Devos, Gabe B. Bleeker, Albert de Roos, Ernst E. van der Wall, Martin J. Schalij, Jeroen J. Bax

J Am Coll Cardiol 2006; 48: 1832-1838

Abstract

Background

Cardiac resynchronization therapy (CRT) is an attractive treatment for selected heart failure patients. Knowledge on venous anatomy may help identifying candidates for successful left ventricular lead implantation. The purpose of the study was to evaluate the value of 64-slice computed tomography (CT) to visualize the cardiac veins and evaluate the relation between variations in venous anatomy and history of infarction.

Methods

The 64-slice CT of 100 individuals (age 61±11 years, 68% men) was studied. Subjects were divided in 3 groups: 28 controls, 38 patients with significant coronary artery disease (CAD), 34 patients with a history of infarction. Presence of the following coronary sinus (CS) tributaries was evaluated: posterior interventricular vein (PIV), posterior vein of the left ventricle (PVLV) and left marginal vein (LMV). Vessel diameters were also measured.

Results

CS and PIV were identified in all individuals. PVLV was observed in 96% of controls, 84% of CAD and 82% of infarction patients. In patients with a history of infarction, a LMV was significantly less observed as compared to controls and CAD patients (27% versus 71% and 61% respectively, $p<0.001$). None of the patients with lateral infarction and only 22% of patients with anterior infarction had a LMV. Regarding quantitative data no significant differences were observed between the groups.

Conclusion

Non-invasive evaluation of cardiac veins with 64-slice CT is feasible. There is considerable variation in venous anatomy. Patients with a history of infarction were less likely to have a LMV which may hamper optimal left ventricular lead positioning in CRT implantation.

Introduction

Cardiac resynchronization therapy (CRT) has become an attractive treatment option for highly symptomatic heart failure patients with a broad QRS complex on the surface ECG and poor left ventricular (LV) systolic function [1-3]. In selected patients CRT reduces symptoms and improves exercise capacity. The CARE-HF trial also reported a significant reduction of morbidity and mortality, compared to optimized medical treatment [4]. However, in large randomized trials, up to 30% of the patients undergoing CRT do not respond favourably to this invasive treatment [5]. In order to improve the success rate, several issues including echocardiographic evaluation of mechanical dyssynchrony and the evaluation of viability in the target region for the LV pacing lead, should be addressed during the selection of potential candidates [6]. Another important pre-implantation issue is knowledge on the cardiac venous anatomy of the candidate. Even if viable tissue is identified in the region with the latest mechanical activation, endocardial CRT implantation will only be successful if the LV lead can be positioned in a vein draining this region. Ideally, venous anatomy should be assessed before implantation, non-invasively in the outpatient clinic, to determine whether a transvenous approach is feasible. The feasibility of multi-slice computed tomography (MSCT) to visualize the venous anatomy was recently demonstrated in a study with 16-detector row CT [7]. The authors described a marked variability in venous anatomy, confirming previous invasive studies [8]. The absence of coronary sinus tributaries may be related to scar formation secondary to previous myocardial infarction in the region drained by these specific veins. In the present study, the cardiac venous anatomy of 100 subjects undergoing non-invasive coronary angiography with 64-slice MSCT was retrospectively evaluated. The study aims were 1) to evaluate the feasibility of 64-slice MSCT to depict the cardiac venous system and 2) to evaluate the relationship between variations in cardiac venous anatomy and previous myocardial infarction.

Methods

Study population

The anatomy of the cardiac venous system was retrospectively studied in 100 consecutive subjects (68 men, age 61 ± 11 years) in whom MSCT was performed for non-invasive evaluation of the coronary arteries. The population was divided in three groups. Twenty-eight subjects had normal coronary arteries (controls). Thirty-eight patients had significant coronary artery disease (CAD) without a history of previous infarction. Thirty-four patients had CAD and a history of myocardial infarction; mean time between occurrence of the myocardial infarction and CT acquisition was 49 ± 7 months.

Multi-slice computed tomography

Imaging was performed with a 64-detector row Toshiba Multislice Aquilion 64 system (Toshiba Medical Systems, Otawara, Japan). Between 80 and 110 ml of contrast material (Iomeron 400, Bracco Altana Pharma GmbH, Konstanz, Germany) at an injection rate of 5 ml/minute was used. Scanning was performed using simultaneous acquisition of 64 sections with a collimated slice thickness of 0.5 mm. Rotation time ranged from 400 to 500 ms depending on heart-rate and tube voltage was 120 kV at 300 mA. A segmental reconstruction algorithm allowed inclusion of patients with a range of heart rates without the need for pre-oxygenation or beta-blocking agents. Retrospective ECG gating was performed to eliminate cardiac motion artefacts. Data reconstruction was performed on a Vitrea post-processing workstation (Vital Images, Plymouth, Minnesota). During analysis, the observers were blinded to the group assignments of the participants.

