Percutaneous mitral annuloplasty through the coronary sinus: An anatomic point of view

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Objective: We assessed the anatomic relationships among the mitral annulus, coronary sinus, and circumflex artery in human cadaver hearts.

Methods: Percutaneous posterior mitral annuloplasty has been proposed to treat functional mitral regurgitation on the basis of the proximity of the coronary sinus to the mitral annulus. However, concern remains about the ability to perform a trigone-to-trigone posterior annuloplasty and the potential for compromise of the circumflex coronary artery. Ten hearts were studied after injection of expansible foam into the coronary sinus and circumflex artery. The mitral annulus perimeter, posterior intertrigonal (T1–T2) and intercommissural (C1–C2) distance, and coronary sinus projection on the native annulus (S1–S2) were measured. The spatial geometry of the coronary sinus was correlated with the circumflex artery route and the distance with the native mitral annulus.

Results: The projection of coronary sinus annuloplasty achieves at best a commissure-to-commissure annuloplasty 14.5 (6–24) mm behind each trigone: T1–T2: 74 (56–114) mm, C1–C2: 62.2 (48–80) mm, S1–S2: 59.5 (40–80) mm. The coronary sinus was distant from the native annulus (8–14 mm at the coronary sinus ostium, 13.7–20.4 mm at the middle of the coronary sinus, 6.9–14 mm at the level of the great coronary vein). The circumflex artery was located between the coronary sinus and the mitral annulus in 45.5% of cases.

Conclusions: This anatomic study highlights the 3-dimensional structure of the coronary sinus and its distance from the native mitral annulus and fibrous trigones. Human anatomic studies are mandatory for the further development of percutaneous mitral repair technology.

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The anatomic basis of percutaneous mitral annuloplasty through the coronary sinus was studied in cadaver hearts. The coronary sinus is distant from the mitral annulus up to 20 mm. Percutaneous annuloplasty achieves at best a commissure-to-commissure annuloplasty. The potential risk for impingement of the circumflex artery exists in 45.5% of cases.

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Mitral regurgitation observed in dilated or ischemic cardiomyopathy is related to mitral annulus and left ventricle dilation, producing tethering on the chordae tendineae associated with abnormal papillary muscle distraction and/or left ventricular wall contraction.[1] Annular remodeling of the mitral valve is the current standard for functional mitral regurgitation, based on the principle of correction of leaflet malcoaptation by decreasing the size of the annulus.[2,3] Optimal surgical correction is obtained by performing an annuloplasty with a complete rather than a partial prosthetic ring firmly anchored on the anterior mitral annulus and fibrous trigones. More recently, a papillary muscle sling was suggested as a useful adjunct to improve the surgical outcome.[4] Given the prevalence of mitral regurgitation and recent recommendations for earlier treatment of regurgitation, attention has been turned to the development of a less-invasive alternative to repair the mitral valve.[5-14] Currently, a myriad of new concepts for percutaneous mitral valve repair are under evaluation in a variety of stages from bench testing to early clinical trials.[5-14] On the basis of the proximity of both structures, percutaneous annuloplasty through the coronary sinus (CS) has been suggested to remodel the mitral

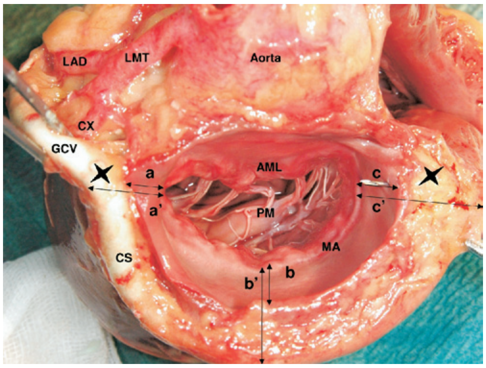

Figure 1. Posterior view from the left atrium: CS, great cardiac vein, left main trunk, circumflex artery, and left anterior descending artery filled with expansible foam. The anchoring points (*black stars*) of the percutaneous device (junction between the great coronary vein and CS; ostium of the CS). Distances between the inferior border of the CS and mitral valve annulus: at the origin of the great cardiac vein (a), at the middle of the CS (b), and at the CS ostium (c). Distances between the superior border of the CS and mitral valve annulus at the same levels are noted as a', b', and c'. *LAD,* Left anterior descending; *LMT,* left main trunk; *CX,* circumflex artery; *GCV,* great cardiac vein; *CS,* coronary sinus; *AML,* anterior mitral leaflet; *PM,* papillary muscle; *MA,* mitral annulus.

