

SURGICAL ANATOMY OF THE MITRAL VALVE

Mitral valve relationship with the circumflex artery and its surgical implications

ABSTRACT

Introduction: The gold standard for mitral valve disease is surgical treatment, for which it is essential to have a deep understanding of its anatomy. Our work aims to specify the relationships of the mitral annulus with the circumflex artery and define areas of proximity and greater risk of compromise during mitral interventions.









Material and methods: A descriptive, observational, cross-sectional study was conducted, in which 39 hearts from adult cadavers fixed in formaldehyde solution were dissected. From an atrial view of the mitral valve, taking the mitral annulus as a reference, several measurements were taken using Carpentier's classification of the sectors of the posterior mitral valve (P1, P2, and P3). Distance 1: from the anterolateral commissure to the circumflex artery. Distance 2: from the middle third of P1 to the artery. Distance 3: from P2 to the artery. Distance 4: from P3 to the artery.

Results: The global mean of distance 1 was 8.38 mm, of distance 2 was 8.16 mm, of distance 3 was 7.09 mm, and of distance 4 was 7.97 mm. We found no statistically significant differences according to coronary dominance.

Conclusion: The area of highest risk of injury to the circumflex artery concerning to the mitral annulus corresponds to the P2 sector of the posterior mitral leaflet. Left dominance and codominance would be associated with a greater risk.

Key words: *Mitral Valve; Coronary Vessels; Cardiac Surgical Procedures.*

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INTRODUCTION

Valvular heart disease is responsible for 10-20% of cardiac surgeries in the US ⁽¹⁾.

The repair of injuries is considered with increasing precociousness due to advances in surgical techniques and the development of percutaneous techniques. The aforementioned has resulted in the relief of symptoms and the preservation of ventricular function, thus improving patients' survival and quality of life ⁽²⁻⁴⁾.

The mitral valve (MV) can be affected by stenosis or regurgitation. About mitral stenosis, in most cases, it is of rheumatic origin and, therefore, nowadays rare ⁽⁴⁾.

Mitral regurgitation can be divided into two major causes: functional or secondary and primary or organic. An imbalance between the closing and anchoring forces, secondary to alterations in the geometry of the left ventricle, produces functional or secondary regurgitation. The initial cause is at the valve level in primary or organic regurgitation. It can be due to various diseases that directly affect the components of the MV (leaflets, chordae tendinous, papillary muscles). Until a few decades ago, its most common cause was rheumatic fever. Nowadays, the most common etiology is degenerative, associated with myxoid degeneration ^(4,5).

The gold standard for the treatment of MV disease is surgical treatment. Endovascular devices are mainly applied to patients with secondary mitral regurgitation who do not benefit from surgical treatment and/or present prohibitive surgical risk or are inoperable ^(2,3,5).

It is, therefore, essential to have a deep understanding of the anatomy of the MV and its relationships with the atrioventricular (AV) node, the circumflex artery, and the great cardiac vein.

Our work aims to specify the relationships of the mitral annulus with the circumflex artery and define areas of proximity and greater risk of injury during mitral interventions.

MATERIALS AND METHODS

A descriptive, observational cross-sectional anatomical study was conducted, and 39 hearts from adult cadavers of both sexes were fixed in a formaldehyde solution to be used. The average age of the donors was 55 to 65 years, and they did not present cardiovascular disease, being excluded those that presented it.

The chest was approached by bilateral paramedian lateral thoracotomy, and posteriorly the cardiopulmonary block was removed. Both

pulmonary pedicles and the great supracardiac vessels were dissected. An inverted "T" pericardiotomy was performed at the same time, and the intrapericardial pulmonary veins, the vena cava, and supra-aortic vessels were sectioned, releasing the heart.

Once the heart was released, the left atrium (LA) was approached by a vertical left atriotomy at the level of the posterior wall of the LA, with a lateral extension of the commissures towards the pulmonary veins. Subsequently, the lower lateral incision was extended parallel to the mitral annulus. In this way, better exposure of the atrial face of the MV was achieved.

The circumflex artery (CxA), its course through the coronary sulcus, and its collateral branches were identified.