Anatomic observations

The tributaries of the cardiac venous system (Figure 1) were identified on volume-rendered reconstructions. Thereafter, the course of the veins was evaluated in three orthogonal planes using multiplanar reformatting. The presence of the following cardiac veins was evaluated: CS, anterior interventricular vein, posterior interventricular vein (PIV), posterior vein of the left ventricle (PVLV) and left marginal vein (LMV). The number of side branches of these tributaries was also evaluated.

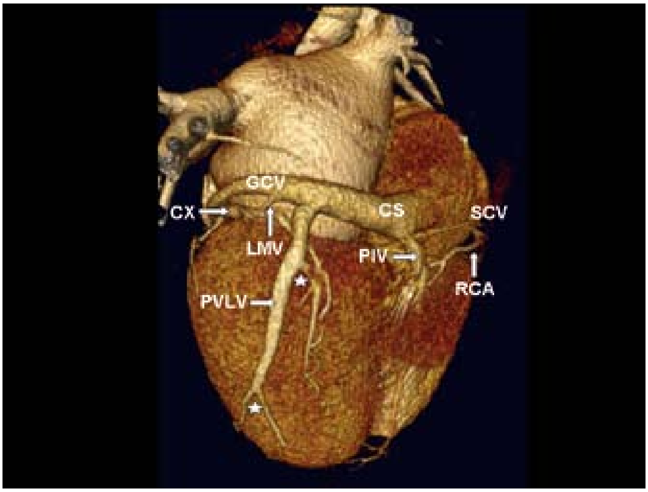

Figure 1. Volume-rendered reconstruction of the heart, posterolateral view. The first tributary of the coronary sinus (CS) is the posterior interventricular vein (PIV), running in the posterior interventricular groove. The second tributary of the CS is the posterior vein of the left ventricle (PVLV) with several side branches (asterix). The next tributary is the left marginal vein (LMV). The great cardiac vein (GCV) will then continue as anterior cardiac vein in the anterior interventricular groove. Also note the circumflex coronary artery (CX) and right coronary artery (RCA).

Quantitative data

The ostium of the CS was defined as the site where the CS makes an angle with the right atrium in the crux cordis area. Multiplanar reformatting was used to determine the size of the ostium in two directions (Figure 2). The diameters of the proximal parts of the PIV, PVLV and LMV were measured.

The proximal diameter of the Great Cardiac Vein (GCV) and the distal diameter of the GCV before continuing its course in the anterior interventricular groove as Anterior Cardiac Vein were also evaluated. Finally, the distance between the origins of the various venous tributaries was measured on volume-rendered reconstructions (Figure 3).

Statistical analysis

A statistical software program SPSS 12.0 (SPSS Inc, Chicago,Il, USA) was used for statistical analysis. Continuous variables are presented as mean ± standard deviation. Categorical variables are presented as absolute number (percentage). Analysis of variance (ANOVA) was used to study differences between the groups regarding continuous variables; Chi-square testing was used to study differences regarding categorical data. A p-value <0.05 was considered statistically significant.

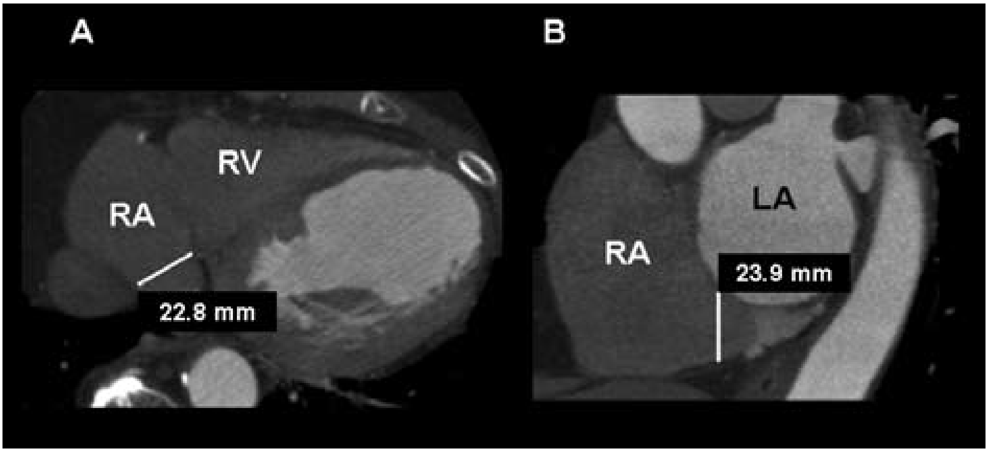

Figure 2. Measurement of the diameter of the Coronary Sinus (CS). The ostium of the CS was defined as the site where the CS makes an angle with the right atrium in the crux cordis area. This is best seen on the transverse plane. The diameter is first measured in the antero-posterior position (Panel A). Multiplanar reformatting was then used to determine the size of the ostium in the supero-inferior direction on the coronal plane (Panel B).
RA: right atrium, LA: left atrium, RV: right ventricle.

