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Echocardiographic Identification of Iatrogenic Injury of the Circumflex Artery During Minimally Invasive Mitral Valve Repair

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Background. **Injury to the circumflex artery after mitral valve (MV) repair or replacement is a recognized complication of this procedure. We designed an echocardiographic method to visualize the course and flow of the circumflex artery, to detect iatrogenic injury to this structure intraoperatively, as well as to predict the coronary dominance pattern in MV surgery patients.**

Methods. **After Ethics Committee approval, a prospective study was undertaken in 110 patients undergoing minimal invasive MV repair. Intraoperative transesophageal echocardiography was used to visualize the circumflex artery using a combination of B-mode imaging and color Doppler with different Nyquist limits. The course of the circumflex artery and the coronary sinus and their corresponding diameters were documented at the proximal and distal ends of both vessels. Preoperative angiographic data were used to determine the coronary dominance type.**

Results. **The course of the circumflex artery could be detected proximally in 109 patients (99%), to the point of intersection with the coronary sinus in 99 patients (90%), and distal to this intersection in 95 patients (86%) using our technique. Three patients had evidence of iatrogenic aliasing (circumflex stenosis) or "no flow" (circumflex occlusion) on transesophageal echocardiography examination after repair and therefore underwent surgical or percutaneous correction. All 3 of these patients had an uncomplicated postoperative course thereafter with no evidence of perioperative myocardial infarction. All remaining patients with normal circumflex examinations after repair did not show any clinical evidence of myocardial infarction or unstable hemodynamics postoperatively. The 95% confidence interval for the diameter of the proximal circumflex artery was 4.5 mm to 5.6 mm for the left dominant type patients and 3.8 mm to 4.2 mm for the right dominant and balanced type patients ($p = 0.01$).**

Conclusions. **The early recognition of iatrogenic injury of the circumflex artery is feasible with intraoperative transesophageal echocardiography examination, and may lead to treatment before extensive myocardial infarction occurs. We suggest that visualization of the circumflex artery with our technique should be performed more frequently in patients undergoing MV surgery.**

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Owing to recent advances in surgical techniques, there has been a significant increase in the frequency of mitral valve (MV) repair. A possible complication of MV repair is compromised flow in the circumflex artery, which may occur in as many as 1.8% of the patients [1]. This complication can occur during implantation of an annuloplasty ring or band, during suture annuloplasty techniques, or during MV replacement surgery [2]. It is controversial whether coronary dominance pattern increases the risk of circumflex injury. Kaklikkaya and colleagues [3] noticed that the risk of injury to the circumflex artery was highest in the left dominant and in balanced coronary circulation, in contrast to the findings of Pessa and associates [4].

Iatrogenic circumflex injury is a potentially life-threatening condition that should be detected early to minimize the risk of myocardial damage. Recently, a case report from our group described a disturbance of flow in the circumflex artery that was detected intraoperatively by transesophageal echocardiography (TEE) [5]. To identify the value of a routine intraoperative echocardiographic examination of the circumflex artery before and after MV repair, we designed this prospective study. The aims of this study were to determine the best TEE view to visualize the circumflex artery; to determine if the circumflex artery can be distinguished from the coronary sinus echocardiographically; to detect any disruption to circumflex arterial flow caused by MV repair surgery; and to identify the coronary dominance pattern by measuring the diameter of the circumflex artery.

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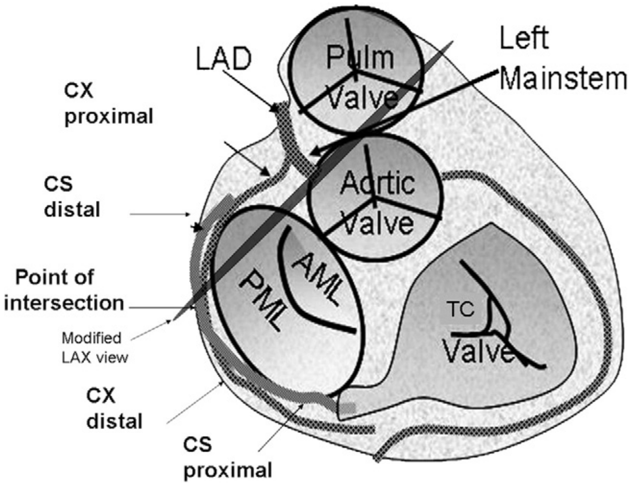

Fig 1. Schematic drawing of the modified midesophageal long-axis (LAX) view. (AML = anterior mitral leaflet; CS = coronary sinus; CX = circumflex artery; LAD = left anterior descending artery; Left mainstem = left main coronary artery; PML = posterior mitral leaflet; Pulm = pulmonary; TC = tricuspid.)