From an atrial view of the MV and taking the mitral annulus as the measurement site, the anterolateral commissure and the sectors of the posterior MV P1, P2, and P3 according to the Carpentier classification (*Figure 1*) were chosen as measurement sites ⁽⁶⁾.

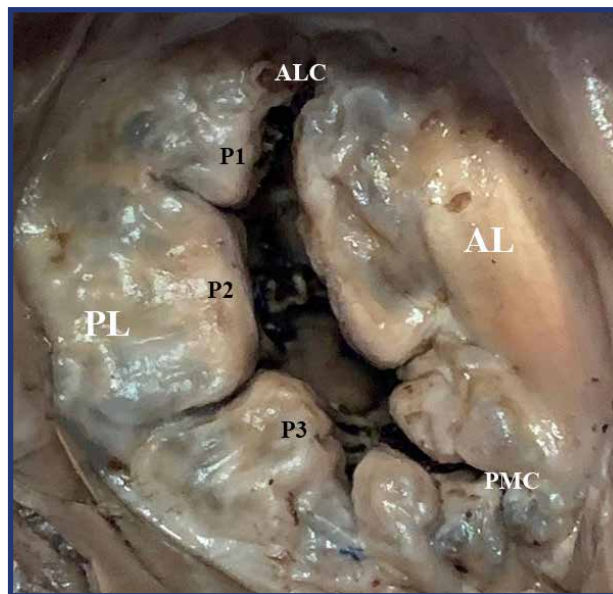


FIGURE 1. Atrial view of the mitral valve in a cadaveric piece. AL: Anterior leaflet, PL: Posterior leaflet, ALC: Anterolateral commissure, PMC: Posteromedial commissure, P1: Lateral portion of the posterior leaflet, P2: Middle portion of the posterior leaflet, P3: Medial portion of the posterior leaflet, CxA: Circumflex coronary artery, CS: Coronary sinus.

Posteriorly, the following measurements were made: from the anterolateral commissure to the CxA (distance 1); from the middle third of P1 to the CxA (distance 2); from the middle third of P2 to the CxA (distance 3) and finally the distance from the middle third of P3 to the CxA (distance 4) (*Figures 1 and 2*).

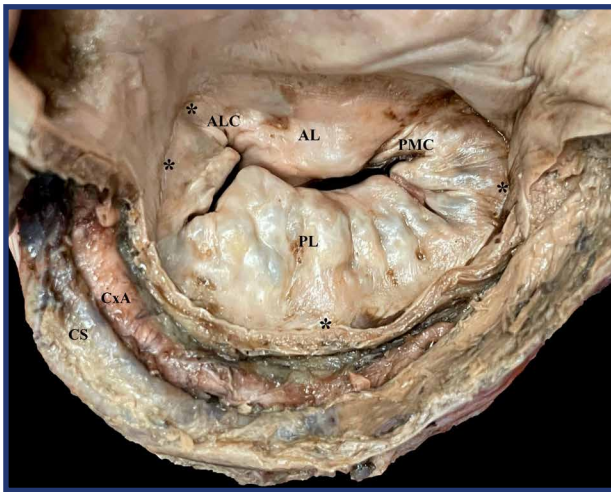


FIGURE 2. Atrial view of the mitral valve in cadaveric piece with a pattern of right dominance. AL: Anterior Anleaflet, PL: Posterior leaflet, ALC: Anterolateral commissure, PMC: Posteromedial commissure, CxA: Circumflex coronary artery, CS: Coronary sinus. Asterisks indicate the points of measure between the annulus to the circumflex coronary artery.

Cardiac dominance was defined according to which coronary artery originated the posterior descending artery. In some right-dominant hearts, measuring the artery in relation to P2 and P3 was impossible.

All measurements were made with a millimeter numerical caliper and by the same observer.

Continuous variables were expressed as a mean, range (minimum-maximum), and standard deviation (SD). Categorical variables were expressed as absolute numbers and percentages. Distances were compared in cadavers with left and right cardiac dominance using the Mann-Whitney U test, and a value of $p < 0.05$ was considered significant.

RESULTS

Of the 39 dissected hearts, 33 presented right coronary dominance (85%), five left coronary dominance (13%), and one codominance (2%).