Results

Baseline characteristics

In Table 1, baseline characteristics of the individuals are summarized. Compared to controls, patients with significant CAD or a history of infarction were older and were more frequently male. They also had a higher frequency of cardiac risk factors including hypercholesterolemia and smoking.

Table 1. Baseline characteristics of the study population.

	Controls n = 28	CAD n = 38	Infarction n = 34	p-value
Age (yrs)	56 ± 11	64 ± 10	62 ± 11	0.02
Male gender	14 (50%)	26 (68%)	28 (82%)	0.03
LV ejection fraction	64 ± 9 %	58 ± 14 %	50 ± 13 %	0.0001
Cardiac risk factors				
Hypertension	10 (40%)	17 (50%)	11(37%)	NS
Hypercholesterolemia	11 (44%)	24 (71%)	22 (73%)	0.047
Smoking	4 (16%)	10 (29%)	14 (47%)	0.048
Diabetes mellitus	9 (35%)	14 (40%)	3 (10%)	0.02
Familial history CAD	7 (28%)	7 (21%)	12 (39%)	NS

CAD: coronary artery disease; LV: left ventricular.

Left ventricular ejection fraction was significantly lower in patients with a history of infarction. Regarding the coronary artery lesions: none of the controls had significant coronary stenosis (by definition). In the CAD group, 10 patients had lesions occluding ± 50% of the coronary lumen, 25 patients had lesions occluding ≥75% of the lumen. A significant stenosis was present in the left anterior descending coronary artery in 78%, in the left circumflex coronary artery in 38% and in the right coronary artery in 30%. For patients with a history of infarction, these percentages were 88%, 46% and 42% respectively. Regarding the location of the infarction, 23 patients (68%) had a previous anterior infarction, 4 (12%) a lateral infarction and 7 (21%) an inferior infarction. Twelve of the 34 infarction (35%) patients had a non-Q wave infarction, 22 (65%) had a Q wave infarction.

Anatomic observations

No patients had to be excluded because of suboptimal study quality. The CS, Anterior Interventricular Vein and PIV were observed in nearly all patients (100%, 100% and 99% respectively). The PVLV was observed in 96% of the controls, in 84% of the CAD patients and in 82% of the patients with previous infarction (p=NS). LMV was significantly less often identified in patients with a previous infarction as compared to CAD patients and controls (27% vs 61% vs 71%, p<0.001, Figure 4). An example of a patient with a previous infarction and absence of the LMV is presented in Figure 5. None of the patients with a history of a lateral infarction had a LMV, only 22% of the patients with a history of an anterior infarction had a LMV whereas 43% of the patients with a previous inferior infarction had a LMV. In the 12 non-Q wave infarction patients the PVLV was present in 11 patients (92%) and the LMV was present in 5 patients (42%). In the 24 Q-wave infarction patients the PVLV was only present in 17 patients (77%) and the LMV in 4 (18%) patients.

In patients with a previous infarction, the presence of both a PVLV and LMV was significantly less often observed as compared to CAD patients and normals (26.5% vs 60.5% vs 71.4%, p<0.01, Figure 6).

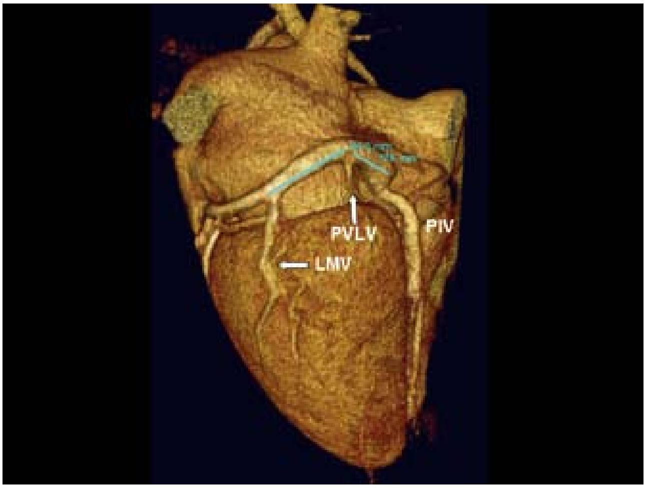

Figure 3. Example of measurement of the distance between the origins of the tributaries of the coronary sinus. *(PIV: posterior interventricular vein, PVLV: posterior vein of the left ventricle, LMV: left marginal vein).*

