Investigation of Coronary Venous Anatomy by Retrograde Venography in Patients With Malignant Ventricular Tachycardia

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Background—The coronary venous system is increasingly used for left ventricular or biventricular pacing in patients with severe heart failure. The present study investigated the structure of the coronary veins in patients presenting with structural heart disease and malignant ventricular tachyarrhythmias. The availability of veins for possible lead placement was assessed.

Methods and Results—The number, relative size, and location of coronary veins were evaluated by retrograde venography in 129 patients undergoing cardioverter-defibrillator implantation. Detailed x-ray image analysis was performed in 86 patients, for whom optimal coronary sinus occlusion and vein visualization was achieved. The anterior interventricular vein and the middle cardiac vein were visible in 85 (99%) of 86 patients and in 86 (100%) of 86 patients, respectively. Between these 2 veins, at least 1 additional prominent vein was visible in 85 (99%) of 86 patients. Just 1 vein was present in 44 (51%) of 86 patients. Two veins were observed in 40 (46%) of 86 patients, and >2 veins were visualized in 2 (2%) of 86 patients. Venous anatomy allowed positioning of a 0.014-in guidewire in a coronary vein in 115 (93%) of 124 patients.

Conclusions—The presence, diameter, angulation, and tortuosity of veins as visualized by retrograde venography determine their acceptability for the placement of a lead in a predetermined location. Despite the considerable variability of the coronary venous system among patients, a lateral vessel for lead introduction was available in 82%, and a posterior or lateral vessel was available in 99% of individuals within a patient population that could potentially benefit from a lead on the left ventricle. (Circulation. 2001;104:442-447.)

Key Words: radiography ■ tachycardia ■ veins ■ arrhythmia

The coronary venous system is increasingly being used for different electrophysiological purposes. Cardiac resynchronization therapy incorporating a left ventricular (LV) coronary vein lead may profoundly improve the condition of patients with severe heart failure.1,2 The coronary venous system has also been used for radiofrequency catheter ablation,3 mapping,4 and defibrillation.5-7

The main purpose of the present study was to investigate the coronary venous system in patients with heart disease and malignant ventricular tachyarrhythmias by means of retrograde venography. The availability of veins for potential placement of a lead was assessed. Attention was focused on the presence and availability of coronary veins on the lateral aspect of the LV, because these vessels have been suggested as the best location for defibrillation and cardiac resynchronization therapy.2,7

Methods
Patients undergoing initial placement of an implantable cardioverter-defibrillator (ICD) system for standard indications were considered for inclusion in the present study. Individuals aged <18 years and with known intolerance to x-ray contrast agents were excluded. An institutional review committee approved the study, and all patients gave written consent. Four cardiologists performed the study. Three had significant prior experience with both ICD implantation and interventional cardiology procedures (PTCA/stents); the fourth had primarily ICD implantation and electrophysiological experience.

Retrograde Coronary Venography
Retrograde venography was performed after the implant of the ICD lead. The coronary sinus (CS) was cannulated from a subclavian entry site by using a commercially available balloon occlusion catheter (Arrow, model AI-07127, or equivalent). Venography began with contrast agent injections with 2 different locations for the occlusion balloon (midlateral CS and close to the CS ostium)8 to ensure that the balloon would not occlude the ostium of a prominent
coronary vein. Three additional venograms (right anterior oblique [RAO] 30°, anteroposterior [AP], and left anterior oblique [LAO] 30° views) were then obtained with an acceptable occlusion balloon position. An average of 5 venograms with contrast agent injection (5 to 10 mL each) was required for an optimal visualization. Only a nonionic contrast agent with low osmolarity was used. The total volume of contrast agent used and preoperative serum creatinine levels were obtained by reviewing hospital records from the last 69 patients enrolled.

Two methods of vein visualization, direct and indirect, were used. Direct visualization occurred when a vein was filled by the direct injection of contrast agent opposite the direction of the venous return flow (retrograde). Indirect visualization occurred when a vein was filled with contrast agent arriving from a communicating vein in the same direction as the venous blood return (anterograde). Illustrations are given in Figure 1b and 1f. Direct visualization occurred immediately after the start of contrast injection. Indirect visualization occurred 5 to 10 seconds (5 to 15 heartbeats) after contrast injection. The balloon remained inflated for 7 to 10 seconds in an attempt to maximize indirect visualization without excessively long occlusion times. Longer CS occlusion times during retrograde CS perfusion have been reported to be acceptable, but most of the contrast agent dispersed within 10 seconds, so longer times were not necessary.

