The three-dimensional geometric relationship between the mitral valvar annulus and the coronary arteries as seen from the perspective of the cardiac surgeon using cardiac computed tomography

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Abstract

OBJECTIVES: Mitral annuloplasty involves sewing a prosthetic ring to the mitral annulus. This involves a risk of damaging the surrounding structures in the left atrioventricular (AV) groove, particularly the left circumflex artery, which may be inadvertently sutured, causing an arterial occlusion. We have used cardiac computed tomography (CT) scans to study the three-dimensional relationship between the mitral valvar annulus and the neighbouring coronary arteries in the AV groove, and to map the distance between the arteries and the annulus.

METHODS: We examined cardiac CT scans of two groups of patient: 40 normal subjects, and 30 patients with left ventricular dysfunction and/or mitral regurgitation. The hinge line of the mitral valve, as well as the location of the coronary arteries within the left AV groove, was manually marked on a workstation and three-dimensional coordinates saved in digital format. Dedicated software was developed to calculate the plane of the mitral annulus, and the smallest distance between each point on the annulus and each of the left circumflex and right coronary arteries, called local minima. The global minimum for each heart is defined as the minimum of all local minima.

RESULTS: The global minimum for the left circumflex averaged 6.4 ± 2.1 mm, usually involving the proximal portion, just laterally to the left trigone. In three-tenths of patients, the global minimum was <5 mm. This was more common in patients with left dominance, and in the normal subjects. The major component of the line vector between the annulus and circumflex is parallel to the plane of the mitral annulus, while the perpendicular component is usually in an atrial direction. For the dominant right coronary artery (RCA), the global minimum distance to the annulus is 14.7 ± 5.7 mm. In no patient did the RCA approach to within 5 mm with respect to the mitral annulus, albeit that 13% were <10 mm.

CONCLUSIONS: In a significant proportion of patients, the left circumflex is in very close proximity to the annulus of the mitral valve. Knowledge of the precise three-dimensional relationships between the structures can be expected to minimize iatrogenic complications.

Keywords: Mitral annulus • Mitral valve surgery • Coronary artery occlusion • Left ventricular geometry

INTRODUCTION

The hinge of the mitral valvar leaflets along the left atrioventricular (AV) junction, also referred to as the mitral valve annulus, is in close proximity to the left AV groove [1]. The groove itself is filled with fibro-adipose tissue, in which is nested the left circumflex artery (LCx), along with inferolateral branches of the right coronary artery (RCA) when this artery is dominant, as well as the coronary sinus and great cardiac vein. Various surgical and interventional percutaneous procedures are routinely performed in the region of the left AV junction, with the operator basically blind to the location of the adjacent coronary arteries, placing them at risk of inadvertent damage. The most important interventions are, first, mitral valvar annuloplasty [2–4], when a rigid annuloplasty ring is sutured in the left AV junction from its atrial aspect, the left atrium having been emptied by the surgeon with the patient on cardiopulmonary bypass. The structures contained within the groove are equally at risk during replacement of the mitral valve with a prosthetic valve [5]. Nowadays, the risk is also present during percutaneous radiofrequency ablations performed during electrophysiological...
procedures, when high energy burns are made within the left atrium, and occasionally within the left ventricle, in order to block accessory pathways or re-entry circuits that cause tachyarrhythmias [6], and during various experimental methods for reduction of the area of the mitral valvar orifice, such as coronary sinus annuloplasty [7], radiofrequency energy application [8] and external basal annuloplasty [9]. Various reports have now appeared in the literature exemplifying the iatrogenic complications [10–16]. Inadvertent damage to, or ligation, of the left proximal circumflex artery usually results in peri-operative myocardial infarction, which may be difficult to diagnose at the time of surgery. An example from our own institution is shown in Fig. 1. The frequency of occurrence of this complication is unknown, albeit that it is probably more frequent than indicated by the paucity of reports in the literature. With this in mind, we have analysed the precise geometric relationship between the annulus of the mitral valve and the coronary arteries, based on high-resolution cardiac computed tomography (CT) studies, presuming that the identification of the distances between the structures, as well as their 3D geometric relationship, might aid the surgeon or operator in avoiding iatrogenic damage.

