MORPHO-FUNCTIONAL ANALYSIS OF THE REGURGITANT MITRAL VALVE AS A GUIDE TO REPAIR: ANOTHER POINT OF VIEW

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Abstract

Based on Carpentier's classification and principles, the techniques for mitral valve repair continue to evolve. We herein report our experience with the morpho-functional echocardiographic analysis of single mitral leaflets, as different anatomic features, even if conflicting, may coexist not only in the two leaflets, but in the same leaflet as well. A classification is proposed, based on the length (normal, short, or long) and mobility (normal, restricted, or excessive) of mitral leaflets. The surgical techniques adopted for mitral valve repair are the direct consequence of this analysis.

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ABSTRACT

Based on Carpentier's classification and principles, the techniques for mitral valve repair continue to evolve. We herein report our experience with the morpho-functional echocardiographic analysis of single mitral leaflets, as different anatomic features, even if conflicting, may coexist not only in the two leaflets, but in the same leaflet as well. A classification is proposed, based on the length (normal, short, or long) and mobility (normal, restricted, or excessive) of mitral leaflets. The surgical techniques adopted for mitral valve repair are the direct consequence of this analysis.

Surgical experience with mitral valve repair (MVr) for mitral regurgitation (MR) started since the '50s, demonstrating the will of surgeons to go beyond the technical limitations of closed heart surgery while moving to open heart surgery. The most important chapter in the huge book on MVr was however written by Carpentier et al[1,2], who defined the terms and introduced the principles that, with some modifications, are still followed by many surgeons. His vision, together with the concept of annuloplasty[3] and the advent of artificial chords[4], are the pillars on which MVr surgery stands.

Globally, many techniques have been proposed to correct MR, but countless variants have been described to modify, simplify, or making each of these techniques more complicated. As a consequence, any surgeon dedicated to MVr developed his own strategy to stay afloat in these deep and stormy waters, trying to pick up the concepts he thought to be the most appropriate for him.

Our long journey started in 1990 and since then, step by step, our understanding of MVr has advanced, with the purpose of making MR correction as easy as possible. In this report, we describe our approach to MVr and the questions to be answered to plan a correct surgery.

CORRECTION OF MITRAL REGURGITATION

Regardless of the etiology, surgical correction of MR is aimed at changing a bileaflet valve where both cusps are moving into a bileaflet valve where only the anterior leaflet (AL) moves whereas the posterior leaflet (PL) is fixed and motionless in vertical position and represents only a door frame for the AL. Both leaflets meet at the edge of the mitral area, avoiding systolic anterior motion (SAM) to occur. This means that the final echocardiographic result is always the same and does not change according to etiology (Figure 1).

To reach this goal, we need to follow two steps: first, to examine echocardiographic anatomy and function of both leaflets, and then to group findings in such a way to address surgical correction.

ECHOCARDIOGRAPHIC ANALYSIS

The morpho-functional echocardiographic analysis of the mitral valve leaflet anatomy is the most important step to identify the underlying lesions and mechanisms of MR in order to define the appropriate surgical strategy. We need then:

* To assess leaflet length . The AL should be long enough to close the mitral area, coapting properly with the PL. The PL should be long enough to offer a good coaptation surface to the AL when fixed in vertical position. However, it should not be too long so in order to avoid any movement that may bring coaptation with the AL inside the mitral area. In general, the excess of AL length and the reduced PL length are not important, as the former will add length to the coaptation, whereas the latter is irrelevant, unless it is, more or less, below 10 mm. Then, according to the length, the leaflets can be classified as normal, short, and long.

* To assess leaflet mobility . If the AL movement is restricted, this would not allow the AL to reach the PL or may reduce the length of the coaptation with the PL. Conversely, if the AL movement is excessive, the AL will continue to coapt properly with the PL. If the PL movement is excessively restricted, the PL position could be not vertical, but posteriorly directed, avoiding the AL to coapt. In contrast, if the PL movement is excessive, the PL will not reach the vertical position, but will meet the AL inside the mitral area with the possibility of causing SAM. Then, according to mobility, the leaflets can be classified as normal, restricted, and excessive.

* To position a ring or a band to fix the PL in vertical position.