The global mean of distance 1 (D1) was 8.38 mm, that of distance 2 (D2) was 8.16 mm, that of distance 3 (D3) was 7.09 mm, and that of distance 4 (D4) was 7.97 mm (Table 1).

In right-dominant hearts, the mean D1 was 8.32 mm (range 1-16 mm); that of D2 was 8.25 mm (range 2-15 mm); that of D3 was 7.41 mm (range 4-18 mm); and that of D4 was 8.63 mm (range 3-15 mm).

In the case of right-dominant hearts in which it was possible to measure D3 and D4, the CxA reached the lower face of the left ventricle, originating a posteroventricular branch for the lower face.

In left-dominant hearts, the mean D1 was 9.40 mm (range 3-11.5 mm); that of D2 was 7.60 mm (range 2-11 mm); that of D3 was 5.20 mm (range 2.5-11 mm); and that of D4 was 6.75 mm (range 3-13 mm).

In the only case of codominance, the mean of D1 was 5.5 mm; that of D2 was 8 mm; that of D3 was 9.5 mm; and that of D4 was 5 mm.

We found no statistically significant differences between hearts with right and left coronary dominance (Table 2).

DISCUSSION

The mitral annulus is part of the central fibrous skeleton of the heart and acquires essential relationships with the AV node, the CxA, and the great cardiac vein. The precise anatomical knowledge of these relationships is of enormous hierarchy during the intervention of the MV in order to reduce complications. The MV is formed by the anterior and posterior leaflets. The posterior veil adheres to the mitral fibromuscular annulus at the base, filling $\frac{2}{3}$ of it. It is divided by two clefts defined in three festoons called P1, P2, and P3 from lateral to medial. The anterior veil occupies $\frac{1}{3}$ of the annulus; and is divided into 3 festoons called A1, A2 and A3, corresponding to festoons 1, 2, and 3 of the posterior leaflet⁽⁶⁾. The CxA runs in the left atrioventricular or coronary groove, closely related to the mitral annulus. In its course, it is accompanied by the great cardiac vein.

In the present work, 85% of the hearts presented right dominance, 13% left dominance, and 2% codominance. Pessa et al. (2004) described the following relative frequencies for 85 hearts fixed with formaldehyde: 81.7% for right dominance, 16.37% for codominance, and 2.35% for left dominance⁽⁷⁾. Likewise, using preoperative CT angiography, Caruso et al. (2020) found that for a total of 95 hearts, right dominance in 80% of cases, codominance in 11%, and left dominance in 9%⁽⁸⁾. For the frequencies of right dominance, the findings are similar. In contrast, Pessa and Caruso described codominance as more frequent than left dominance.

Virmani et al. (1982), in a study that included 15 cadaveric hearts, recorded in an anteroposterior plane, lateral to the left appendage, average distances of 8.4 mm (6.0-11.5 mm) for right dominance, 4.1 mm (3.0-6.5 mm) for left dominance and 5.5 mm (4.5-7.5 mm) for codominance⁽⁹⁾. These results are similar to those recorded in the present work, observing that the shortest distance between the CxA and the mitral annulus is found in left dominance.

Pessa et al. (2004) recorded the shortest distance between the anterolateral commissure and the CxA,

Distance*	N	Mean	Minimum	Maximum	SD
1 (mm)	39	8,385	1,00	16,00	4,3626
2 (mm)	38	8,158	2,00	15,00	3,4467
3 (mm)	28	7,089	2,50	18,00	3,4455
4 (mm)	17	7,971	3,00	15,00	4,0907

TABLE 1. Distance between the mitral annulus and the circumflex coronary artery. *Distance 1: distance of the anterolateral commissure to the circumflex artery (CxA). Distance 2: distance of the middle third of P1 to the CxA. Distance 3: distance of the middle third of P2 to the CxA. Distance 4: distance of the middle third of P3 to the CxA. SD: Standard deviation.

