Noninvasive Evaluation of Coronary Sinus Anatomy and Its Relation to the Mitral Valve Annulus
Implications for Percutaneous Mitral Annuloplasty

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Background—Percutaneous mitral annuloplasty has been proposed as an alternative to surgical annuloplasty. In this respect, evaluation of the coronary sinus (CS) and its relation with the mitral valve annulus (MVA) and the coronary arteries is relevant. The feasibility of evaluating these issues noninvasively with multislice computed tomography was determined.

Methods and Results—In 105 patients (72 men, age 59±11 years), 64-slice multislice computed tomography was performed for noninvasive evaluation of coronary artery disease. Thirty-four patients with heart failure and/or severe mitral regurgitation were included. Three-dimensional reconstructions and standard orthogonal planes were used to assess CS anatomy and its relation with the MVA and circumflex artery. In 71 patients (68%), the circumflex artery coursed between the CS and the MVA with a minimal distance between the CS and the circumflex artery of 1.3±1.0 mm. The CS was located along the left atrial wall, rather than along the MVA, in the majority of the patients (ranging from 90% at the level of the MVA to 14% at the level of the distal CS). The minimal distance between the CS and MVA was 5.1±2.9 mm. In patients with severe mitral regurgitation, the minimal distance between the CS and the MVA was significantly greater as compared with patients without severe mitral regurgitation (mean 7.3±3.9 mm versus 4.8±2.5 mm, P<0.05).

Conclusion—In the majority of the patients, the CS courses superiorly to the MVA. In 68% of the patients, the circumflex artery courses between the CS and the mitral annulus. Multislice computed tomography may provide useful information for the selection of potential candidates for percutaneous mitral annuloplasty. (Circulation. 2007;115:1426-1432.)

Key Words: imaging ■ mitral valve ■ tomography, x-ray computed ■ coronary vessels

Mitral annuloplasty is the most commonly performed surgical procedure for ischemic mitral regurgitation (MR).1 Recently, a percutaneous approach to mitral annuloplasty was proposed. Validation studies in animals have shown the feasibility of the percutaneous transvenous mitral annuloplasty.2–5 In addition, preliminary results of the first human experience with percutaneous mitral annuloplasty have been described.6

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However, anatomic studies have demonstrated the variable relation between the coronary sinus (CS) and the mitral valve annulus (MVA).7–9 It was noted that the CS may course adjacent to the posterior wall of the left atrium rather than along the MVA. Furthermore, a close relation between the CS and the left circumflex coronary artery (LCX) was detected, which potentially limits the use of percutaneous mitral annuloplasty. However, these anatomic studies were performed on structurally normal hearts.

Evaluation of the CS anatomy and its relation to the MVA and the coronary arteries may be of value in patients who are considered for percutaneous mitral annuloplasty. Multislice computed tomography (MSCT) can provide an accurate noninvasive evaluation of the anatomy of the CS.10 Recent preliminary data suggest a potential use of MSCT scanning in patients considered for percutaneous mitral annuloplasty.11

Accordingly, the purpose of the present study was to evaluate the relation between the CS, the MVA, and the coronary arteries by 64-slice MSCT in patients with structurally normal hearts and in patients with severe MR.

Methods

Study Population

The study population comprised 105 consecutive patients referred for MSCT coronary angiography. The total study population was divided into 3 groups: group I (controls, n=35) included patients without coronary artery disease (CAD) and without structural heart disease; group II (CAD, n=36) comprised patients with either a...
history of myocardial infarction/percutaneous transluminal coronary angioplasty/coronary artery bypass grafting, or a significant stenosis in ≥1 coronary artery on the MSCT scan; group III (heart failure, n=34) included patients with severe heart failure (left ventricular ejection fraction ≤35%).

Data Acquisition

**Multislice Computed Tomography**
MSCT was performed with a Toshiba Multislice Aquilion 64 system (Toshiba Medical Systems, Tokyo, Japan) with a collimation of 64×0.5 mm and a rotation time of 400 to 500 ms, depending on the heart rate. The tube current was 300 mA at 120 kV. Nonionic contrast material (Iomeron 400, Bracco, Altana Pharma, Konstanz, Germany) was administered in the antecubital vein, in an amount of 80 to 110 mL, depending on the total scan time, and a flow rate of 5.0 mL/s. Automated peak enhancement detection in the descending aorta was used to time the contrast bolus. After the threshold level of +100 Hounsfield units was reached, data acquisition was automatically initiated. Data acquisition was performed during an inspiratory breath-hold of 8 to 10 seconds, and the ECG was recorded simultaneously to allow retrospective gating of the data. The data set was reconstructed at 75% of the RR interval, with a slice thickness of 0.5 mm and a reconstruction interval of 0.3 mm.