Terminology
The terminology illustrated in Figure 1a (defined below) was used in identifying the coronary veins. Others8,10,11 have used a similar terminology.

Anterior Interventricular Vein
In most patients, the anterior interventricular vein (AIV) originates at the lower or middle third of the anterior interventricular groove. It follows the groove toward the base of the heart and then turns posterior at the atrioventricular groove to enter the great cardiac vein.

Middle Cardiac Vein
The middle cardiac vein (MCV) originates close to the apex of the heart and follows the posterior interventricular groove toward the base. Usually, the MCV drains into the CS close to its ostium in the right atrium.

Posterior/Left Marginal Veins
The posterior veins (PVs)/left marginal veins (LMVs) originate either from the posterior or lateral aspects of the LV and drain into the great cardiac vein or into the CS.

Venogram Analysis
Three experienced medical observers assessed the presence and the number of prominent PVs and LMVs and their relative sizes and locations. A vein was considered to be prominent when its diameter midway between the heart base and apex was at least 50% of the diameter of the distal coil of the ICD lead (2.8 mm) (Figure 1d). This simple analysis was chosen because the purpose of the present study was to assess the potential availability of veins for placement of an electrophysiological lead or catheter. Any physician planning to implant a lead transvenously into a vein on the LV could also use this method of analysis. The diameters of prominent veins could not be measured exactly because they were dependent on the vein being filled with x-ray contrast medium, on the extent of CS occlusion, and on the position of the occlusion balloon that varied from patient to patient.

The location of a prominent vein was determined by overlapping templates onto the venogram images (Figure 1d). The base was determined by the location of the proximal CS. The apex was identified by the coronary veins surrounding it. The LAO venogram image was used to distinguish a PV from an LMV.

Guidewire and Prototype Lead Placement
In all patients, an attempt was made to place a 0.014-in guidewire (Balance Middle Weight ACS HI-Torque Guide Wire with Hydrocoat) into one of the major veins (PV, LMV, or AIV) previously visualized by retrograde venography to evaluate the potential accessibility of the veins. In a subpopulation of patients, the guidewire was visualized by retrograde venography to evaluate the potential accessibility of the veins. A number of prominent PVs and LMVs and their relative sizes and locations. A vein was considered to be prominent when its diameter midway between the heart base and apex was at least 50% of the diameter of the proximal CS. The apex was identified by the coronary veins surrounding it. The LAO venogram image was used to distinguish a PV from an LMV.

Figure 1. a, Schematic representation of AP view of heart showing coronary venous system as defined for present study. GCV indicates great cardiac vein. b, Representative venogram in AP view with ideal occlusion of CS allowing detailed analysis. d, Representative venogram (same as in panel c) but in RAO view with incomplete CS occlusion and direct visualization. e, Venogram illustrating that a vein was counted as an LMV if its longest part was located on lateral wall even if its Os was located close to CS Os. f, Direct vs indirect visualization. White dotted arrows indicate direction of contrast agent flow distal from OCB opposite normal venous blood flow direction in area of direct visualization. Complete occlusion is indicated by absence of contrast agent proximal to OCB outside lumen of catheter. Black dotted arrows show contrast agent flow together with venous blood return after passing collateral vessels and anastomosis (asterisks).

guidewire was used as a tool for inserting a prototype over-the-wire lead into the coronary vein to simulate implantation of a permanent lead. The prototype LV lead was constructed by using a single 1.2-mm-diameter wire with insulation. Guidewire or lead placement was considered to be successful if it extended at least halfway down the LV wall (50% of the distance between base and apex), as illustrated in Figure 1d and Figure 5f.

Results

Patient Demographics
Demographic data shown as mean±SD in the Table suggest that the enrolled patients were representative of a typical ICD patient population.

Results
Retrograde Venography

Cannulation of the CS was successful in 124 (96%) of 129 patients (Figure 2). Complete occlusion of the CS was achieved in 86 (67%) of 129 patients. Communicating vessels between coronary veins were well developed, and both direct and indirect visualization contributed to the venogram (Figure 1c, 1d, and 1f and Figure 4a through 4d). Collaterals surrounding the apex were used as an indicator of complete occlusion and a complete venogram. Only data from these 86 patients were used for the detailed analysis of coronary venous anatomy.