Patients with a PIV exhibited one side branch in 7%, two side branches in 28% and three side branches in 2% of patients; 63% of these patients had no side branches. In the patients in whom a PVLV was identified, one side branch was observed in 2%, 2 side branches in 16% and 3 side branches in 1% of patients; 81% had no side branches. In patients with a LMV, one side branch was present in 4% and two side branches in 23% of patients, 73% of these patients had no side branches. No significant differences were observed between controls, patients with CAD with or without previous infarction regarding the number of side branches.

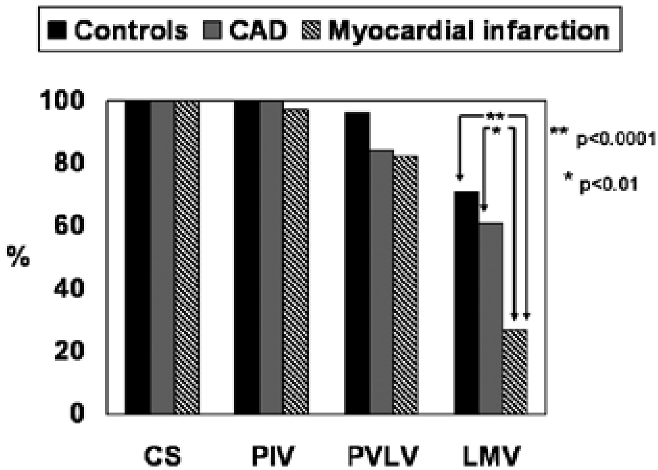

Figure 4. Presence of the coronary sinus (CS) and its main tributaries: posterior interventricular vein (PIV), Posterior vein of the left ventricle (PVLV) and left marginal vein (LMV) in the three subsets (controls, patients with coronary artery disease (CAD) and patients with CAD and history of myocardial infarction).

Quantitative measurements from MSCT

The quantitative measurements are presented in Table 2. Inter- and intra-observer agreement were assessed in 10 patients; percentage agreements were 94% and 97%. For all patients, the diameter of the CS in the supero-inferior direction was significantly larger as compared to the antero-posterior direction: 12.2 ± 3.3 mm versus 11.3 ± 3 mm ($p = 0.002$). The more distant tributaries of the CS had smaller diameters. Within the three groups (controls, CAD patients or patients with previous infarction) no significant differences were noted. The distances between the origins of the different vessels were also comparable between the three groups.

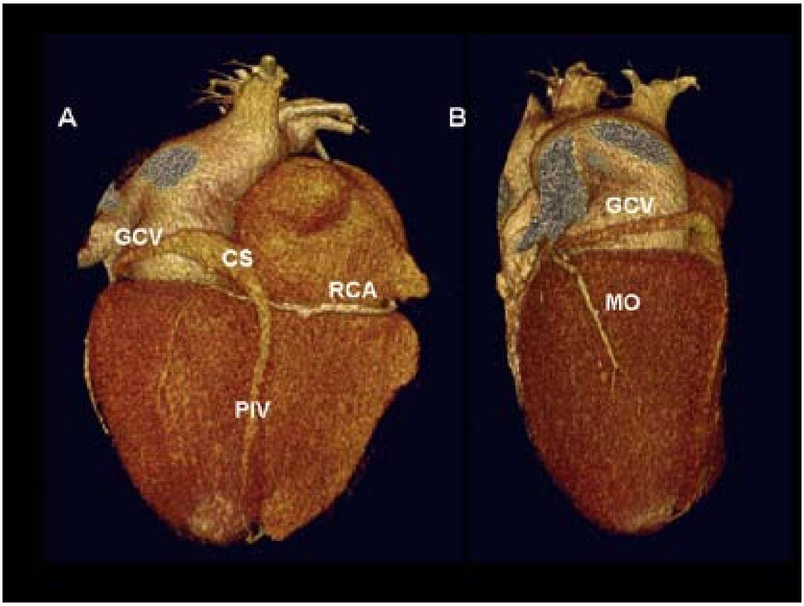

Figure 5. Example of absence of the posterior and left marginal vein in a patient with a history of an anterolateral infarction. Panel A: posterior view, Panel B: left lateral view. The only tributary of the coronary sinus (CS) and great cardiac vein (GCV) is the posterior interventricular vein (PIV). Also note the obtuse marginal (MO) branch of the circumflex coronary artery and the right coronary artery (RCA).