The information we obtain from mitral leaflet analysis can lead to a**surgical classification** , with first the leaflet (AL or PL), then the length and after the mobility for each of them. For instance, if the AL length is short and tethered, and the PL is long and prolapsing, this feature can be defined as AL(short with restricted mobility) and PL(long with excessive mobility) (Figure 2). The same leaflet may also show two different abnormalities. In Figure 3, the PL has normal length and mobility, and the AL is long, but tethered and prolapsing. This feature can be classified as AL(long with both restricted and excessive mobility) and PL(normal with normal mobility), focusing where to address the correction.

SURGICAL STRATEGIES

Let us now examine the mitral valve leaflets to answer the previous questions and to decide the proper strategy to correct any anomaly.

Leaflet length (Table 1)

Anterior mitral leaflet . The normal length of the AL is 23.4±2.9[5], but, in our practice, we always considered 26 mm the minimum length necessary to obtain a competent valve. This is supported by a study of Gupta et al[6], who found that 26 mm was the cut-off value for a successful MVr in patients with rheumatic disease. With this cut-off in mind, AL length can be normal (26 to 30 mm), short ([?]25 mm), or long (>30 mm).

Normal . Nothing has to be done.

Short. This causes a potentially dangerous situation as it may avoid the AL to reach the PL or may reduce the coaptation length (CL). It is independent of the etiology, either primary or secondary. In this eventuality, patch augmentation (always accompanied by second-order chord cutting) is the solution (Table 1, A-C). The position of the primary chords will not change, but the coaptation with the PL will increase.

Long. The excess length does not create problems, as it increases only the CL, provided the PL remains in vertical position, motionless, at the border of the mitral area (Figure 4). An excess of AL length may be corrected only if asymmetric septal hypertrophy coexists with severe MR and the AL is too long (Figure 5). The procedure is performed through the same aortotomy.

Posterior mitral leaflet. The normal length of the PL is 13.8+-2.9 mm[5]. As the PL has to maintain a vertical position, from the surgical point of view a cut-off length of 11 to 15 mm would be appropriate.

Normal. (11-15 mm), nothing has to be done.

Short. ([?]10 mm), as typically happens in rheumatic MR, patch augmentation (with chordal cutting) will restore the vertical position we are looking for (Table 1, D).

Long. An excess of PL length is associated with prolapse, which can be localized to one (typically P2) or more scallops. As our purpose is to join all scallops to allow a reciprocal support, the height of the scallops should be more or less equal. The longitudinal plication of the long scallop(s)[7] will make the height similar, facilitating scallop suturing (Table 1, E-F).

Mobility (Table 2).

Anterior mitral leaflet .

Normal . Nothing has to be done.

Restricted . The limitation can be at the level of the first or second-order chords. In the first case, typical of rheumatic valves, the decision is difficult and will depend on the specific anatomy. A solution can be patch augmentation to facilitate leaflet coaptation, but in other cases cutting all the first-order chords and their replacement with artificial chords is the only solution. However, this is an extreme solution. If the restriction is at the level of the second-order chords (the most frequent feature), the AL is augmented with a pericardial patch and the second-order chords are cut (Table 1, A-C). This typically occurs in ischemic or non-ischemic functional MR. In both cases, we prefer to increase the AL length in order to increase the CL. However, if AL length is normal, we prefer to cut the second-order chords through a transaortic approach[8] (Table

2, A). Second-order chord tethering can be present in degenerative disease as well, as recently reported by Sakaguchi et al[9], causing moderate or greater MR during follow-up after correction of PL prolapse. Our group described a case of intermittent tethering of second-order chords of the AL causing left ventricular outflow tract obstruction and severe MR. Second-order chords were cut during a second pump run, with immediate resolution of both MR and obstruction[10]. Any second-order chord tethering, even if mild, should be avoided in any patients, regardless of the etiology of valve regurgitation (Figure 6).