Venograms were not acceptable for detailed analysis in 38 patients (Figure 2). In 18 of these 38, only manually captured single venogram images from low-resolution x-ray equipment were available. The poorer quality of these images limited analysis. In the remaining 20 patients (17 men and 3 women), incomplete occlusion of the CS during contrast injection resulted in poor visualization of the venous structure. With incomplete occlusion, veins could be identified only by direct visualization. Indirect visualization did not contribute to the venograms, because the contrast agent was expelled through the CS too quickly. Incomplete occlusion was typically due to a CS diameter >11 mm (4 of 20 patients), a sharp change in direction of the CS near the ostium (4 of 20 patients), a funnel-like shape of the terminal CS (3 of 20 patients), a combination of the above issues, or operator learning curve (9 of 20 patients). Incomplete venograms were obtained in 5 (33%) of the first 15 patients versus 15 (14%) of the remaining 109 patients in whom the CS was successfully cannulated. In the 38 patients with poor quality images or incomplete venograms, the presence and location of some LV veins could still be determined (Figure 1b), and that information would have been adequate to place an LV lead, but the information was inadequate for the detailed analysis required by the present study.

The time required to obtain the RAO, AP, and LAO venogram images was analyzed for the last 69 patients enrolled to minimize influence from a learning curve phenomenon. The time required was 25±22 minutes (mean±SD; minimum 4 minutes, maximum 105 minutes, and mode 19 minutes). The volume of contrast agent used was available for 66 of these 69 patients. The average volume was 169±105 mL (mean±SD; minimum 40 mL, maximum 500 mL, and median 150 mL).

Transient renal failure occurred during the postoperative period in 1 of 129 patients. Several unsuccessful attempts to enter the CS with differently shaped guiding catheters resulted in the use of 420 mL of contrast agent. Serum creatinine level increased from 1.5 mg/100 mL (125 µmol/L) before the procedure to 2.64 mg/100 mL (220 µmol/L) after the procedure. Controlled infusion and diuretics restored renal function, and the patient recovered completely. There was no increase in heart failure in this or any other patient. Tissue staining with contrast agent was observed in 6 (5%) of 129 patients. The staining disappeared by the end of the procedure in 3 patients. All patients remained asymptomatic.

Tributaries of the CS

The location, size, and course of major coronary veins varied considerably among patients. The presence and the distribution of LMV and PV as identified by retrograde venography are shown schematically in Figure 3. Examples of representative venograms from different patients are shown in Figure
4. A prominent AIV was identified in 85 (99%) of 86 patients. The MCV was identified in 86 (100%) of 86 patients. Only 1 additional vein was identified in 44 (51%) of 86 patients (Figure 4a and 4b). In 14 (16%) of 86 patients, this vein was judged to be the PV (Figure 4b), whereas in 30 (35%) of 86 patients, it was judged to be the LMV (Figure 4a). In 3 patients, a vein originated in a more lateral area of the heart and drained into the CS close to its ostium on the posterior side. In these 3 patients, the vein was classified as LMV because its longest part was located on the left marginal aspect of the LV. This classification was justified because this analysis was primarily concerned with the final position of an electrophysiological lead, not the location of the ostium of the vein. A representative example is given in Figure 1e. In 40 (46%) of 86 patients, 2 additional prominent veins were observed between the AIV and the MCV (Figure 4c). Seven (8%) of 86 venograms showed both veins to be on the marginal LV wall and were therefore classified as LMV. In 33 (38%) of 86 patients, 1 of the 2 veins was a PV, and the other was an LMV (Figure 4c). More than 2 additional prominent veins were observed between the AIV and the MCV in 2 (2%) of 86 patients (Figure 4d).

**Coronary Vein Accessibility for Placement of a Standard 0.014-in Guidewire and a Prototype Over-the-Wire Defibrillation Lead**

Coronary vein accessibility was assessed in 124 patients by an attempt to place a 0.014-in guidewire into a PV, LMV, or AIV that was visualized by retrograde venography. The guidewire was successfully advanced at least 50% of the way down the LV wall in 115 (93%) of 124 patients. A representative example for this is given in Figure 5f. The guidewire could not be advanced into a coronary vein in 9 of 124 patients because of difficult anatomic situations illustrated in Figure 5a through 5e. In 3 patients, the target vessel drained into the CS at a sharp angle after another directional change. (Figure 5a). Although the target vein could be entered, the guidewire could not be advanced toward the apex (Figure 5b). In 2 of these 9 patients, multiple changes in direction appeared as a complete U-turn (representative example given in Figure 5c) and allowed guidewire advancement only into a very short part of the target vein (Figure 5d). These types of multiple sequential changes in the direction of a target vein were called “tortuosity.” In 3 patients, the ostium of the PV...
was very close to the ostium of the CS (example given in Figure 5e). In this situation, it was impossible to enter the target vessel with the guidewire because stable positioning of the occlusion catheter or guide catheter required it to be placed deeper in the CS, beyond the ostium of the PV. In 1 patient, the existence of an anatomic obstacle inside the CS prevented the advancement of the guidewire. This anatomic obstacle was judged to be a valve.