Distance*	Right dominance Mean (SD)	Left dominance Mean (SD)	P value
1 (mm)	8,39 (4,53)	9,40 (6,60)	0,501
2 (mm)	8,25 (3,41)	7,60 (4,39)	0,714
3 (mm)	7,41 (3,41)	5,20 (3,55)	0,129
4 (mm)	8,63 (4,17)	6,75 (4,35)	0,446

TABLE 2. Distance comparison between hearts with right and left dominance. *Distance 1: distance of the anterolateral commissure to the Circumflex Artery (CxA). Distance 2: distance of the middle third of P1 to the CxA. Distance 3: distance of the middle third of P2 to the CxA. Distance 4: distance of the middle third of P3 to the CxA. SD: Standard Deviation.

with an average value of 3.99 mm (\pm 1.86 mm) in right-dominant hearts, 3.56 mm (\pm 1.63 mm) in hearts with codominance, and 4.09 and 3.69 mm for the two hearts with left dominance ⁽⁷⁾. These results differ from those analyzed in this work since the global distance measured at the level of the anterolateral commissure (distance 1) was the most significant observed: 8.38 mm (1-16 mm). The site with the shortest distance between the mitral annulus and the CxA was at the level of P2 (distance 3) with a global mean of 7.09 mm (range 2.5-18 mm), 7.41 mm (range 4-18 mm) for right dominance, 5.20 mm (range 2.5-11 mm) for left dominance, and the only case of codominance was 9.5 mm. In any case, Pessa et al. (2004) propose that the iatrogenic susceptibility of the CxA is unrelated to the dominance pattern.

Caruso et al. (2020) found that the smallest distance between the mitral annulus and the CxA was zone 1, defined as the distance between the anterolateral commissure and the midpoint of the scallop P1, corresponding to a global average of 5.49 mm (\pm 3.13 mm), 5.9 mm (\pm 3.2 mm) for right dominance, 3 mm (\pm 2.1 mm) for left dominance, and 4.6 mm (\pm 2.3 mm) for codominance ⁽⁸⁾. However, it should be mentioned that the authors mentioned above clarify that the differences found in the dominance pattern were not significant.

Ghersin et al. (2013) studied the relationships of the coronary vessels for the mitral and tricuspid annulus using computed tomography. In said study, they observed that the minimum distance from the mitral annulus to the CxA was 6.4 (\pm 2.1 mm). The

cases that presented left cardiac dominance presented shorter distances compared to those that presented right cardiac dominance 4.3 mm (\pm 1.0 mm) vs. 6.5 mm (\pm 2.0 mm). In addition, they presented a higher percentage of cases in which the distance was less than 5 mm. Regarding the topography, they found that the initial and middle portion of the artery is the one with the greatest proximity to the mitral annulus, lateral to the left trigone, which corresponds to the area of the anterolateral commissure⁽¹⁰⁾. The findings mentioned above are comparable to ours in that the left-dominant hearts were the ones that indicated the shortest distance, but not about topography.

The iatrogenic compromise of the CxA is a rare complication, but with severe consequences of not performing an early diagnosis and treatment. There can be direct damage when sutures are passed through the mitral annulus or indirectly by pulling the tissues close to it, generating distortion or kinking of the artery. The location of the lesion is usually posterior to the anterolateral commissure and the first segments of the posterior leaflet (P1 and P2), and it is proposed that left cardiac dominance is a risk factor. For those above, a coronary angiography is recommended before any valve procedure in adults^(11,12).

Ziadi et al. (2013) report the case of a CxA occlusion during a mitral plasty procedure. In this study, they refer to the fact that it occurs more frequently in patients with left dominance and codominance. In hearts with left dominance, the mean distance between the mitral annulus and the CxA was 4.1 mm (range 3-6.5mm), 5.5 mm (range 4.5-7.5mm) in codominance, and 8.4 mm (range 6-11.5 mm) in dominance right. In the said study, there is no reference to which sector of the posterior annulus is the one that is closest to it⁽¹³⁾. The distances analyzed are consistent with the values found in our work.

Yavari et al. (2021) report the case of a patient who underwent mitral valve replacement due to severe mitral stenosis, which presented an inferior acute ST-elevation myocardial infarction in the immediate postoperative period. An emergency cineangiocoronariography showed an occlusion in the middle part of the CxA. The mechanisms of injury to the CxA after mitral valve replacement include: air embolism, compromise of the artery by a suture, coronary spasm, oversized prosthesis, excessive resection of valve tissue, and excessive proximity of the CxA to the mitral annulus, especially in hearts with left dominance⁽¹⁴⁾.