MATERIALS AND METHODS

Patient population

We studied two groups of patients. The first was a group of 40 consecutive patients undergoing cardiac CT, and having no evidence of organic heart disease. We identify these patients as being our normal controls. The second group of 30 patients was selected from our database, with 15 having evidence of left ventricular dysfunction and no more than mild mitral regurgitation (MR) by echocardiography, and 15 with greater than mild MR on echocardiography. The cause of MR was tethering related to a dilated ventricle in 5, mitral valvar prolapse in 1 and mitral annulus calcification in 1. The regurgitation was moderate in 8, and severe in 7 patients.

We examined our normal group of consecutive patients so as to establish the normal geometry of the mitral valvar annulus. Since surgery is usually performed in patients with abnormal ventricular and mitral valvar geometry, we chose to also examine abnormal patients, examining whether the distorted ventricular geometry affected the relationship between the mitral annulus and the coronary arteries. We show details of the two groups in Table 1.

Computed tomography scan

All studies were performed on a Brilliance 64 slice scanner (PMS, Cleveland, OH, USA), following IV injection of 80 ml non-ionic contrast. Scan parameters were 64 slices × 0.625 mm, rotation time 0.42 s, pitch 0.2, tube voltage 120 kV, tube current 800–1000 mAs, tube current modulation was used with maximum current applied between 40 and 75%, with the current reduced to 20% of maximum for the remainder of the heart cycle. Scans were taken during Inspiration and lasted ~10 s. Studies were reconstructed at end-diastole (0%), end-systole (40% of R–R cycle) and mid-diastole (75% of R–R cycle) at a slice thickness of 0.67 mm and a soft reconstruction filter (CB).

Data analysis

CT data were loaded to an Extended Brilliance workstation (PMS, Cleveland, OH, USA), and the centre points of the coronary arteries, along with the annulus of the mitral valve, were marked and stored in digital format. The annulus was marked on the axial images starting from the right trigone (the right hand extreme of the region of mitral-aortic fibrous continuity) and continuing in a medial direction, every 2–3 mm until the entire mitral ring at the left AV junction was completed. The mitral annulus was defined as the atrial aspect of the attachment of the mitral valvar leaflet to the AV junction (Fig. 2). We chose to mark the atrial aspect, since this is the approach the surgeon sees when inserting the sewing ring. The locations of the right and left trigones were then marked to serve as landmarks, since these are the two points that are most easily identified, as well as forming the two extremes of the region of aortic-mitral fibrous continuity.

The coronary arterial centrelines were then marked semi-automatically, starting at the respective orifices of the left and right coronary arteries, and continuing along the portions of the arteries within or closest to the AV grooves. This meant that we usually marked the left circumflex and the RCA, together with the inferolateral branch of the latter artery within the left AV groove (Figs 3 and 4).

Only the centre of the lumen was marked in this process. So to account for the entirety of the coronary arterial tube, we also measured the diameter of each artery proximally and distally. At the end of the process, the coordinates of the coronary centrelines and mitral valvar insertion points were saved in an ASCII format.

We defined coronary arterial dominance according to which artery supplied the inferior interventricular artery, placing any patients with co-dominant circulations in the left dominant group. We also noted for each artery whether or not it gave rise to inferolateral branches. Analysis was later performed according to the patterns of branching observed.
Left ventricular and atrial volumes were measured for 0, 40 and 75% phases, which approximately represent end-diastolic and end-systolic phases, and diastasis. Measurements were performed using semi-automatic 3D model-based segmentation software (Extended Brilliance Workstation, Philips Medical Systems, Cleveland, OH, USA). From these volumes, we calculated left ventricular ejection fraction, and left atrial emptying volumes.

Special dedicated software was written using Matlab (version 7.12.0.635) to extract the following:

(i) The smallest distance between each point on the mitral annulus and the LCx and RCA, henceforth referred to as the local minima. The minimum of all local minima for each heart is referred to as the global minimum.