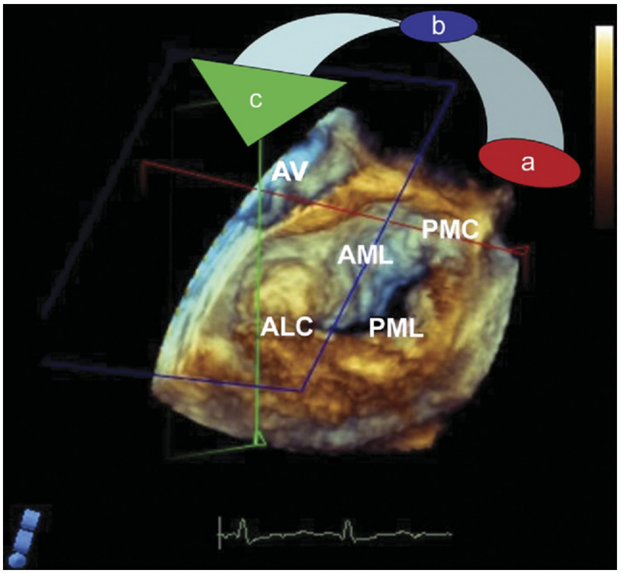

Fig 2. Three-dimensional transesophageal echocardiogram showing the cross-section views by rotating the probe counterclockwise from the modified midesophageal aortic valve (AV) long-axis view. (a, b, and c) Planes of cross-section required for acquisition of the course of the circumflex artery. (ALC = anterolateral commissure; AML = anterior mitral leaflet; PMC = posteromedial commissure; PML = posterior mitral leaflet.)

Material and Methods

After approval from the Ethics Committee and written informed consent, 110 patients undergoing minimal invasive MV repair between November 2007 and April 2008 were included in this prospective study. The MV repair was done using a right lateral minithoracotomy and femoral cannulation for cardiopulmonary bypass (CPB). The MV repair techniques consisted of ring annuloplasty with or without chordae replacement or Carpentier-type leaflet resection.

After standardized induction of general anesthesia, a TEE probe (IE 33, Sonos 5500; Philips, Amsterdam, The Netherlands) was inserted, and routine examination was performed. In addition to the recommended views of American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists guidelines (6), we also attempted to visualize the circumflex artery. Initially from the midesophageal aortic valve long-axis view, the multiplane transducer was rotated between 90 and 130 degrees so that the sinus of Valsalva was seen in a modified long axis along with the origin of the left coronary artery (Fig 1). The TEE probe was then slowly turned to the left of the patient to follow the course of the left main coronary artery (LMCA [Fig 2]), and subsequently the circumflex artery.

The circumflex artery usually diverges from the LMCA in a perpendicular direction to the left side, whereas the left anterior descending artery follows a more or less straight course downward (Fig 3). The examination is performed in two-dimensional mode, then with color Doppler using various Nyquist limits. Starting with a Nyquist limit between 50 cm/s and 60 cm/s (necessary for quantification of the mitral regurgitation), it is adjusted as required for optimal visualization of coronary flow The frame rate was also recorded for study purposes. For qualitative assessment of circumflex flow, the artery was arbitrarily divided into three sections: section 1, from the origin of the LMCA to the origin of the circumflex artery; section 2, from the origin of the circumflex artery to the point of intersection with coronary sinus; and section 3, from the point of intersection with coronary sinus to the most distal part of circumflex artery that could be visualized.