Excessive . It is due to elongated or ruptured chords. In both cases, the correction is achieved by adding artificial chords. In most cases, two pairs of Gore-Tex 4/0 or 5/0 sutures positioned at the A2 level, close to A1 and A3, are sufficient. There are many techniques to decide the length of the neo chords. In 2008, we described a technique that works every time and it is very simple[11]. Briefly, the AL is pulled up, at its maximum extension, toward the left atrial central point. Then the artificial chord is tied 5 mm higher than the AL border where it is passing through (Table 2, B). There are several reasons for this choice. First, during diastolic cardiac arrest, the position of the mitral valve is higher than normal and we have no reference point to decide the correct length. Second, artificial chords are not elastic as native chords are. Third, the position in the left atrium of any prolapsing AL segment always does not exceed 2-3 mm above the mitral annulus, which makes possible to use the same concept for all prolapsing segments, all of which being the reference point for itself. In case of ruptured chords, the 5 mm extra height can be calculated using the closest non-prolapsing AL segment (Table 2, C) or tying the Gore-Tex suture at the same level as the artificial chord if the closest segment is prolapsing (Table 2, D).

Posterior mitral leaflet.

Normal . Nothing to be done.

Restricted . Generally, the restriction is not such to make correction necessary. If, for any reason, there is the need to increase leaflet mobility, the solution is patch augmentation with second-order chord cutting (Table 1, D).

Excessive . Chords can be elongated or ruptured. The concept is always the same: all scallops are sutured each other for reciprocal support[12]. If chords are elongated, suturing is the only maneuver necessary to correct the prolapse (Table 2, E). In case of extra length (often at P2 level), the scallop(s) is (are) longitudinally plicated so as all scallops are at the same level, facilitating their suture. If chords are ruptured, the scallop closer to the ruptured segment is brought below the unsupported segment and fixed with a U suture (from the ventricle to the left atrium)[12]. Once the border of the scallop is supported with ruptured chords, it is possible to keep up to 10 mm of the body of the scallop unsupported by chords. Finally, all the scallops are sutured together (Table 2, F). If ruptured chords are in the middle P2, a small triangular resection and scallop suture will correct the lesion.

Moderate overreduction

Once the specific aspects of each leaflet (length and mobility) have been evaluated and solved, the next step is to reshape the mitral annulus to obtain a moderate overreduction, in such a way that the PL will become vertical and fixed. This can be obtained with a complete ring of any design or with a band. We specifically prefer a 50 mm band from trigone to trigone, but this is only a personal choice. A moderate overreduction aims to enhance the CL and to maintain the coaptation point between the leaflets at the edge of the mitral annulus in order to prevent the occurrence of anatomic SAM (Figure 4).

CONCLUSION

The morpho-functional approach (length and mobility) to MVr allows us to correct the specific pathology of each mitral leaflet. We should keep in mind that apparently conflicting abnormalities may coexist not only in the same valve, but in the same leaflet as well, and may affect the success of MR correction. The use of moderate overreduction synchronizes surgical correction to obtain a competent valve, avoiding anatomic SAM, an enemy that we must fight against.

The intrinsic mitral valve plasticity[13] (a term that defines the adaptability of a living structure to changes in its environment) can induce a change in leaflet length and mobility. The mitral valve is not a structure that remains inert if the environment around it changes, but is able to modify its shape and its characteristics in the attempt to react to altered geometry and stress distribution to prevent or reduce regurgitation. Under this aspect, the mitral valve is a living organism, capable of responding to external stimuli to counteract any changes that can impair its function (regurgitation). This can affect the leaflet itself and the chordae tendinae, which can elongate or thicken or retract due to multiple mechanisms, mostly driven by activation of the transforming growth factor-β pathway. Triggers that stimulate the plasticity of the mitral leaflets and chordae may be either unrelated to valve geometry (e.g. aortic regurgitation)[14], or related to valve geometry (e.g. changes in mechanical stress)[15], MR itself[16] or acute myocardial infarction[17-19].

Mitral plasticity is at the basis of any coexisting abnormalities in the same valve or in the same leaflet, as the adaptation mechanisms may not be sufficient to reduce MR, inducing thickening and/or retraction of the leaflets or of the chords. When the adaptive process starts, even if not effective, it will continue, leading to MVr failure. While it is not possible to foresee or prevent the future anatomy of the mitral valve, second-order chords are a variable out of control and we must be very careful in our decision making at the time of surgery (Figure 6).

The classification we propose is focused on the different anatomical characteristics related to MR, helping to correct all the morpho-functional changes that can coexist independently of the etiology and that likely contribute to regurgitation.