(ii) Each 3D line segment representing the local minimum was expressed as two perpendicular components relative to the plane of the annulus: an in-plane and a through-plane component, since it is essential for the surgeon to know, not only the distance, but also the orientation of the coronary artery relative to the AV junction. In order to do this, an imaginary plane was passed through the coordinates of the annulus using least squares analysis, which approximates the best-fitting plane to the known coordinates.

(iii) In order to compare and summate results from different patients, the points around the annulus were converted to polar coordinates, in such a way that it was divided into 90 equi-angular points around its centre, defined as its centre of gravity, with 0° defined as the right trigone, and angles measured in a clockwise direction, when looking from the atrial side.

(iv) The distance of each point on the annulus from the centre of the valvar orifice represents its ‘radius’, and enables the symmetry or lack of symmetry, to be expressed relative to its centre.

Analysis was performed for the normal patients vs abnormal subjects, and for those with up to mild as opposed to greater-than-mild mitral regurgitation. We also analysed separately those with left as opposed right coronary arterial dominance. Analysis was performed at both mid-diastole and end-systole. Since mid-diastolic datasets are generally of better image quality, and because this is probably closer to the situation encountered in surgery, we report most results only for mid-diastole.

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**Table 1: Population details**

<table>
<thead>
<tr>
<th></th>
<th>Normal controls (n = 40)</th>
<th>LV dysfunction without MR (n = 15)</th>
<th>LV dysfunction with MR (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>52 ± 9**</td>
<td>56 ± 11*</td>
<td>67 ± 13</td>
</tr>
<tr>
<td>Sex - male (%)</td>
<td>73</td>
<td>87</td>
<td>67</td>
</tr>
<tr>
<td>Diabetes (%)</td>
<td>15</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>Hypertension (%)</td>
<td>48</td>
<td>53</td>
<td>67</td>
</tr>
<tr>
<td>Smoking (%)</td>
<td>36</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Dyslipidemia (%)</td>
<td>55</td>
<td>60</td>
<td>53</td>
</tr>
<tr>
<td>Previous CABG (%)</td>
<td>0**</td>
<td>27</td>
<td>40</td>
</tr>
<tr>
<td>Previous MI (%)</td>
<td>3**</td>
<td>67</td>
<td>53</td>
</tr>
<tr>
<td>Calcium score (Agatston units)</td>
<td>49 ± 125**</td>
<td>378 ± 569</td>
<td>122 ± 105</td>
</tr>
<tr>
<td>CAD: (%)</td>
<td>53%/47%/0%/0%</td>
<td>13%/20%/0%/67%</td>
<td>7%/40%/20%/33%</td>
</tr>
<tr>
<td>MR &gt;mild (%)</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>LVEDV (ml)</td>
<td>154 ± 30**</td>
<td>211 ± 53</td>
<td>278 ± 144</td>
</tr>
<tr>
<td>LVESV (ml)</td>
<td>56 ± 18**</td>
<td>122 ± 47</td>
<td>183 ± 130</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>64 ± 7**</td>
<td>43 ± 10</td>
<td>38 ± 12</td>
</tr>
<tr>
<td>LA ESV (ml)</td>
<td>94 ± 22**</td>
<td>108 ± 17*</td>
<td>165 ± 56</td>
</tr>
<tr>
<td>LA AVolume (ml)</td>
<td>41 ± 10**</td>
<td>35 ± 16</td>
<td>28 ± 13</td>
</tr>
</tbody>
</table>

**P < 0.05 for normals vs LV dysfunction, *P < 0.05 for up to mild vs greater than mild mitral regurgitation.**

Mi: myocardial infarction; CABG: coronary artery bypass graft; CAD: coronary artery disease; N: normal; NSCAD: non-significant CAD; 1VD: 1-vessel disease; MVD: multivessel disease; LVEDV: left ventricular end-diastolic volume; LVESV: left ventricular end-systolic volume; LVEF: left ventricular ejection fraction; LA ESV: left atrial end-systolic volume; LA Δvolume: left atrial volume change from end-systole to end-diastole.