Data Analysis

**Anatomic and Quantitative Analyses**
With the use of reconstructed long-axis 2- and 4-chamber views and volume-rendered 3-dimensional reconstructions, the relation between the CS and the MVA was assessed (Figure 2). The position of the CS in relation to the MVA (superior/inferior/same level) and the minimal distance between the CS and the MVA were determined (Figure 3). The anatomic and quantitative data were assessed at 3 different levels: at the proximal CS, the distal CS, and at the level of the MVA. The proximal CS was defined as the site where the CS makes an angle with the right atrium. The distal CS was defined as the site where the CS makes a sharp angle anteriorly and continues as the anterior interventricular vein.12 The level of the MVA was reconstructed with the long-axis 2- and 4-chamber views.

**Figure 1.** Volume-rendered reconstructions show the relation between the CS and the left circumflex coronary artery (Cx). A, The Cx courses deeper than the CS and lies between the CS and the mitral valve annulus. B, The Cx courses superiorly to the CS.

**Figure 2.** Long-axis 2-chamber (A) and 4-chamber (B) views were used to assess the course of the CS (white arrow) in relation to the MVA and the diameter of the MVA (black arrow). Furthermore, at the reconstructed level of the MVA (C), the CS location and the MVA perimeter were determined. D, Volume-rendered 3-dimensional reconstruction demonstrates the course of the CS and its relation to the MVA and the left circumflex coronary artery.
Echocardiography
Standard 2-dimensional echocardiograms were obtained with patients in the left lateral decubitus position with a commercially available system (Vingmed Vivid 7, General Electric-Vingmed, Milwaukee, Wis). Images were obtained with a 3.5-MHz transducer at a depth of 16 cm in the parasternal (long- and short-axis) and apical (2- and 4-chamber) views. Standard 2-dimensional images and color Doppler data triggered to the QRS complex were digitally stored in cine-loop format. Left ventricular ejection fraction was calculated from apical 2- and 4-chamber images with the biplane Simpson’s rule. The severity of MR was graded semiquantitatively by color-flow Doppler in the conventional parasternal long-axis and apical 4-chamber images. MR was characterized as: minimal, 1+ (jet area/left atrial area <10%), moderate, 2+ (jet area/left atrial area 10% to 20%), moderate–severe, 3+ (jet area/left atrial area 20% to 45%), or severe, 4+ (jet area/left atrial area >45%).

Statistical Analysis
Continuous data are presented as mean values ± SD; categorical data are presented as frequencies and percentages. Differences between the 3 groups were compared with 1-way ANOVA with Scheffé post hoc testing for continuous variables, and χ² tests for dichotomous variables. Differences between patients with and without severe MR were evaluated with the Mann-Whitney U test (continuous variables), or Fisher exact tests (dichotomous variables). All statistical analyses were performed with SPSS software (version 12.0, SPSS Inc., Chicago, Ill). All statistical tests were 2-sided, and a P value <0.05 was considered statistically significant.

The authors had full access to and take responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

Results
Study Population
A total of 105 patients (age 59±11 years, 72 men) were studied. The study population was divided into 3 groups: controls (n=35), patients with CAD (n=36), and patients with severe heart failure (n=34; 19 (56%) with ischemic cardiomyopathy, 15 (44%) with idiopathic cardiomyopathy). The baseline characteristics of the patients are listed in Table 1.

Anatomic Observations
Coronary Arteries and Relation With CS
Right coronary artery dominance was observed in 91 patients (87%), left coronary dominance in 13 patients (12%), and balance in 1 patient (1%). In 71 patients (68%), the LCX coursed inferiorly to the CS (ie, between the CS and the mitral annulus). In 34 patients (32%), the LCX coursed superiorly to the CS (Figure 1). The minimal distance between the CS and the LCX was 1.3±1.0 mm. The mean number of marginal branches was 1.2±0.6; No differences existed in number of marginal branches between the 3 groups or between the patients with right or left coronary dominance.