The diameter of the circumflex artery was measured proximally (immediately distal to its origin from the

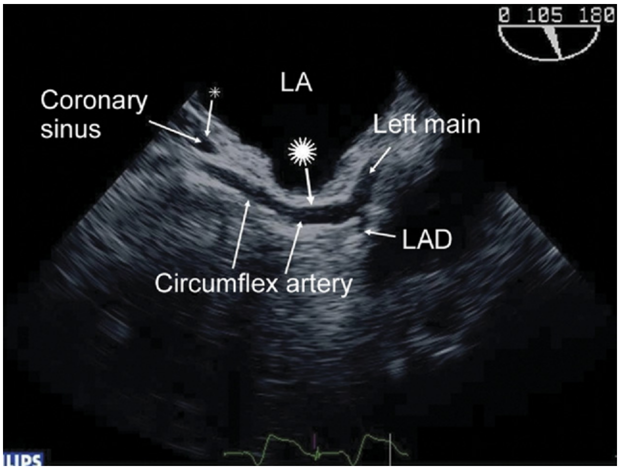

Fig 3. Color Doppler of the circumflex artery. (LA = left atrium; LAD = left anterior descending artery; Left main = left main coronary artery.) (Large asterisk = strong echodense wall of the circumflex artery; small asterisk = weak echodense wall of the coronary sinus.)

Table 1. Demographic Data

Sex, male/female, n	60/50
Age, years	57.1 ± 12.6
Height, cm	173.2 ± 10.6
Weight, kg	75.3 ± 15.1

LMCA) and distally (after crossing the coronary sinus), and vice versa for coronary sinus (see Fig 1). All patients underwent preoperative angiographic evaluation of their coronary anatomy that determined the dominance pattern. Intraoperative TEE was used to corroborate the angiographic findings of coronary dominance. The echocardiographer was blinded to the angiographic data. Additionally, we measured the distance between the circumflex artery and the mitral annulus at the region of the anterolateral commissure, as it is the point of closest proximity between these two structures.

Perioperative myocardial infarction (MI) was defined as a significant increase in creatine kinase–myocardial band levels (>10 times upper normal limit or >10% of elevated creatine kinase level) or new Q waves on electrocardiogram. Postoperative cardiac catheterization was performed for patients with suspected perioperative MI or new localized electrocardiographic changes, as per our institutional protocol.

Statistics were performed using SPSS for Windows. All values are expressed as means ± SD throughout the manuscript. A statistically significant difference was assumed to be present for a value of p less than 0.05.

Results

A total of 110 patients (50 female, 60 male) were included in the study (Table 1). None of them had significant coronary artery disease preoperatively. All patients, with the exception of 3, underwent successful MV repair without clinical evidence of circumflex injury. All of these patients had an uneventful postoperative course without hemodynamic instability or clinical evidence of perioperative MI. The course of the circumflex artery could be detected proximally in 109 patients (99%), to the point of intersection with the coronary sinus in 99 patients (90%), and distal to the point of intersection in 95 patients (86%).

The diameter of the circumflex artery decreased an average of 29% from its proximal to distal end (from 4.1 ± 0.8 mm to 2.9 ± 0.7 mm). In contrast, the coronary sinus diameter increased an average of 72% in these views (from 3.9 ± 0.8 mm to 6.6 ± 1.4 mm; Table 2). The circumflex artery could be differentiated from the coronary sinus by observing the opposing diameter changes in both the vessels. Whereas the diameter of the circumflex artery decreases from proximal to distal, the diameter of the coronary sinus increases, as illustrated in Figure 1. The ratio between the proximal circumflex artery diameter and the distal coronary sinus diameter (before the point of intersection of these two vessels) was 1.05, whereas the ratio between the distal circumflex and proximal coronary sinus (after the point of intersection) was 0.44.

Angiography revealed that 49% of patients had a right dominant type coronary dominance pattern, 38% had a balanced type, and 13% had a left dominant pattern. Furthermore, the 95% confidence interval for the diameter of the proximal circumflex artery was 4.5 mm to 5.6 mm for the left dominant type and 3.8 mm to 4.2 mm for the right dominant and balanced types ($p = 0.01$). Distally, the circumflex artery measured 3.0 mm to 4.2 mm for the left dominant type and 2.6 mm to 3.0 mm for the right dominant and balanced type ($p = 0.07$).

The mean distance between the circumflex artery and the mitral annulus at the region of the anterolateral commissure was 3.1 ± 1.3 mm, ranging from 1.1 mm to 8.1 mm. This varied according to arterial dominance, being 3.4 mm ± 1.2 mm for the left dominant type, 3.0 mm ± 1.2 mm for the balanced, and 2.8 mm ± 1.3 mm for the right dominant type.