In a subgroup of 99 patients, the guidewire was used as a tool for the advancement of a simple prototype over-the-wire coil-like lead. The prototype lead was successfully placed in a coronary vein in 89 (90%) of 99 patients. Successful placement of the lead in both a PV and an LMV was demonstrated in 1 patient (Figure 6). Failure to place the prototype lead occurred when either the guidewire could not be placed in the vein (8 patients) or because the lead did not slide over the wire and the guidewire got dislocated (2 patients).

For the last 69 patients, the total procedure time, including both venogram and lead placement, was measured. The total procedure time was 46 ± 30 minutes (mean ± SD; minimum 9 minutes, maximum 166 minutes, and mode 23 minutes). Total fluorography time was 32 ± 16 minutes (mean ± SD; minimum 10 minutes, maximum 74 minutes, and mode 16 minutes).

Discussion

The present study provides important practical information for the development and insertion of leads into the coronary venous system. Major findings include the high prevalence of a prominent vein on the lateral or posterior aspect of the LV and high success rates in inserting a guidewire or prototype over-the-wire lead, and the findings demonstrate the value of retrograde venography in guiding the lead insertion process.

Retrograde Venography

Placement of an electrophysiological lead in a coronary vein requires knowledge of the venous structure of the individual patient. This information is most reliably obtained by retrograde venography immediately before coronary vein lead placement. Once the CS has been cannulated for obtaining a venogram, the same entry path can be used for lead placement. However, retrograde venography may require a considerable volume of contrast agent. The greatest volume was used to locate the ostium of the CS. A bolus of contrast agent...
was injected through a catheter in the right atrium into the region where the CS ostium was expected to be located. The observation of a dilution effect of the contrast agent by the coronary venous blood stream leaving the CS ostium was a clear location marker. A smaller volume of the contrast agent was used for obtaining the venograms in different x-ray projections. These volumes of contrast agent may not be inconsequential in patients with either LV dysfunction and/or impaired kidney function. Therefore, renal and heart function should be appropriately controlled before and after the retrograde venography. Sufficient hydration together with the application of diuretics should be used to support the clearance of contrast agent.

Coronary Vein Availability
In the present study, retrograde venography demonstrated the existence of anatomic constraints to placing leads in very specific target areas (Figure 3). LV therapies requiring very specific lead locations may be less successful. For example, a therapy that requires placement of a lead in a left marginal region may be somewhat limited, inasmuch as the present study showed that the LMV occurred in 71 (82%) of 86 patients. Similarly, the present study showed that only 47 (55%) of 86 patients had a posterior vein. However, if either an LMV or a PV location was acceptable, a high percentage of patients (85 [99%] 86) would be eligible.

The present study also showed that the MCV and the AIV are found in nearly every patient, suggesting that these veins might be useful for some therapeutic approaches. The MCV and AIV have been used as conduits for the passage of mapping catheters in connection with different ablation procedures, and for defibrillation lead placement, but neither the MCV nor the AIV seems to be useful for pacing the LV, inasmuch as hemodynamic improvement has not been reported for leads positioned in these veins.

Lead Placement in Coronary Veins
Even with the very preliminary tools used in the present study, the success rates for placing a guidewire or a prototype over-the-wire lead in a coronary vein were high (93% and 90%, respectively). An increase in the use of coronary vein leads will accelerate the development of leads and implantation tools. A wide array of guidewires, guide catheters of many different shapes, and better occlusion tools should improve on these implantation success rates. Although lead insertion is a prerequisite for LV therapy, the success rates found in the present study cannot be directly equated to therapy success because therapies, such as pacing, were not evaluated.

Patient Safety
No severe adverse events in terms of coronary vein injury requiring an intervention or prolonged hospitalization were observed during the entire study of 129 patients. The observation of vascular tissue staining in 5% of the patients could be indicative of damage to the vessel, but there did not appear to be any noticeable clinical consequences.

Clinical Implications
The data described in the present study are potentially of great clinical importance for LV pacing therapies in congestive heart failure patients that use the CS and its tributaries as conduits for the passage of permanently implanted leads. New therapy concepts that use leads in coronary veins for LV sensing and possibly even defibrillation may be impacted by the presence and pathways of LV veins reported in the present study.

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