Discussion

The main findings in the current study are two-fold. First, non-invasive evaluation of the cardiac venous system in CAD patients is feasible using 64-slice MSCT. Second, variation of the cardiac venous anatomy in CAD patients appears related to a history of previous myocardial infarction; patients with previous infarction have significantly less left marginal veins. These observations may have important implications for selection of potential CRT candidates with a history of myocardial infarction.

Non-invasive evaluation of the cardiac venous system

Until recently, the cardiac venous system could only be evaluated invasively using retrograde venography, either by direct manual contrast injection or after occlusion of the coronary sinus [8,9]. In 2000, few studies reported on the use of non-invasive imaging with electron beam CT to depict the cardiac venous system [10,11]. Recently, Mao et al analyzed the electron beam CT of 231 patients and demonstrated that this technique provides 3-D visualization of most components of the coronary venous system [12]. In 2003, Tada et al reported the feasibility of MSCT to obtain high quality three-dimensional images of the cardiac venous system in one patient [13]. Recently, preliminary studies were published on the value of 16-slice MSCT to evaluate the cardiac veins [7,14,15]. Since then, 16-slice MSCT is gradually being replaced by 64-slice MSCT, offering a higher spatial resolution with a decreased acquisition time. Abbara et al suggested that due to the shorter scanning time, venous opacification might be insufficient using scanning protocols tailored for imaging the coronary artery system [14]. However, the feasibility of depicting the cardiac venous system with 64-slice MSCT was clearly demonstrated in the present study. Despite a shorter scanning time, the CS and its tributaries could be evaluated in all individuals. Prominent side branches - suitable for insertion of pacemaker leads - were adequately visualized but the distal parts of side branches with a smaller diameter could not be detected in all patients.

Table 2. Quantitative measurements in venous anatomy from MSCT.

	Controls n = 28	CAD n = 38	Infarction n = 34	p-value
Diameters				
CS antero-posterior (mm)	11.5 ± 2.4	11.2 ± 3.7	11.2 ± 2.9	NS
CS supero-inferior (mm)	12.6 ± 3.2	11.7 ± 3.3	12.5 ± 3.3	NS
GCV proximal (mm)	7.2 ± 1.4	7.0 ± 1.8	7.4 ± 1.4	NS
GCV distal (mm)	4.9 ± 1.1	5.0 ± 1.0	5.1 ± 1.3	NS
PIV (mm)	5.0 ± 0.7	5.2 ± 1.3	5.2 ± 1.3	NS
PVLV (mm)	3.8 ± 0.7	3.9 ± 1.0	4.1 ± 1.1	NS
LMV (mm)	3.1 ± 0.8	3.6 ± 1.5	5.3 ± 5.8	NS
Distance between origin of				
PIV and PVLV (mm)	32 ± 17	27 ± 14	36 ± 22	NS
PVLV and LMV (mm)	41 ± 13	39 ± 15	38 ± 17	NS
PVLV and AIV (mm)	51 ± 16	55 ± 17	57 ± 10	NS
LMV and AIV (mm)	45 ± 9	44 ± 14	46 ± 13	NS

AIV: anterior interventricular vein; CS: coronary sinus; GCV: great cardiac vein; LMV: left marginal vein; PIV: posterior interventricular vein; PVLV: posterior vein.

Variations in cardiac venous anatomy

In the current report the accepted terminology for the CS and its tributaries of the Nomina Anatomica (English version) as described by von Lüdinghausen was used to permit comparison with previous studies [16]. Of note, in various studies the PVLV is often described as the Middle Cardiac Vein. Both in anatomical series and imaging series, either invasive venography or non-invasive evaluation with CT, a substantial variation in anatomy was reported.

First, the CS was analyzed. The CS is the most constant component of the cardiac venous system and was detected in all patients. The diameter of the CS was larger in the supero-inferior direction as compared to the antero-posterior direction, indicating an oval shape of the ostium, confirming the 16-slice MSCT observations of Jongbloed et al [7]. and MRI observations by Wittkamp et al [17].