In our experience, the best view to visualize the circumflex artery was a modified midesophageal long-axis view of the aortic valve with the transducer angle at 110 (±20) degrees. The mean Nyquist limit for best visualization of arterial flow was 23 ± 17 cm/s, with a mean frame rate of 13.8 ± 13.6 frames/s. The visualization of circumflex artery flow before and after MV repair is summarized in Table 3.

Three of the 110 patients (3%) had an iatrogenic disturbance of flow in the circumflex artery after MV repair. All 3 patients were diagnosed with no flow (circumflex obstruction) or aliasing (circumflex stenosis) postoperatively. In patient 1, ST-segment elevation in leads II, III, and aVF, and a new regional wall motion abnormality of the posterior wall were noted after repair. The findings were reported to the operating surgeon, and the patient was weaned from CPB. The patient was hemodynami-

Table 2. Diameter (in Millimeters) of Circumflex Artery and Coronary Sinus

	CX Proximal	CX Intersection	CX Distal	Percent Decrease	CS Proximal	CS Distal	Percent Increase
Total	4.1 ± 0.8	3.4 ± 0.8	2.9 ± 0.7	28.9 ± 13.0	6.6 ± 1.4	3.9 ± 0.8	72.2 ± 55.3
Right dominant	3.9. ± 0.8	3.4 ± 0.9	2.8 ± 0.8	27.9 ± 12.7	6.6 ± 1.4	3.8 ± 0.9	86.3 ± 70.8
Balanced	4.1 ± 0.7	3.5 ± 0.9	2.8 ± 0.7	31.4 ± 11.9	6.8 ± 1.6	4.1 ± 0.7	68.2 ± 55.7
Left dominant	5.0 ± 0.6	4.0 ± 0.8	3.6 ± 0.7	28.0 ± 13.6	6.5 ± 1.6	4.1 ± 0.8	60.9 ± 34.5

Continuous variables are expressed as means ± SD. CX proximal is the circumflex artery (CX) immediately after its origin; CX intersection is the CX at the point of intersection with the coronary sinus (CS); CX distal is the CX at the most distal point; percent decrease is the lumen percentage decrease between proximal and distal CX measurements; CS proximal is the CS in the region of the distal CX; CS distal is the CS in the region of the proximal CX; percent increase is the lumen percentage increase between distal and proximal CS measurements.

Table 3. Arterial Flow Using Color Doppler Before and After Mitral Valve Repair

Class	Before, n	After, n
3	70	69
2	14	19
1	10	7
0	1	7
Total	95	102

There were four classes to define: class 3, arterial flow could be detected in sections 1 to 3; class 2, arterial flow could be detected clearly in 2 of 3 sections; class 1, arterial flow could be detected clearly in 1 of 3 sections; and class 0, flow could not be detected in any of the sections.

cally stable without inotropic support, although electrocardiographic changes persisted. Coronary angiography performed immediately postoperatively confirmed the TEE diagnosis of a new circumflex stenosis. The patient was immediately reoperated on, and four annular sutures in the P1 region were removed and then placed more superficially. After 30 minutes of reperfusion, there were minimal ST-segment changes, and good flow was noted in the circumflex artery per TEE.

In patient 2, aliasing was noted in the circumflex artery after repair. There were no other associated findings. The patient was hemodynamically stable, and weaning from CPB was performed uneventfully. The echocardiographic findings were discussed with the intensive care unit physician during handover. The patient became hemodynamically unstable 6 hours after surgery. Inotrope infusion was required for hemodynamic stabilization. Urgent angiography revealed occlusion of the distal circumflex artery. Stenting of the artery was performed, and repeat angiogram documented good flow through the circumflex artery.