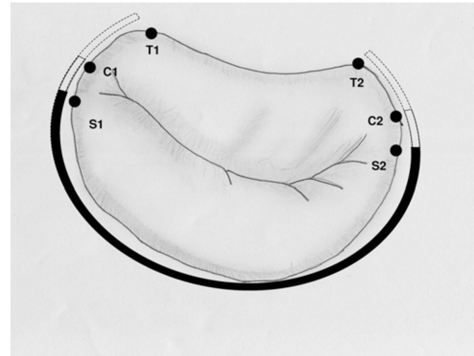

Figure 2. Anatomic landmarks on the mitral annulus. Left and right fibrous trigones (T1 and T2); anterior and posterior commissures (C1 and C2); projections of CS ostium (S2); origin of the great cardiac vein (S1). Posterior intertrigonal distance ("trigone to trigone," posterior T1–T2): *dashed line*; posterior intercommissural distance (posterior C1–C2): *full line*; projection of posterior annuloplasty through the CS (posterior S1–S2): *full black line*.

annulus.[9-14] The placement of a self-compressing device along the region of the posterior annulus has reduced mitral regurgitation and addressed annular dilation in animal models.[12-14] Potential shortcomings may ultimately limit the transposition of this approach in humans, including the inconstancy of the relation between the CS and the mitral annulus and possible impingement of the device on the circumflex coronary artery.[15-18] To complete these previously published findings,[16-18] the surgical anatomy and spatial relationships among the CS, mitral annulus, and the crossover with the circumflex artery were studied in 10 structurally normal cadaver hearts. Special attention was paid to anatomic landmarks for surgical mitral annuloplasty to assess the ability of a percutaneous device through the CS to be anchored on both fibrous trigones.

Materials and Methods

Ten excised fresh cadaver human hearts, obtained from patients who died of noncardiac causes, were examined at the Laboratory of Anatomy, Ecole de Chirugie de l'Assitance Publique Hôpitaux de Paris, France. The study was approved by the scientific institutional committee.

Before dissection of the left atrium and CS, the wall of the right atrium was incised along the sulcus terminalis to view the ostium of the CS. Expansible polyurethane foam (Ayrton S.A, Blyes, France) was injected through the CS ostium and the left main trunk to fill the left anterior descending and circumflex arteries. After the foam hardened, dissection was performed by a cardiac surgeon. The roof of the left atrium was resected, exposing the mitral leaflets and mitral annulus (Figure 1). The fibrous trigones (left T1, right T2) and commissures (anterior C1 and posterior C2) were identified by using a hook to pull the free edge of the anterior leaflet downward (Figure 2).[19]

The great cardiac vein and CS were followed along the posterior mitral annulus up to the confluence into the right atrium. The 2 anchoring points of percutaneous mitral annuloplasty devices, defined as the distal CS (junction with the great cardiac vein) and the ostium of the CS (at the level of the Thebesian valve), were orthogonally projected on the mitral annulus, noted as S1 and S2, respectively (Figure 2).

The mitral annulus was analyzed as follows (Figure 2): mitral annular perimeter; anterior intercommissural distance (insertion perimeter of the anterior leaflet, anterior C1–C2); posterior intercommissural distance (insertion perimeter of the posterior leaflet, posterior C1–C2); anterior intertrigonal distance (anterior perimeter distance between the fibrous trigones corresponding to the fibrous portion of the mitral annulus, anterior T1–T2); and posterior intertrigonal distance (posterior perimeter distance between fibrous trigones corresponding to the muscular portion of the mitral annulus, posterior T1–T2).