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**Figure 2:** A CT multiplanar reformat perpendicular to the LCx centreline, showing the LCx centreline point (.) and its proximity to the mitral annulus (x). Notice that the mitral leaflet inserts into the base of the left ventricular myocardium, while the LCx is more atrial than the annulus.
Statistical analysis

Differences between subgroups were tested using the non-paired Student’s t-test for continuous variables, and by the χ² statistic for categorical variables. Pearson’s correlation coefficient was used to test for similarity between different cardiac phases.

RESULTS

The patients with MR were older, had more coronary arterial disease, and had larger left ventricular and atrial volumes and worse ventricular and atrial function (Table 1). Those with greater-than-mild regurgitation were older than those with mild or no regurgitation, and had larger left atrial chambers.

Results will generally be presented only for the 75% phase, since the image quality is usually optimal at mid-diastole, and this is most likely closest to the ‘neutral’ state to which the heart conforms during surgery, which is following passive relaxation but before active atrial contraction. In addition, we subsequently present data showing the similarity between the two phases.

A typical case utilizing real 3D data from a CT scan is presented in Fig. 3, which we use to describe how the data were analysed. The heart is viewed from the surgeon’s perspective, from above (Fig. 5, shown for reference). The oval hinge line of the leaflets of the mitral valve is viewed from the left atrial side, with the left ventricle away from us distal to the plane of the AV junction. The valvar orifice is related to the aortic root on the right, the LCx superiorly and on its left, and the distal RCA inferiorly. The common border with the aorta represents the region of mitral-aortic valvar continuity, with its two extremes made up by the left and right trigones. All analyses are made relative to the right trigone, which is defined as 0°, and are continued in a clockwise direction. In the example shown, the RCA approaches the valvar orifice at ~50°, while the LCx is closest to the hinge of the mural or posterior leaflet at ~230°. The left trigone is seen at ~300°. In our overall cohort, the average angle between the two trigones is 72°, such that, on average the left trigone appears at 286 ± 12°.

Minimum distance between the annulus and the left circumflex artery

Figure 6A shows the local minimum distance between each point on the mitral annulus and the closest point on the LCx. The LCx approaches close to the annulus between 220 and 270° for all patients, with narrow standard deviation (SD), while a
second zone of proximity occurs at $\approx 100$–$120^\circ$ for certain cases (wide SD). Between $290^\circ$, through $360^\circ$ and continuing to $60^\circ$, the two structures are distant from one another in all cases. The average global minimum distance from the LCx is $6.4 \pm 2.1$ mm, occurring at an angle of $236 \pm 35^\circ$ from the right trigone (Table 2). Looked at from the opposite direction, after removing six outliers, the mean distance from the left trigone was $42 \pm 17^\circ$ in an anticlockwise direction. Overall, 22 (31%) patients have a global minimum distance of <5 mm, occurring mostly around $236^\circ$. The patients with MR have a larger global minimum distance (7.6 ± 2.3 mm) compared with their normal controls (5.8 ± 1.8 mm, $P = 0.005$). Patients with a dominant LCx have a smaller global minimum distance than patients with a dominant RCA (4.3 ± 1.0 vs 6.5 ± 2.0 mm, $P = 0.01$), and also have a larger percent with <5 mm proximity (5 (83%) vs 15 (23%), $P = 0.002$). Examples of left and right dominant circulations are shown in Fig. 4. The above values relate to the distance relative to the centerline of the LCx. If we take into account the circumference of the arteries, then distances are approximately 1.4 mm closer, since the mean diameter of the proximal-mid LCx is 2.7 ± 0.6 mm.