Anatomic Relation Between the CS and MVA
At the level of the MVA, the CS was located more superiorly in 95 patients (90%), more inferiorly in 1 patient (1%), and at the same level in 9 patients (9%). The minimal distance from the CS to the MVA was

TABLE 1. Baseline Characteristics of the 3 Patient Groups

<table>
<thead>
<tr>
<th></th>
<th>Controls</th>
<th>CAD</th>
<th>HF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y, mean±SD</td>
<td>54±11</td>
<td>61±10*</td>
<td>63±11*</td>
</tr>
<tr>
<td>Gender, M/F</td>
<td>21/14</td>
<td>25/11</td>
<td>26/8</td>
</tr>
<tr>
<td>LVEF, %, mean±SD</td>
<td>62±5</td>
<td>61±9</td>
<td>27±7†‡</td>
</tr>
<tr>
<td>Previous MI, n (%)</td>
<td>0</td>
<td>9 (25)</td>
<td>19 (56)</td>
</tr>
<tr>
<td>Risk factors, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>12 (34)</td>
<td>14 (39)</td>
<td>6 (18)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>15 (43)</td>
<td>17 (47)</td>
<td>14 (41)</td>
</tr>
<tr>
<td>Hypercholesterolemia</td>
<td>14 (40)</td>
<td>22 (61)</td>
<td>17 (50)</td>
</tr>
<tr>
<td>Smoking</td>
<td>5 (14)</td>
<td>15 (42)</td>
<td>17 (50)</td>
</tr>
<tr>
<td>Positive family history</td>
<td>11 (31)</td>
<td>10 (28)</td>
<td>11 (32)</td>
</tr>
</tbody>
</table>

CAD indicates coronary artery disease; HF, heart failure; LVEF, left ventricular ejection fraction; and MI, myocardial infarction.

*P<0.05 vs controls; †P<0.001 vs controls; ‡P<0.001 vs CAD.
TABLE 2. Quantitative Analyses of the CS and the MVA in the 3 Patient Groups

<table>
<thead>
<tr>
<th></th>
<th>Controls (n=35)</th>
<th>CAD (n=36)</th>
<th>HF (n=34)</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal distance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>between CS and MVA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At MVA level</td>
<td>4.4±2.2</td>
<td>4.9±2.7</td>
<td>6.2±3.4†</td>
<td>0.019</td>
</tr>
<tr>
<td>At proximal CS</td>
<td>7.6±1.6</td>
<td>7.9±2.1</td>
<td>9.3±2.8†</td>
<td>0.006</td>
</tr>
<tr>
<td>At distal CS</td>
<td>7.3±3.3</td>
<td>8.5±3.2</td>
<td>10.7±3.0†</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CS diameter at</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>proximal CS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP diameter</td>
<td>10.5±2.7</td>
<td>9.7±2.3</td>
<td>9.9±3.3</td>
<td>0.5</td>
</tr>
<tr>
<td>SI diameter</td>
<td>15.0±3.2</td>
<td>14.0±3.0</td>
<td>14.2±3.0</td>
<td>0.3</td>
</tr>
<tr>
<td>CS diameter at</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>distal CS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP diameter</td>
<td>3.9±0.7</td>
<td>3.9±0.6</td>
<td>4.0±0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>SI diameter</td>
<td>4.1±0.9</td>
<td>3.9±0.7</td>
<td>4.0±0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Total CS length</td>
<td>108±12</td>
<td>106±14</td>
<td>126±19†‡</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

AP indicates anterior–posterior; SI, superior–inferior.

*Assessed by ANOVA with Scheffe post hoc testing.
†P<0.05 vs controls; ‡P<0.001 vs controls; §P<0.05 vs CAD; ||P<0.001 vs CAD.

5.1±2.9 mm (range 1.4 to 16.8 mm). Also, the relation of the CS and the MVA was determined at the proximal and the distal CS. At the proximal CS, the CS was located more superiorly to the MVA in 57 patients (54%), more inferiorly in 7 patients (7%), and at the same level in 41 patients (39%). The minimal distance between the CS and the MVA at the proximal CS was 8.3±2.3 mm (range 2.2 to 15.3 mm). At the distal CS, the CS was located more superiorly to the MVA in 15 patients (14%), more inferiorly in 31 patients (30%), and at the same level in 59 patients (56%). The minimal distance between the CS and the MVA at the distal CS was 8.8±3.4 mm (range 2.6 to 18.6 mm).

No statistical differences existed between the 3 groups with regard to the location of the CS in relation to the MVA at any level. In contrast, the minimal distance between the CS and the MVA was significantly greater in the heart failure patients than in the control patients and the patients with CAD (Table 2).