In patient 3, there was a failed attempt to wean from CPB after MV repair. The TEE evaluation preoperatively showed good flow in circumflex artery and bifurcation into a large obtuse marginal artery and a small ongoing circumflex artery (Fig 4). The TEE pictures corresponded well to the preoperative angiogram (Fig 5). There was flow interruption in the circumflex artery in combination with aliasing in the left anterior descending and obtuse marginal artery (Fig 6). Dyskinesia was observed in the posterior wall with mild ST-segment elevation. Air was visualized in the left ventricle, and the patient was reperfused for 30 minutes. A second attempt to wean from CPB was not successful, and the possibility of a complete occlusion of the circumflex artery was discussed with the surgeon. It was thought that the annuloplasty ring (Carpentier-Edwards Physio, 34 mm; Edwards Lifesciences, Irvine, CA) was perhaps too large for the patient. The ring was therefore removed, the annular sutures placed a little more superficially in the P1 region, and a smaller ring was inserted (Carpentier-Edwards Physio, 30 mm). The patient was successfully weaned from CPB thereafter. There was flow without aliasing visible in the circumflex artery after a second MV repair (Fig 7). Additionally, the diameter of the proximal circumflex artery was comparable to that of the preoperative measurement, whereas there was an increase in diameter during the flow interruption phase (compare Figs 6 and 7).

All 3 of these patients had an uncomplicated course thereafter and were discharged from the hospital within 10 days postoperatively without evidence of extensive myocardial damage (ie, no decrease in postoperative ejection fraction).

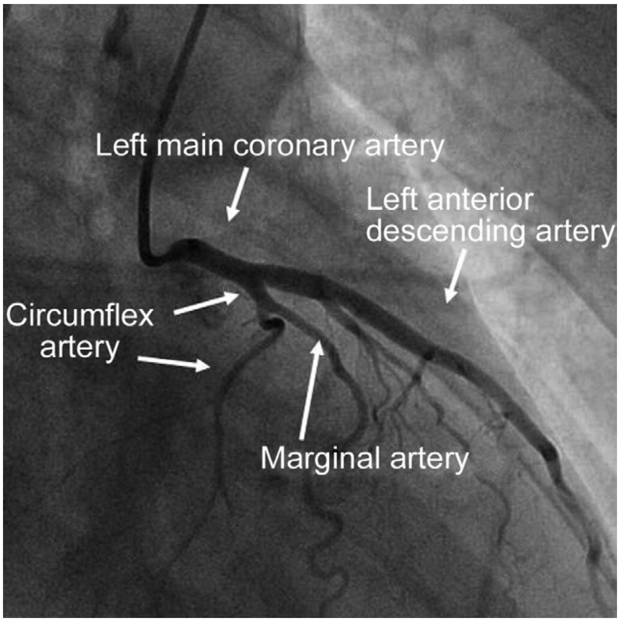

Fig 5. Preoperative angiogram of patient 3. The circumflex artery is bifurcating into a large obtuse marginal artery and a small ongoing circumflex artery.

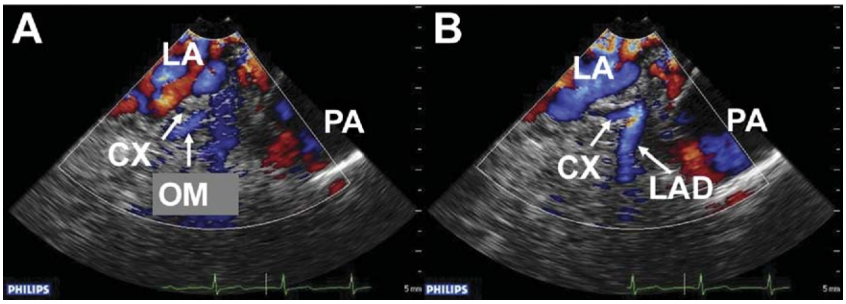

Fig 4. Preoperative color Doppler examinations of the circumflex artery in patient 3, showing (A) obtuse marginal artery (OM) and (B) left anterior descending artery (LAD). (CX = circumflex artery; LA = left atrium; PA = pulmonary artery.)