**Figure 4:** Examples of a patient with severe functional MR and a left dominant circulation (A, B) and a normal control with a right dominant circulation (C, D), viewed from above (left) and from the left lateral perspective (right). Note how the dominant LCx (A) basically hugs the circumference of the mitral valve, between $\approx 200^\circ$ and $270^\circ$ with a minimum of 2.8 mm at 240°. The non-dominant LCx, however, only approaches the annulus shortly at $\approx 270^\circ$ (C). Note also how the LCx is mostly situated more atrial relative to the annulus (B, D), while the RCA is more ventricular. MV = annulus of mitral valve leaflets, TV = annulus of tricuspid valve leaflets.

**Figure 5:** A photograph of the mitral valve and annulus taken during surgery is shown as a reference. The left bracket shows the main danger zone where the LCx tends to approach the annulus while the three stars mark the location of the second region where the LCx less frequently approaches the mitral annulus. Courtesy of Joseph Lamelas, M.D., Chief of Cardiac Surgery, Mount Sinai Medical Center, Miami Beach, FL, USA. Photograph supplied by courtesy of and with permission from J. Lamelas.

**Orientation of left circumflex with respect to the mitral annulus**

The major component of the local vector separating the annulus and the LCx is in-planar, with a relatively small component being perpendicular to the plane of the AV junction. The latter through-plane component becomes relatively larger when the LCx approaches the annulus between 180 and 260°. The LCx is mostly on the atrial side of the annulus, occasionally reaching the AV junctional plane. Of 22 cases that had a minimum distance of <5 mm from the LCx, 8 reached or passed through the AV junctional plane. This has important implications when the
surgeon places his or her sutures in the proximity of the annulus. Occasionally, the attachment of the posterior leaflet is more basal, when it attaches to the left atrial wall. In such cases, the LCx may be more ‘ventricular’, as shown by the example in Fig. 2. Also, the marginal branches cross from the atrial to the ventricular aspect of the AV junction. These arteries, however, tend to distance themselves immediately from the AV junction by crossing to the epicardial surface of the left ventricle. Looking specifically at the global minimum vector for each heart, we find that the mean global minimum (6.4 ± 2.1 mm) is composed of a mean in-plane component of 5.4 ± 2.1 mm and a mean through-plane component of 2.8 ± 1.9 mm. This corresponds to a mean angle of 27 ± 17° for the line vector of the minimum distance, relative to an imaginary AV junctional plane, and directed in the direction of the left atrium. For the 15 cases with MR, the mean global minimum of 7.6 ± 2.3 mm is composed of a mean in-plane component of 6.6 ± 2.3 mm and a mean through-plane component of 3.0 ± 2.1 mm, corresponding to a mean angle of 24 ± 17°.

**Figure 6:** (A) Minimum distance between the MV annulus and the LCx. A graph of the minimum distance ± SD between each point on the annulus and the closest point on the LCx artery centreline. In addition, the grey points mark the number of cases which have a minimum distance <5 mm for each point around the annulus, for example for angles between 230 and 260° corresponding to the left side of the valvar orifice just before the left trigone, ~5 cases each have a minimum distance of <5 mm from the LCx artery at those angles. (B) Minimum distance between the MV annulus and the RCA. A graph of the minimum distance ± SD between each point on the annulus and the closest point on the RCA centreline. In addition, the grey points mark the number of cases which have a minimum distance <10 mm for each point around the annulus.

**Minimum distance between the annulus and the right coronary artery**

For most of its circumference, the mitral annulus is much more distant from the RCA compared with the LCx. The RCA approaches fairly closely to the annulus only between 60 and 120°, with a wide SD (Fig. 6B). Even at its closest, the global minimum distance between the RCA and the annulus is 17.5 ± 7.9 mm. When this analysis is performed only for right coronary arteries having an inferolateral branch, found in 57 of 70 cases, the global minimum distance between these structures is 14.7 ± 5.7 mm, occurring at an angle of 90 ± 43° from the right trigone (Table 2). No RCA approaches <5 mm with respect to the mitral annulus, albeit that 9 (13%) were <10 mm.
Orientation of the right coronary artery with respect to the mitral annulus

The global minimum between the two structures (17.5 ± 7.9 mm) can be separated into an in-plane component of 15.7 ± 7.5 mm, and a through-plane component of 6.4 ± 5.4 mm, corresponding to an angle of 16 ± 7° with respect to the AV junctional plane. The RCA, in contrast to the LCx is usually situated on the ventricular aspect of the mitral annulus.