Secondly, the tributaries of the CS were evaluated. The PIV was observed in (nearly) all patients. The highest variability was observed in the number of tributaries between the PIV and the Anterior Interventricular Vein. In anatomical series the PVLV existed as a single large vessel in 63% of the cases (diameter ranging from 1.0 – 5.5 mm) and the prevalence of the LMV was between 73% and 88% of cases (diameter varying from 1.0 – 3.0 mm) [15]. Meisel et al studied 129 patients referred for cardioverter-defibrillator implantation with invasive venography and noted a PVLV in 55% and a LMV in 83% [8]. In studies using noninvasive modality (Electron Beam CT or 16 slice MSCT), the prevalence of the PVLV varied between 13% and 80 % and the prevalence of the LMV between 38% and 93% [11-14]. The number of patients with CAD was not specified in every study and data on the prevalence and site of infarction were frequently lacking. Mao and co-workers, analyzed 231 patients and found the CS in 100%, the PIV in 100%, the Posterior Vein in 78% and the Marginal Vein in 81% [12]. Abbara et al [14] included 54 patients with suspected CAD, referred for 16-slice MSCT. In 4 patients (7.4%) no LMV could be identified and in 11 (20.4%) patients no Posterior Vein could be found; however none of

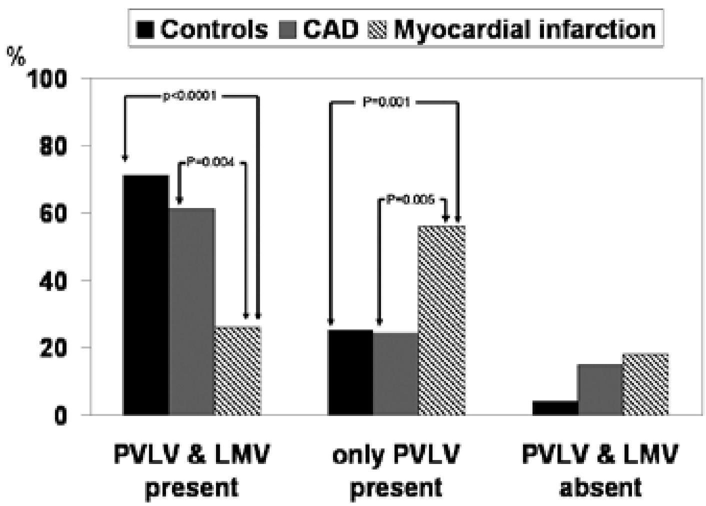

Figure 6. Prevalence of both the posterior vein of the left ventricle (PVLV) and the left marginal vein (LMV), only the PVLV and neither PVLV and LMV according to subject category: controls, coronary artery disease (CAD) and myocardial infarction patients. Overall p = 0.003.

the patients had a definite diagnosis of acute myocardial infarction [14]. Jongbloed et al studied 38 patients including 18 CAD patients [7]. The CS and PIV were observed in all patients, the PVLV was found in 95% and the LMV in 60% of patients.

A novelty of the current study is the demonstration of an association between these anatomic variations and the history of a previous myocardial infarction. None of the patients with a previous lateral infarction had a LMV and patients with anterolateral myocardial infarctions and especially Q-wave infarctions were lacking the LMV. Post-mortem studies on cardiac veins in ischemic heart disease are scarce. Hansen studied several series of patients who died from ischemic heart disease and detected thrombosis of the epicardial veins in large transmural infarctions [18]. In all cases the thrombosed veins were those draining the infarcted myocardium [19]. Indirect evidence supporting the association between previous infarction and absent cardiac veins is provided by Komamura et al who used thermodilution meaurements of great cardiac vein flow after reperfusion and demonstrated that salvaged myocardium after successful thrombolysis was not observed in patients demonstrating a progressive decrease in great cardiac vein flow [20].

Clinical implications

The observation that patients with previous infarction are frequently lacking the LMV has important implications for the selection of potential candidates for CRT. Positioning the LV lead is the most challenging part of CRT implantation. Before referring the patient with previous infarction for CRT implantation, a triad of questions (Figure 7) has to be answered. First: where is the area of latest activation located? As shown by Ansalone et al, the best clinical response occurs in patients who had their LV lead placed in or near the site of latest activation [21]. Echocardiography with tissue Doppler imaging is an adequate non-invasive imaging modality to answer this question [22,23]. Second: does the area of latest mechanical activation not contain transmural scar tissue? Recently, Bleeker et al observed that patients with transmural posterolateral scar tissue on contrast-enhanced MRI failed to respond to CRT [24]. This observation underscored that assessment of LV dyssynchrony in patients with ischemic cardiomyopathy should be combined with assessment of scar tissue, to verify whether the region that will be targeted for LV pacing does not contain transmural scar tissue. After having identified the region of latest activation without scar tissue a final and third question has to be answered: are their cardiac veins, draining this target region, suitable for LV lead placement? MSCT can provide an answer to this question that appears important in patients with a history of myocardial infarction. If suitable cardiac veins are absent, a surgical approach is preferred over transvenous LV lead positioning. MSCT is a reliable technique to depict the cardiac venous system and the 3D reconstruction will also allow segmental classification to map the cardiac veins and tributaries in relation to the left ventricular wall in a manner comparable to that of echocardiography. (25) MSCT is able to detect anatomic and quantitative differences that may occur in CS and venous anatomy of heart failure patients who are candidates for CRT. MSCT will not only confirm the presence of a specific CS tributary but will also provide information on the course of the vessel, side-branches, the diameter, the distance from the CS and the relation with adjacent structures. Depending on the experience of the implanting cardiologist, no invasive venography at all or only selected venography of the target cardiac vein may be sufficient to implant the lead successfully, based on the MSCT data. In addition, information on cardiac venous anatomy acquired with MSCT could possibly also be used during CRT implantation for 3-D navigation into the heart cavities and veins [26].