The distance between the mitral annulus and the closest intimal surface of the CS was measured at 3 levels: the junction between the CS and the great cardiac vein (a), the middle of the CS (b), and the CS ostium (c) (Figure 1). The same landmarks were used to measure the distance between the mitral annulus and the superior border of the CS: a', b' and c', respectively (Figure 1). The geometry of the mitral

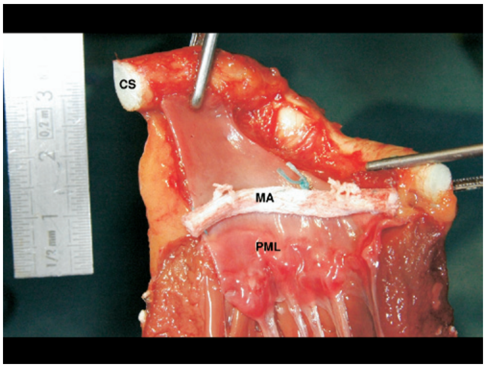

Figure 3. Cross-section of the posterior mitral annulus and left atrium. Distance between the CS and MA. Surgical position of a prosthetic ring annuloplasty. *CS,* Coronary sinus; *MA,* mitral annulus; *PML,* posterior mitral leaflet.

annulus and CS were studied (planar or saddle-shaped), as well as spatial relationship between both structures. The position of the circumflex artery relative to the mitral annulus and CS was also assessed.

Statistical Analysis

Categoric data are presented as absolute values and percentages; continuous data are summarized as mean ± standard deviation (range). Comparisons of anatomic distances between the CS and the mitral annulus at 3 sites along the CS were made with repeated-measures analysis of variance. The authors had full access to the data and take full responsibility for their integrity. All authors have read and agree to the article as written.

Results

In all cases, the mitral annulus, leaflets, and CS were morphologically normal. The CS was separated from the mitral annulus by atrial myocardium, coronary sulcus fat, and connective tissue. The CS wall was pellucid. On the atrial side, a myocardial sleeve extended almost the entire length around the CS, composed of muscle bands from the left and right atrial walls. On the epicardial side, the CS wall is covered only by a thin epicardial layer (Figure 3).

The projection of CS annuloplasty (S1–S2) covered 54.2% (42%–75%) of the total mitral annulus perimeter and 80.4% (53.5%–90%) of the posterior intertrigonal distance. Therefore, it achieved at best a commissure-to-commissure posterior annuloplasty, distant from the fibrous trigones. The results are reported in Table 1. The CS to mitral annulus distance at the middle of the CS (b: 13.7 ± 3.6 [4–18] mm; b': 20.4 ± 4.3 [13–26] mm) was significantly larger than the distance at the ostium (c: 8 ± 4.6 [4–13] mm; c':14 ± 4.1 [6–20] mm, $P < .05$) and the junction with the great cardiac vein (a: 6.9 ± 5.4 [0–17] mm; a' 14 ± 6.5 [6–25] mm, $P < .05$). The distance between the CS to the mitral annulus was not significantly different at both extremities (S1 and S2).

The CS and the mitral annulus presented a 3-dimensional saddle-shape, but they were not coplanar (Figure 3). The

TABLE 1. Mitral annulus and coronary sinus anatomic measures

Anatomic measures		Mean ± SD (range)
Mitral annulus perimeter (mm)		110.1 ± 14.1 (76–146)
Anterior intertrigonal distance (T1–T2) (mm)		36.1 ± 9.2 (20–32)
Posterior intertrigonal distance (T1–T2) (mm)		74 ± 12 (56–114)
Anterior intercommissural distance (C1–C2) (mm)		47.9 ± 12.5 (40–63)
Posterior intercommissural distance (C1–C2) (mm)		62.2 ± 12.3 (48–80)
Orthogonal projection of the CS on the mitral annulus (S1–S2) (mm)		59.5 ± 11.7 (40–80)
Distance S2–T2 (mm)		15.2 ± 5.4 (6–24)
Distance C2–T2 (mm)		11.6 ± 4.2 (7–17)
Distance S1–T1 (mm)		13.9 ± 5 (8–23)
Distance C1–T1 (mm)		11.5 ± 2.5 (8–18)
Distance between junction of great cardiac vein and S1 (mm)	a	6.9 ± 5.4 (0–17)
	a′	14 ± 6.5 (6–25)
Distance between CS and midportion of the posterior mitral annulus (mm)	b	13.7 ± 3.6 (4–18)
	b′	20.4 ± 4.3 (13–26)
Distance between ostium CS and S2 (mm)	c	8 ± 4.6 (4–13)
	c′	14 ± 4.1 (6–20)