Similarity between different phases of the cardiac cycle

The average local minimum distance per case, between each point on the annulus relative to the LCx is 19.8 ± 4.6 mm at 75% and 20.1 ± 4.5 mm at 40%, mean difference 0.3 ± 1.7 mm, r = 0.93. The corresponding values for the RCA were 34.6 ± 6.1 mm at 75% and 33.9 ± 5.9 mm at 40%, mean difference 0.7 ± 2.7 mm, r = 0.90. For all patients, the mean global minimum distance between the annulus and the LCx was 6.4 ± 2.1 mm at 75% vs 6.2 ± 2.0 mm at 40%, mean difference 0.2 ± 1.4 mm, r = 0.77. For the RCA, the mean global minimum distance was 17.5 ± 7.9 mm for 75% and 15.9 ± 7.3 mm for 40%, mean difference 1.5 ± 4.2 mm, r = 0.85.

Radius of the mitral annulus

The mean radius relative to the centre of mass varies from 15 to 18 mm, with maxima at ~80 and 260°. The 40% phase is very similar to 75% with a slight rotation of ~10–20° anticlockwise relative to the right trigone, corresponding to the expected systolic rotation of the base relative to the apex of the heart.

DISCUSSION

Our major contribution when compared with previously published studies is our comprehensive analysis of the three-dimensional relationship between the mitral annulus and both the left and right coronary arteries contained within the left AV junction as revealed using high-resolution CT images of the beating heart. Previous studies have used two-dimensional analysis, and have examined only specific locations around the mitral valvar orifice. The more comprehensive picture provided by our study should give the surgeon important information with which to avoid injuring the coronary arteries during procedures in the vicinity of the left AV junction.

We have demonstrated a fairly consistent relationship between the LCx and the mitral annulus. The proximal to mid portion of the LCx is usually closest to the annulus just lateral to the left trigone, corresponding to the region of the superolateral commissure. A second less-common region of proximity occurs when the distal part of the LCx approaches the annulus at 100–120° clockwise relative to the right trigone, corresponding to the inferior aspect of the valvar orifice. The dominant RCA, on the other hand, never approaches <5 mm to the annulus. Thus, the surgeon should be aware of the regions where care is most needed to avoid the coronary arteries. This, together with our results regarding the orientation of the LCx and the mitral annulus, should enable surgeons to plan the optimal angle for insertion of sutures. In this regard, we have found that, for most arteries, the LCx is more ‘atrial’ relative to the hinge of the posterior leaflet, albeit that, when the artery gets close to the annulus, it often approaches the AV junctional plane. The surgeon should thus be aware, when choosing the size of the mitral prosthetic ring, that larger rings may result in radial pressure on those arteries that reach the AV junctional plane. Our study also has relevance for electrophysiology procedures, since the majority of LCx arteries are on the atrial side of the mitral annulus, usually between it and the coronary sinus and great coronary vein. When performing ablation procedures in the proximity of the mitral annulus or coronary sinus, therefore, special care should be made not to apply excessive radiofrequency energies.

Our results using three-dimensional analysis are compatible with previous studies that relied on two-dimensional findings. Moreover, anatomical studies have found the distance between the mitral annulus and the LCx to be as little as 1 mm, with the