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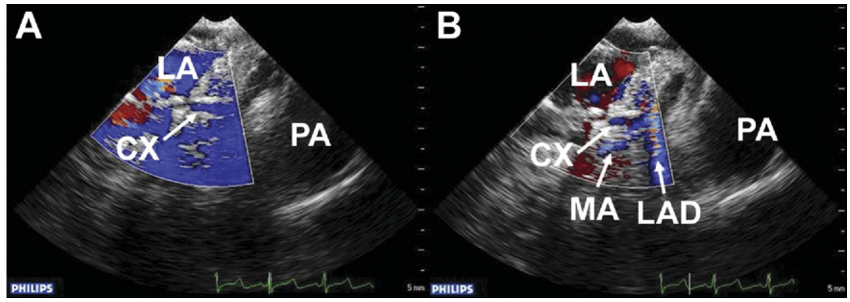

Fig 6. Color Doppler examination of the circumflex artery (CX) after mitral valve repair in patient 3, showing (A) interrupted flow in the CX and (B) aliasing flow in the left anterior descending artery (LAD) as well as in the obtuse marginal artery (MA). (LA = left atrium; PA = pulmonary artery.)

Comment

Compromised flow of the circumflex artery due to annular ring sutures is an uncommon but well-known complication of MV repair or replacement surgery and cannot be completely avoided [1, 7]. Coronary compromise can be a result of ligation or, probably more often, distortion of the vessels by the annular sutures, and may result in myocardial infarction if not detected early. There is a higher occurrence of this complication in patients whose circumflex artery is anatomically situated very close to the native MV annulus. It has also been described that the circumflex artery is most at risk for being injured near the anterior commissure, because of the proximity of these two structures at this location [8–10].

Whether the dominance pattern of the coronaries influences the proximity of the circumflex artery to the anterior commissure is controversial. All 3 patients who suffered injury to the circumflex artery in our study had a left dominant coronary pattern. Previous studies by Virmani and colleagues [8] showed that in left dominant and balanced pattern patients, the distance between the circumflex and the anterior commissure was between 3.5 mm and 7 mm, whereas patients with a right dominant pattern always had a distance between these two structures of more than 5 mm. However, this study was limited by its small sample size (n = 15). Kalikkaya and colleagues [3], as well Cornu and coworkers [9], were of the similar opinion that the risk of causing damage to the circumflex artery was higher in patients with left dominant and balanced coronary patterns. These findings were in contrast to the anatomic study of Pessa and colleagues [4] who claimed that the susceptibility of the coronary artery to injury is not related to the dominance pattern. In this study, most patients (81%) had right coronary dominance, 17% had balanced, and 2% had left dominance. The distance between the mitral annulus and the circumflex artery was 3.9 ± 1.8 mm in patients with right dominance, 3.5 ± 1.6 mm in patients with balanced dominance, and in the 2 patients with a left dominant pattern, the distance was 4.1 mm and 3.7 mm. In our study population, most of the patients had a right dominant pattern and a distance of 2.8 ± 1.3 mm from the mitral annulus. The balanced pattern had a distance of 3.0 ± 1.2 mm and the left dominant pattern had a distance of 3.4 ± 1.2 mm between the circumflex artery and the mitral annulus at the region of the anterolateral commissure. Our echocardiographic measurements were in accordance with the anatomical study from Pessa and colleagues [4]. The nearest distance measured in our study population was 1.3 mm for the right and balanced type, and 2.2 mm for the left dominance type.