SD, Standard deviation. T1 and T2: left and right fibrous trigones; C1 and C2: anterior and posterior commissures; S2: projections of CS ostium on the mitral annulus; S1: projection of the origin of the great cardiac vein on the mitral annulus. (a) Distance between the inferior border of the CS and the mitral valve annulus, (b) at the level of the CS ostium, at the middle of the CS, and (c) at the origin of the great cardiac vein. Distances between the superior border of the CS and the mitral valve annulus at the same levels are noted as a′, b′, and c′.

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TABLE 2. Literature analysis

	Present study	Maselli and coworkers[16]	El-Maasarany and coworkers[22]	Yamanouchi and coworkers[25]	Shinbane and coworkers[23]	Mao and coworkers[24]	Choure and coworkers[17]	Tops and coworkers[18]
Methods	Cadaver hearts	Cadaver hearts	Cadaver hearts	Cadaver hearts	Cadaver hearts	Cardiac computed tomography†	Cardiac computed tomography†	Cardiac computed tomography†
No. of hearts (n)	10	61	40	50	10	231	27	35
Distance between junction of great cardiac vein and mitral annulus (mm)	6.9 ± 5.4	NA	5.8	8.2 ± 2.9	10.7 ± 3.5	NA	7.8 ± 2.8	7.3 ± 3.3
Distance between CS* and midportion of the posterior mitral annulus (mm)	13.7 ± 3.6	5.7 ± 3.3	9.9	10.2 ± 3.6	10.2 ± 4.9	NA	12.2 ± 3.2	NA
Distance between CS* ostium and mitral annulus (mm)	8 ± 4.6	9.7 ± 3.2	9.4	9.7 ± 2.3	14.1 ± 3.1	NA	10.4 ± 2	7.6 ± 1.6
Crossing of the circumflex artery with the CS (%)	45.5% Below§	63.9% Below§	95% Below§	NA	NA	80.0% Below§	80% Below§	68% Below§

NA, Not available; *CS,* coronary sinus; *NA,* not available. *Distances are measured between the inferior border of the CS and the mitral annulus. †Electron beam computed tomographic angiography. §Defined by the circumflex artery crossing between the CS and the mitral annulus.

circumflex artery was located between the mitral annulus and the CS in 45.5% of cases.

Discussion

Mitral valve repair is considered the current standard treatment for functional mitral regurgitation; it is superior to valve replacement because of lower operative mortality, improved late survival, reduced risk of endocarditis, fewer thromboembolic complications, and better preservation of left ventricular function.[2] Some 46.5% of patients with mitral valve regurgitation undergo mitral valve repair, but this rate can increase up to 90% in centers with expertise.[3] Although valve surgery can have low operative morbidity and mortality in selected patient groups, comorbidities often associated with dilated idiopathic or ischemic cardiomyopathy are risk factors for an adverse outcome.[20] Therefore, alternative approaches have been developed to reduce the morbidity and mortality of conventional surgery.[5-14] Currently, 2 concepts are under way for percutaneous mitral valve repair: 1) partial mitral annuloplasty through the CS to reduce the circumference of the posterior mitral annulus[9-14] and 2) anterior and posterior leaflet attachment using an edge-to-edge clip or suture.[6-8] A PubMed search with the terms "percutaneous mitral repair" provides 36 hits focusing on this procedure. Most of them concern animal studies (n = 6), editorials, or reviews (n = 21). Six studies report early human experience,[6-11] and 3 studies are dedicated to human anatomic study of relationships among the CS, mitral annulus, and risk of circumflex artery impingement.[16-18] However, these latter have not addressed the ability to achieve the anatomic challenge of a trigone–trigone annuloplasty or the potential for further dilation of the anterior mitral annulus regarding lone posterior annuloplasty.[20,21]