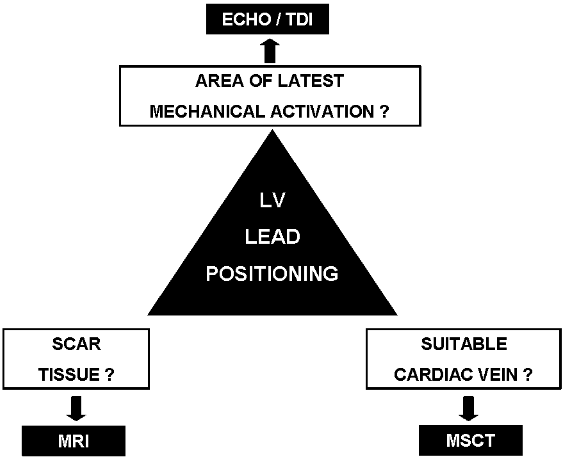

Figure 7. Non-invasive approach for left ventricular (LV) lead positioning.

Limitations

The 64-slice MSCT scans were tailored for optimal visualization of the coronary arteries. This could have caused suboptimal enhancement of the coronary veins, particularly of second and third degree side branches with a small diameter. Since atrial fibrillation is considered a contraindication for MSCT of the coronary arteries only patients in sinus rhythm were included. Prospective confirmation of the current findings is needed in patients referred for CRT.

Conclusion

Non-invasive evaluation of the cardiac venous anatomy with 64-slice MSCT is feasible. There is considerable variation in cardiac venous anatomy. Patients with a history of myocardial infarction were less likely to have a LMV possibly limiting optimal LV lead positioning for CRT.