CS and MVA: Quantitative Observations

The mean diameter of the MVA at the 2-chamber view was 40.8±4.7 mm, the mean diameter at the 4-chamber view was 36.4±4.6 mm. The mean perimeter of the MVA was 119.4±13.3 mm. The mean diameter of the CS at the proximal part was 10.0±2.8 mm in the anterior–posterior direction and 14.4±3.1 mm in the superior–inferior direction. The diameter of the CS at the distal part was 3.9±0.7 mm in the anterior–posterior direction and 4.0±0.9 mm in the superior–inferior direction. No significant differences in diameter of the CS were observed between the 3 groups (Table 2). With the use of multiplanar reformatted images, the total length of the CS was calculated. The mean length was 113±18 mm (range 76 to 170 mm). The mean CS length was significantly larger in the heart failure patients than in the controls and the patients with CAD (Table 2).

Mitral Regurgitation

In the total study population, 50 patients (48%) had no MR, 30 patients (29%) had MR grade 1+, and 10 patients (9%) had MR grade 2+. MR was characterized as 3+ in 13 patients (12%) and 4+ in 2 patients (2%). To detect differences in the anatomic and quantitative data between patients with and without severe MR, the study population was divided into 2 groups: patients with MR grade ≤2+ (n=90) and patients with MR grade 3+ or 4+ (n=15).

No differences existed between the 2 groups in the anatomic relation between the CS and MVA at any level. Furthermore, no significant differences in diameters of the CS were noted. However, the minimal distance between the CS and the MVA at all levels was significantly greater in the patients with severe MR than in the patients without severe MR (Table 3). In addition, the diameters of the MVA and the total length of the CS were significantly larger in the patients with severe MR than in the patients without severe MR (Table 3).

Discussion

In the present study, the relation between the CS, the MVA, and the coronary arteries was evaluated noninvasively with MSCT. The major findings of the study are as follows: In 68% of the patients, the LCX courses between the CS and the MVA. In the majority of the patients, the CS courses superiorly to the MVA. In addition, the minimal distance between the CS and the MVA is greater in patients with heart failure and severe MR. The findings of the present study have important implications for percutaneous mitral annuloplasty.

Anatomic Observations

CS and Coronary Arteries

A close relation between the CS and the LCX may limit the use of percutaneous mitral annuloplasty. Circumflex artery compression has been reported as a serious complication in one of the first animal studies on percutaneous mitral annuloplasty. Previous anatomic studies have reported the relation between the CS, the coronary arteries, and the MVA. Maselli et al demonstrated that the LCX coursed between the CS and the MVA in 63.9% of the 61 human hearts that were...
studied. Of note, when the LCX coursed inferiorly to the CS, the number of marginal branches of the LCX was larger. However, no data on the minimal distance between the CS and the LCX were provided. These anatomic observations have previously been confirmed with electron-beam computed tomography.\textsuperscript{15,16} Mao et al\textsuperscript{15} reported that the LCX coursed inferiorly to the CS in 80.8\% of the studied patients. Furthermore, it was demonstrated that the overlapping segment of the CS and the LCX was >30 mm in 17.8\% of the cases. However, once again no data on the minimal distance between the CS and the LCX were provided.

In the present study, the LCX coursed inferiorly to the CS in 68\% of the patients, with a minimal distance between the CS and the LCX of 1.3\(\pm\)1.0 mm. The close relation between the CS and the LCX may limit the use of percutaneous mitral valve annuloplasty, particularly when the LCX courses inferiorly to the CS over a long distance (Figure 4).

CS and MVA
Several anatomic studies have addressed the relation between the CS and the MVA.\textsuperscript{7–9} Shinbane et al\textsuperscript{7} studied 10 normal adult cadaver hearts and reported variable distances between the CS and the MVA along the course of the CS. Mean distances between the CS and the MVA were 14.1\(\pm\)3.1 mm, 10.2\(\pm\)4.9 mm, and 10.7\(\pm\)3.5 mm at distances of 20, 40, and 60 mm, respectively, from the ostium of the CS. El-Maasarany et al\textsuperscript{8} studied the distances between the CS and the MVA in 32 normal cadaver hearts. Distances were assessed in 6 separate regions along the course of the CS. Mean distance was highly variable for the 6 regions; the shortest distance (5.8 mm) was observed at the anterolateral commissure of the MVA. Unfortunately, no data were provided about the position of the CS in relation to the MVA (superior/inferior/same level). In the largest anatomic study reported, Maselli et al\textsuperscript{9} also noted variable distances between the CS and the MVA. At the level of the P2 and P3 scallops of the mitral valve, mean distances between the CS and the MVA of 5.7\(\pm\)3.3 mm and 9.7\(\pm\)3.2 mm were reported.