The CS is described in *Gray's Anatomy* as a "wide venous channel situated in the posterior part of the coronary sulcus, and covered by muscular fibbers from the left atrium. It ends in the right atrium between the opening of the inferior vena cava and the atrioventricular aperture, its orifice being guarded by a semilunar valve (Thebesius valve)."[22] This anatomic description does not consider the 3-dimensional shape of the CS or its relationships with the mitral annulus. The assumption of a close proximity of the CS to the mitral annulus in humans is used by electrophysiologists for mapping and reaching accessory atrioventricular pathways around the mitral valve.[23-26] According to previous anatomic works, the present study confirms that the CS in humans is distant from the mitral annulus. As summarized in Table 2, this distance ranges from 5.8 to 14 mm, depending on the distance from the coronary ostium. Few studies provide in vivo quantitative information regarding the normal relationship between the mitral annulus and the CS, and their modifications in hearts with mitral regurgitation, whether ischemic or idiopathic.[17,18,23,27] Recently, 2 studies based on contrast-enhanced cardiac computed tomography compared healthy patients with patients with severe mitral regurgitation caused by mitral prolapse[17] or

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with ischemic or idiopathic heart failure.[18] These studies showed that the distance between the CS and the mitral annulus was significantly increased in hearts with mitral regurgitation or heart failure. Both structures were saddle-shaped but not coplanar, with the CS coursing superiorly to the mitral annulus, as found in our study on isolated hearts after the injection of expansible foam.[18]

Surgical experience advocates remodeling mitral annuloplasty by the means of a complete ring to achieve optimal results. More recently, posterior partial rings, anchored on both fibrous trigones, were suggested as an alternative. The distance between each trigone and the projection of the CS extremities have not been documented. The present study emphasizes that it could reach up to 24 mm, achieving at best a commissure-to-commissure annuloplasty. Therefore, the clinical efficacy of the CS approach is questionable. Moreover, because dilation of the mitral annulus is proportional in mitral regurgitation, concern remains for further dilation of the uncovered anterior mitral annulus.[21,27]

The relationship among the CS, mitral annulus, and circumflex artery also raises concern. The main circumflex coronary artery was located between the CS and the mitral annulus in 45.5% of patients. Literature data highlight the significant variability of this location, with a range of 45.5% to 95% (Table 2).[16-18,21,23-25] Therefore, a theoretic risk exists of coronary ischemia induced by device placement in a subsequent number of cases. Last, beyond the myocardial sleeve covering the CS, the venous wall is thin, with the potential for perforation of an extensive hardware left in the CS.

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Study Limitations

The number of anatomic samples is insufficient to reach statistical power in the analysis of relationships between the circumflex artery and the CS. However, our results are in accordance with earlier studies stating that in 45.5% to 95% of cases, the potential risk of circumflex artery impingement exists. A shortcoming of this study is that the anatomic analysis was performed in healthy hearts rather than diseased hearts. However, previous studies showed that the separation between the CS and the mitral annulus was also increased in patients with annular dilation and mitral regurgitation.[17,18,27] Furthermore, because of the flaccid conditions of the experiments, this anatomic work could not address the in vivo effectiveness of CS annuloplasty when suggested to treat moderate mitral regurgitation to improve the natural history of dilated cardiomyopathies.

Conclusions

Although percutaneous mitral annuloplasty through the CS seems to be a reasonable approach, our results confirm that the CS is distant from the mitral annulus. Percutaneous treatment offers at best a commissure-to-commissure annuloplasty with a theoretic risk of compression of the circumflex artery. Anatomic assessment of the relationship among the circumflex artery, mitral annulus, and CS seems mandatory for each patient before considering implantation of percutaneous mitral annuloplasty devices. Analysis of early clinical trials will provide informative data on these anatomic end points while correlating quantitative efficacy on mitral regurgitation with the CS and mitral annulus distance. Surgeons and cardiologists should continue pooling expertise and experience to further refine percutaneous technology for mitral annuloplasty.

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