### Table 2: Average minimum distances between the mitral annulus and coronary arteries

<table>
<thead>
<tr>
<th></th>
<th>Min distance (mm)</th>
<th>No. with min &lt;5 mm</th>
<th>Angle at min (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCx</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All (n = 70)</td>
<td>6.4 ± 2.1</td>
<td>22 (31%)</td>
<td>236 ± 35</td>
</tr>
<tr>
<td>Normals (n = 40)</td>
<td>5.8 ± 1.8</td>
<td>14 (35%)</td>
<td>234 ± 37</td>
</tr>
<tr>
<td>Abnormals (n = 30)</td>
<td>7.1 ± 2.2</td>
<td>7 (23%)</td>
<td>239 ± 34</td>
</tr>
<tr>
<td>LV enlargement (n = 15)</td>
<td>6.6 ± 2.1</td>
<td>5 (33%)</td>
<td>242 ± 34</td>
</tr>
<tr>
<td>Mitral regurgitation (n = 15)</td>
<td>7.6 ± 2.3</td>
<td>2 (13%)</td>
<td>236 ± 34</td>
</tr>
<tr>
<td>Left dominant (n = 6)</td>
<td>4.3 ± 1.0</td>
<td>5 (83%)</td>
<td>232 ± 17</td>
</tr>
<tr>
<td>Right dominant (n = 64)</td>
<td>6.5 ± 2.0</td>
<td>15 (23%)</td>
<td>236 ± 36</td>
</tr>
<tr>
<td>LCx has a PL branch (n = 28)</td>
<td>6.4± 2.3</td>
<td>9 (32%)</td>
<td>229 ± 45</td>
</tr>
<tr>
<td>LCx has no PL branch (n = 36)</td>
<td>6.7 ± 1.9</td>
<td>7 (19%)</td>
<td>242 ± 28</td>
</tr>
<tr>
<td>RCA has a PL branch (n = 57)</td>
<td>6.7 ± 2.0</td>
<td>12 (21%)</td>
<td>237 ± 34</td>
</tr>
<tr>
<td>RCA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All (n = 70)</td>
<td>17.5 ± 7.9</td>
<td>9 (13%)</td>
<td>107 ± 78</td>
</tr>
<tr>
<td>Right dominant (n = 64)</td>
<td>16.6 ± 7.4</td>
<td>9 (14%)</td>
<td>93 ± 56</td>
</tr>
<tr>
<td>RCA has a PL branch (n = 57)</td>
<td>14.7 ± 5.7</td>
<td>9 (16%)</td>
<td>90 ± 43</td>
</tr>
</tbody>
</table>

Min: minimum distance; PL: posterolateral; LV: left ventricular.
common than generally thought. For example, Ender signi
fl
concerning its location. Ender et al. [21] measured the distance between the LCx and the annulus by transesophageal echo at the level of the superolateral commissure at 3.1 ± 1.3 mm, finding no significant difference according to coronary arterial dominance.

The incidence of LCx injury is unknown, but may be more common than generally thought. For example, Ender et al. [21] performed intraoperative transesophageal echo in 110 patients undergoing minimally invasive MV repair, finding LCX injury in 3 patients, all of whom were treated immediately. Wong et al. [14] found angiographic evidence of acute sub-clinical circumflex arterial injury in 15 of 54 patients studied following ablation of the mitral isthmus. We showed that the presence of left ventricular enlargement or MR was associated with greater separation between the LCx and the mitral annulus. This is compatible with a study showing the coronary sinus to be closer to the annulus of the mitral valve in normal hearts than in hearts with MR [22].

CT has been used previously to study the geometrical relationships of the vessels around the mitral valve orifice [22–25]. All these studies, however, concentrated on the role of percutaneous mitral annuloplasty via the coronary sinus, and did not examine closely the relationship between the orifice and the LCx. To the best of our knowledge, only a single study has studied the relationship between a mitral annuloplasty ring and the LCx subsequent to implantation [4], studying 10 cadaveric human hearts, and showing the LCx to be at a safe distance from the ring in all cases.

The limitations of our study include the relatively small number of cases with MR and the small number of left- or co-dominant circulations, as well as the possibility that the relationships between the structures studied might change in the surgical setting.

Our results suggest that, for the majority of cases, it would be sufficient for the surgeon to avoid the atrial aspect of the annulus, where the LCx resides, and to take special care in the region lateral to the superolateral commissure. In the presence of a dominant LCx, however, there may be value in performing a presurgical coronary CT, thus demonstrating its precise course and adjacency relative to the annulus.

Conflict of interest: none declared.

REFERENCES