References

1. Leclercq C, Hare JM. Ventricular resynchronization. Current state of the art. *Circulation* 2004; 109: 296-299.
2. Auricchio A, Abraham WT. Cardiac resynchronization therapy: Current state of the art. Cost versus benefit. *Circulation* 2004; 109: 300-307.
3. Willerson JT, Kereikaes DJ. Cardiac resynchronization therapy: helpful now in selected patients with CHF. *Circulation* 2004; 109: 308-309.
4. Cleland JGF, Daubert J-C, Erdmann E, Freemantle N, Gras D, Kappenberger L, Tavazzi L, for the Cardiac Resynchonization – Heart Failure (CARE-HF) Study Investigators. The effect of cardiac resynchronization on morbidity and mortality in heart failure. *N Engl J Med* 2005; 352: 1539-1549.
5. Mehra M, Greenberg B. Cardiac Resynchronization Therapy: Caveat Medicus! *J Am Coll Cardiol* 2004; 43: 1145-1148.
6. Bax JJ, Abraham T, Barold SS Breithardt OA, Fung JWH Garrigue S, Gorcsan J, Hayes DL, Kass DA, Knuuti J, Leclercq C, Linde C, Mark DB, Monaghan MJ, Nihoyannopoulos P, Schalij MJ, Stellbrink C, Yu CM. Cardiac resynchronization therapy: Part 1—issues before device implantation. *J Am Coll Cardiol* 2005; 46: 2153-2167.
7. Jongbloed MRM, Lamb HJ, Bax JJ, Schuijf JD, de Roos A, van der Wall EE, Schalij MJ. Noninvasive visualization of the cardiac venous system using multislice computed tomography. *J Am Coll Cardiol* 2005; 45: 749-753.
8. Meisel E, Pfeiffer D, Engelmann L, Tebbenjohanns J, Schubert B, Hahn S, Fleck E, Butter C.Investigation of coronary venous anatomy by retrograde venography in patients with malignant ventricular tachycardia. *Circulation* 2001; 104: 442-447.
9. De Martino G, Messano L, Santamaria M Parisi Q, Dello Russo A, Pelargonio G, Sanna T, Narducci ML, Chiriaco T, Bellocci F, Zecchi P, Crea F. A randomized evaluation of different approaches to coronary sinus venography during biventricular pacemaker implants. *Europace* 2005; 7: 73-76.
10. Schaffler GJ, Groell R, Peichel KH, Rienmüller R. Imaging the coronary venous drainage system using electron-beam CT. *Surg Rad Anat* 2000; 22: 35-39.
11. Gerber TC, Sheedy PF, Bell MR Hayes DL, Rumberger JA, Behrenbeck T, Holmes DR Jr, Schwartz RS. Evaluation of the coronary venous system using electron beam computed tomography. *Int J Cardiovasc Imaging* 2001; 17: 65-75.
12. Mao S, Shinbane JS, Girsky MJ Child J, Carson S, Oudiz RJ, Budoff MJ. Coronary venous imaging with electron beam computed tomographic angiography: Three-dimensional mapping and relationship with coronary arteries. *Am Heart J* 2005; 150: 315-322.
13. Tada H, Naito S, Koyama K, Taniguchi K. Three-dimensional computed tomography of the coronary venous system. *J Cardiovasc Electrophysiol* 2003; 14: 1385.
14. Abbara S, Cury RC, Nieman K Reddy V, Moselewski F, Schmidt S, Ferencik M, Hoffmann U, Brady TJ, Achenbach S. Noninvasive evaluation of cardiac veins with 16-MDCT angiography. *AJR* 2005; 185: 1001-1006.
15. Mühlenbruch G, Koos R, Wildberger JE, Günther R, Mahnken AH. Imaging of the cardiac venous system: comparison of MDCT and conventional angiography. *AJR* 2005; 185: 1252-1257.
16. von Lüdinghausen M. The venous drainage of the human myocardium. *Adv Anat Embryol Cell Biol* 2003; 168 Suppl I: 1-107.
17. Wittkamp FH, Vonken EJ, Derksen Loh P, Velthuis B, Wever EF, Boersma LV, Rensing BJ, Cramer MJ. Pulmonary vein ostium geometry: analysis by magnetic resonance angiography. *Circulation* 2003; 107:21-23.
18. Hansen BF. Ischaemic heart disease. Patho-anatomic findings revealed by comprehensive autopsy technique. *Acta Pathol Microbiol Immunol Scan* 1982; 90: 37-49.
19. Hansen BF. Thrombosis of epicardial coronary veins in acute myocardial infarction. *Am Heart J* 1979; 97: 696-700.
20. Komamura K, Kitakaze M, Nishida K Naka M, Tamai J, Uematsu M, Koretsune Y, Nanto S, Hori M, Inoue M. Progressive decreases in coronary vein flow during reperfusion in acute myocardial infarction: clinical documentation of the no reflow phenomenon after successful thrombolysis. *J Am Coll Cardiol* 1994; 24: 370-377.

21. Ansalone G, Giannantoni P, Ricci R, Trambaiolo P, Fedele F, Santini M. Doppler myocardial imaging to evaluate the effectiveness of pacing sites in patients receiving biventricular pacing. *J Am Coll Cardiol* 2002; 39:489-499.
22. Blank AJ, Kelly AS. Tissue Doppler Imaging and left ventricular dyssynchrony in heart failure. *J Card Fail* 2006; 12: 154-162.
23. Van de Veire N, De Sutter J, Van Camp G Vandervoort P, Lancellotti P, Cosyns B, Unger P, Gillebert TC; Belgian Multicenter Registry on Dyssynchrony. Global and regional parameters of dyssynchrony in ischemic and nonischemic cardiomyopathy. *Am J Cardiol* 2005; 95: 1020-1023.
24. Bleeker GB, Kaandorp TA, Lamb HJ Boersma E, Steendijk P, de Roos A, van der Wall EE, Schalij MJ, Bax JJ. Effect of posterolateral scar tissue on clinical and echocardiographic improvement after cardiac resynchronization therapy. *Circulation* 2006; 113: 926-928.
25. Singh JP, Houser S, Heist KE, Ruskin JN. The coronary venous anatomy. A segmental approach to aid cardiac resynchronization therapy. *J Am Coll Cardiol* 2005; 46:68-74.
26. Rioual K, Unanua E, Laguitton S, Garreau M, Boulmier D, Haigron P, Leclercq C, Coatrieux JL. MSCT labelling for pre-operative planning in cardiac resynchronization therapy. *Computer Med Imaging Graph* 2005; 29: 431-439.