FIGURE LEGENDS

Figure 1 – TEE. Preoperative. A: bileaflet prolapse. B: tethering of both leaflets after acute myocardial infarction. Postoperative. C (same patient as A), D (same patients as B): the AL covers the mitral area and the PL is motionless in fixed vertical position.

Classification. A: AL (long with excessive mobility)-PL(long with excessive mobility), typical of Barlow's disease. B: AL (normal with restricted mobility)-PL (normal with restricted mobility), typical of IMR.

TEE, transesophageal echocardiography; AL, anterior mitral leaflet; PL, posterior mitral leaflet; IMR, ischemic mitral regurgitation.

Figure 2 – TEE. Preoperative. A: the PL is prolapsing, the AL is short and tethered. 3D reconstruction (B, C) confirms the findings (the arrow shows AL tethering). Postoperative. D: correction of PL prolapse and patch augmentation of the AL with second-order chord cutting. From Calafiore at al[20], with permission.

Classification. AL (short with restricted mobility)-PL (long with excessive mobility)

TEE, transesophageal echocardiography; PL, posterior leaflet; AL, anterior leaflet; 3D, three dimensional.

Figure 3 – TTE. PL length and mobility are normal. AL length is normal, but the leaflet is both restricted (arrow) and prolapsing.

Classification. AL (normal with both restricted and excessive mobility)-PL (normal with normal mobility).

TTE, transthoracic echocardiography; PL, posterior leaflet; AL, anterior leaflet.

Figure 4 – TTE. The AL is long (A), but its length increases only the coaptation length (dotted line) (B).

TTE, transthoracic echocardiography; AL, anterior leaflet.

Figure 5 – TEE. Patient with HOCM, severe MR and long AL (A). After myectomy, the AL was plicated through the aorta (arrow) (B).

TEE, transesophageal echocardiography; HOCM, hypertrophic obstructive cardiomyopathy; MR, mitral regurgitation; AL, anterior leaflet.

Figure 6 – TEE. A: persisting tethering of the second-order chords (arrow) causing mitral valve repair failure after isolated mitral annuloplasty for IMR. B: 3D reconstruction of the mitral valve and mitral leaflets. The AL is attracted toward the apex due to further retraction of the second-order chords (arrow) not cut at the time of the first repair procedure (same case as in Figure 3).

TEE. Transesophageal echocardiography. IMR, ischemic mitral regurgitation. AL, anterior leaflet.

A: from Calafiore et al[20], with permission. B: from Calafiore et al[21], with permission.

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Table 1 – Length of the leaflets.

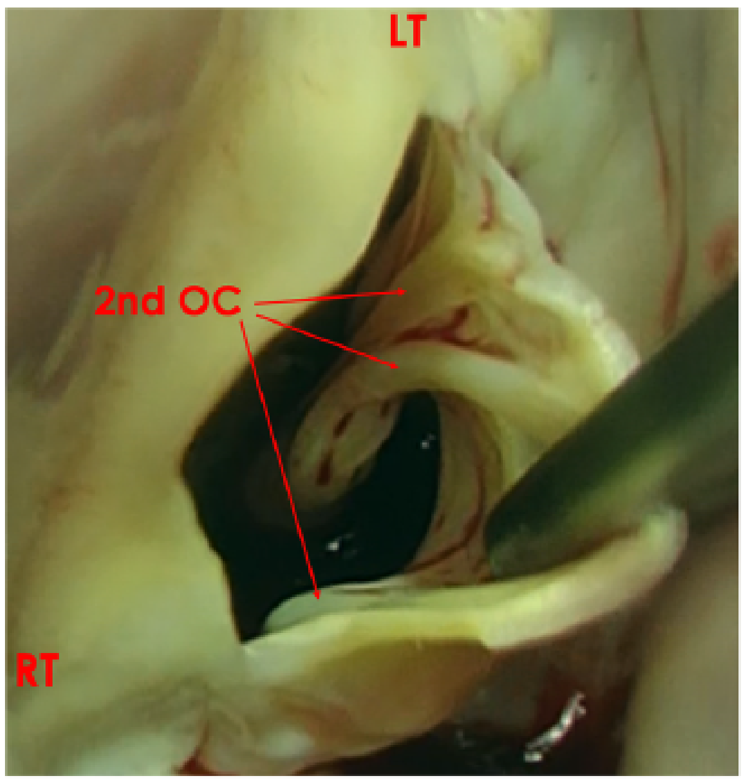
ANTERIOR LEAFLET POSTERIOR LEAFLET

Normal if 26 to 30 mm: no action if 11 to 15 mm: no action

Short if [?]25 mm if [?]10 mm

PA and CC PA and CC

(A)