Pettinari et al. (2015) describe the case of iatrogenic CxA lesion after mitral valve plasty. In this case, the CxA had an abnormal origin from the right coronary artery taking a close relationship to the

aortic annulus and the anterior mitral annulus⁽¹⁵⁾. It was compromised at the level of the anterior mitral ring, so when performing mitral surgery, cases with anomalous origins of the CxA should also be considered.

Husain et al. (2019) conducted a retrospective study on the incidence of iatrogenesis on CxA during mitral valve surgery in Saudi Arabia. Of 1706 patients who underwent mitral surgery between 2000 and 2016, 95 were evaluated by postoperative cineangiocoronariography for suspected CxA injury, and nine (0.5%) showed injury to the CxA. Of the nine cases, all occurred in valve replacement surgery but not mitral plasty⁽¹⁶⁾. The distribution of these was similar for the coronary dominance pattern.

Arévalos et al. (2021) report the case of a patient who suffers an acute occlusion of the CxA after mitral valve plasty. In their analysis, as suggested by the bibliography, they mention that it is more frequent in left dominance and codominance, where the proximity of the CxA is more significant than the anterolateral commissure and the posterior mitral annulus⁽¹⁷⁾.

Finally, we recognize as a limitation of our work that it was carried out on hearts fixed with formaldehyde. This method of cadaveric fixation dehydrates the tissues, which can determine alterations in the measurements concerning fresh tissues or living tissue. We must also consider that the measurements taken were only analyzed in the transverse plane, not making measurements between the annulus and the CxA in the vertical plane.

CONCLUSIONS

The anatomical knowledge of the MV and its relationships is essential to reduce complications during surgical and endovascular procedures.

The area of most significant risk of injury to the CxA in relation to the mitral annulus corresponds to the P2 sector of the posterior mitral leaflet (*Figure 3*).

Left dominance and codominance would associate a greater risk of vascular injury during surgical procedures on the MV.

Declarations

The authors declare no conflict of interest.

Acknowledgments

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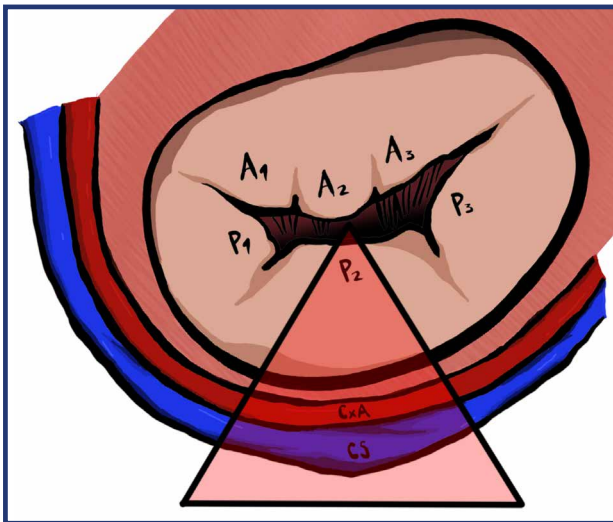


FIGURE 3. Schematic representation of the mitral valve (atrial view) in relation to the circumflex coronary artery and the coronary sinus. AL: Anterior leaflet, PL: Posterior leaflet, ALC: Anterolateral commissure, PMC: Posteromedial commissure, A1: Lateral portion of the anterior leaflet, A2: Middle portion of the anterior leaflet, A3: Medial portion of the anterior leaflet, P1: Lateral portion of the posterior leaflet, P2: Middle portion of the posterior leaflet, P3: Medial portion of the posterior leaflet, CxA: Circumflex coronary artery, CS: coronary sinus, Red zone shows the area with the most significant risk.

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ETHICAL STATEMENT

The authors declare having respected the ethical principles underpinning the research. Regarding informed consent, the corpses in which the dissections were performed were obtained from voluntary donors who expressed their consent in writing, freely and voluntarily, while alive. The Departamento de Anatomía, Facultad de Medicina, Universidad de la República, has these informed consents that enable said corpses to be used for teaching and research tasks.