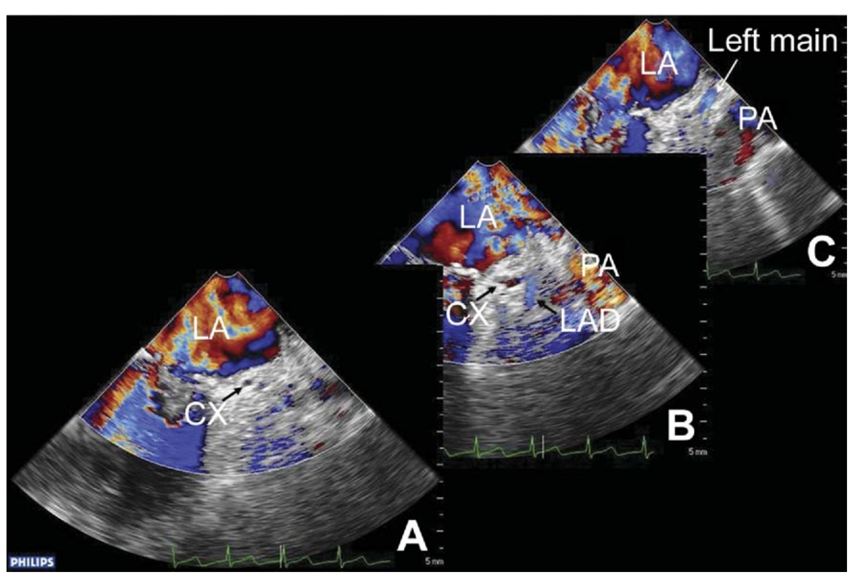

Fig 7. Color Doppler flow in the circumflex artery (CX) after implantation of a smaller annuloplasty ring. Note the absence of aliasing as compared with Figure 6. (A): Flow in CX; (B): Flow in LAD and in CX; (C): Flow in left main coronary artery. (LA = left atrium; LAD = left anterior descending artery; PA = pulmonary artery.)

There have been two documented case reports of circumflex artery ligation in a right dominant pattern of coronary network. Mulpur and associates [10] reported occlusion of the circumflex artery 14 years after mitral valve replacement, with hemangioma formation at the origin of the circumflex artery. More recently Grande and coworkers [11] reported acute lateral MI after MV repair. Emergency cardiac catheterization revealed a subtotal occlusion of the distal circumflex coronary artery, which was corrected with percutaneous angioplasty and stenting. These same authors reported their first case of echocardiographic diagnosis of circumflex artery ligation after MV repair in a patient with a left dominant pattern [5]. Grande and colleagues [11] also claimed that the dominance of coronary system is not related to the risk of circumflex lesion.

We believe that our method of echocardiographic visualization of the circumflex artery is reproducible and should be performed more frequently in patients undergoing MV surgery. The current study did not focus on intraobserver and interobserver variability for our technique, although we have subjectively noted a definite learning curve as for all new methodologies. Anatomically, both the circumflex artery and the coronary sinus lie within the atrioventricular groove. Differentiation of these two structures can be performed by observing that the circumflex artery lies near the anterolateral commissure of the MV and that the coronary sinus lies in close proximity to the P2/P3 portion of the MV. In addition, the coronary sinus is a venous structure with a thin vessel wall that becomes larger in diameter along its course to the right atrium, whereas the circumflex artery has a strong echodense wall and becomes smaller along its course. A decreased Nyquist limit is also very helpful when visualizing these vessels, as flow is better recognized under these conditions. Difficulties may arise when there is development of collateral flow because of the perpendicular alignment of the color Doppler beam, leading to difficulties determining the direction of flow.

Unfortunately, coronary artery air embolism during open heart surgery is also a common clinical problem that can produce the same clinical picture (ie, ST-segment elevation and regional wall motion abnormalities) as a circumflex injury [12]. Obarski and associates [13] hypothesized that air embolism into the right coronary artery can occur when the surgeon manually tries to test the patency of the repaired MV. The main method of differentiating air embolism from iatrogenic circumflex injury is that the observed changes are reversible with time for air embolism.

Not all circumflex injuries are caused by suture misplacement during MV surgery. Other potential mechanisms include a thrombus or hematoma formation due to surgical trauma, or direct injury associated with a Maze procedure or radiofrequency ablation [14].

Study Limitations

We did not perform postoperative angiography in all patients in the current study and therefore cannot completely rule out an iatrogenic injury of the circumflex artery in patients with a normal TEE examination after repair. However, none of these patients had clinical, biochemical, or electrocardiographic evidence of MI, making it unlikely that a significant circumflex injury occurred.

In conclusion, MV surgery is associated with a risk of injury to the circumflex artery. Early detection of this complication can prevent poor surgical outcome. Our experience suggests that a modified midesophageal aortic valve long-axis view with a transducer angle of 110 ± 20 degrees and counterclockwise rotation of the probe permits best visualization of the circumflex artery. The circumflex artery can be distinguished from the coronary sinus by measuring the differences in the diameter of the respective vessels, and the coronary dominance pattern can be ascertained. Using this technique, we were able to diagnose a circumflex injury in 3 of 110 patients undergoing minimal invasive MV repair, all of whom underwent rapid correction of the coronary problem with an uncomplicated postoperative course thereafter. Although the incidence of injury to circumflex coronary artery during MV surgery is quite low, we suggest that our technique be performed more frequently to detect this complication intraoperatively and to develop treatment strategies that can prevent extensive myocardial injury.

ADULT CARDIAC

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