In the present study, the highly variable relation between the CS and the MVA was assessed noninvasively with MSCT. The CS was located more superiorly to the MVA in the majority of the patients (ranging from 90\% at the level of the MVA to 14\% at the level of the distal CS). Furthermore, minimal distances between the CS and the MVA were assessed at the proximal and the distal CS and appeared to be highly variable (Table 2). Although this finding confirms the previous anatomic studies, the use of different reference points makes a direct comparison between the present study and previous in vitro studies difficult. Importantly, in patients with severe MR, the minimal distance between the CS and the MVA may increase significantly. In particular, the use of percutaneous mitral annuloplasty may be not feasible in patients where the CS courses along the left atrial wall (Figure 5).

It should be noted that in the present study images were routinely reconstructed at 75\% of the RR interval. However, the diameter and the distance between the CS and the MVA may vary during the cardiac cycle. Nevertheless, the present study shows that MSCT can accurately depict CS anatomy and its relation with the MVA and thereby provides important information on patients who are being considered for percutaneous mitral annuloplasty.

Implications for Percutaneous Mitral Annuloplasty
The present study shows the feasibility of the noninvasive evaluation of the CS anatomy and its relation with the MVA and the coronary arteries. In previous in vitro\textsuperscript{7–9} and in vivo\textsuperscript{15,16} studies, the relation between the CS, the MVA, and
the coronary arteries has been investigated. However, none of these studies included patients with severe MR. The present study emphasizes the variability in the relation between the CS and MVA. More importantly, it demonstrates that, in patients with severe MR, the minimal distance between the CS and the MVA is larger than in control patients (Table 3).

The close relation between the CS and the LCX and the variable distance between the CS and the MVA may hamper the clinical use of the percutaneous mitral annuloplasty in selected patients. MSCT may identify the patients in whom percutaneous transvenous mitral annuloplasty may not be feasible. In 68% of the patients, the LCX courses between the CS and the MVA (Figure 4), with a potential risk of compression of the LCX when percutaneous mitral annuloplasty is applied. Furthermore, in a large number of patients the CS courses along the left atrial posterior wall rather than along the MVA (Figure 5). In addition, in patients with severe calcifications of the MVA (Figure 6), a surgical approach may be preferred over a percutaneous approach.

Our findings coincide with recent data that demonstrate the feasibility of noninvasive evaluation with MSCT of the CS anatomy in relation to the MVA. As in the present study, large variability in the distance between the CS and the MVA was noted. Novelties of the present study include the use of a 64-slice MSCT scanner, whereas in the previous study a 16-slice CT scanner (with a collimation of 4 × 1 mm) was used. In addition, in the present study, patients with heart failure and patients with severe left ventricular dilatation and subsequent functional MR were included. Therefore, a substantial part of the present study population consisted of potential candidates for percutaneous mitral annuloplasty. Both studies show that MSCT can accurately depict CS anatomy and its relation with the MVA and thereby provide important information on patients who are considered for percutaneous mitral annuloplasty.

Conclusions
The relation between the CS, the MVA, and the LCX can be evaluated noninvasively with MSCT. In 68% of the patients, the LCX coursed between the CS and the mitral annulus. Furthermore, at the level of the MVA, the CS was located more superiorly in 90% of the patients. In the patients with severe MR, the minimal distance between the CS and the MVA was significantly greater at all levels than in the patients without severe MR. MSCT may provide useful information on the selection of potential candidates for percutaneous mitral annuloplasty.

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Disclosures
None.

References

CLINICAL PERSPECTIVE

Mitral annuloplasty is the most commonly performed surgical procedure for ischemic mitral regurgitation. Recent studies have shown the feasibility of a percutaneous alternative to mitral annuloplasty. In percutaneous mitral annuloplasty, a device is placed in the coronary sinus (CS) to remodel the mitral valve annulus (MVA). However, previous anatomic studies have demonstrated that the CS may be at variable distance from the MVA. In the present study, the relation between the CS, the MVA, and the circumflex artery was studied noninvasively with multislice computed tomography. Our results indicate that, in the majority of the patients, the CS is located along the left atrial wall rather than along the MVA. In addition, the circumflex artery courses between the CS and the MVA in the majority of the patients. Importantly, we noted that, in patients with severe mitral regurgitation, the minimal distance between the CS and the MVA is larger than in control patients. The close relation between the CS and the circumflex artery and the variable distance between the CS and the MVA may hamper the clinical use of the percutaneous mitral annuloplasty in selected patients. Multislice computed tomography may be a valuable tool to depict CS anatomy and its relation with the MVA and the circumflex artery, thus providing important information in patients who are considered for percutaneous mitral annuloplasty.
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