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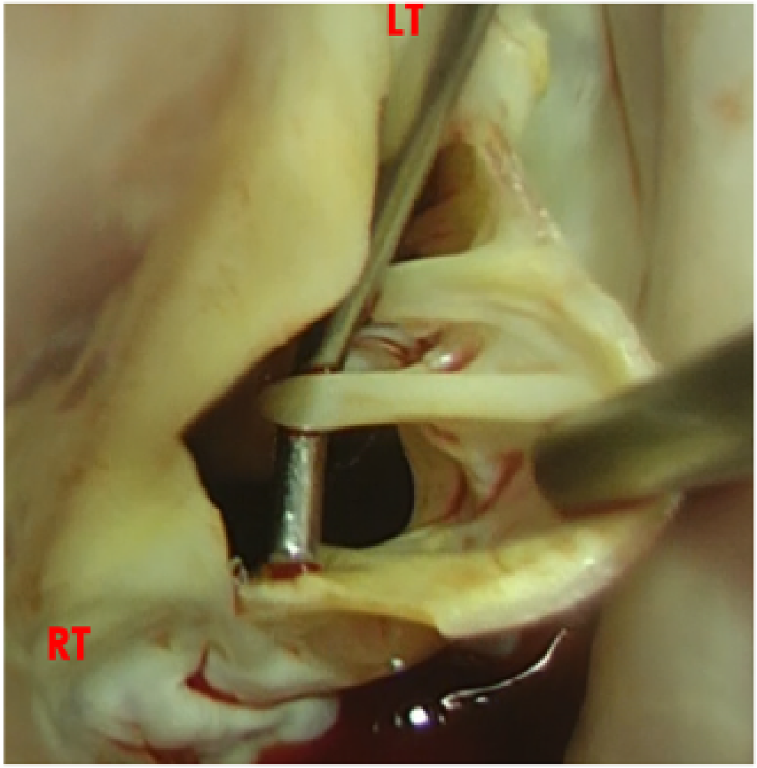
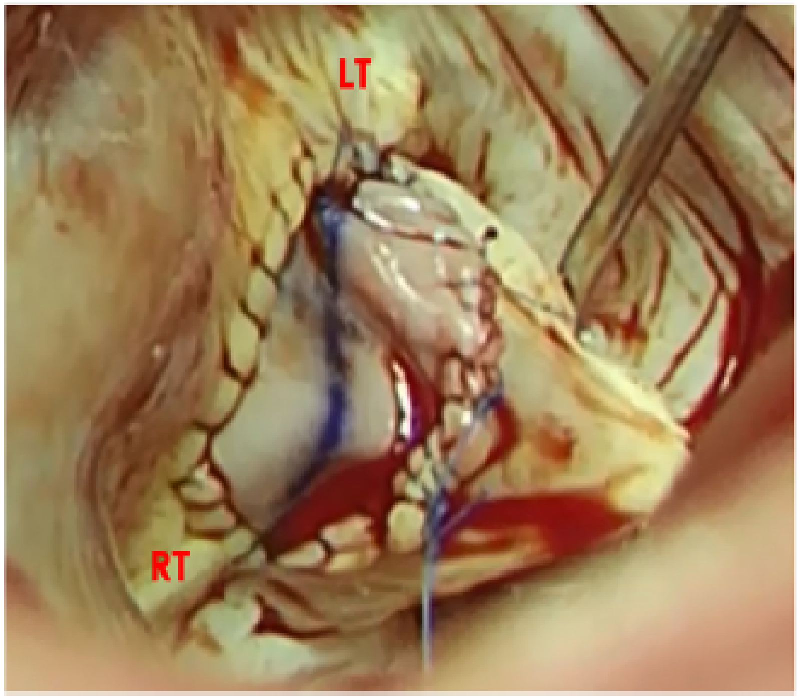
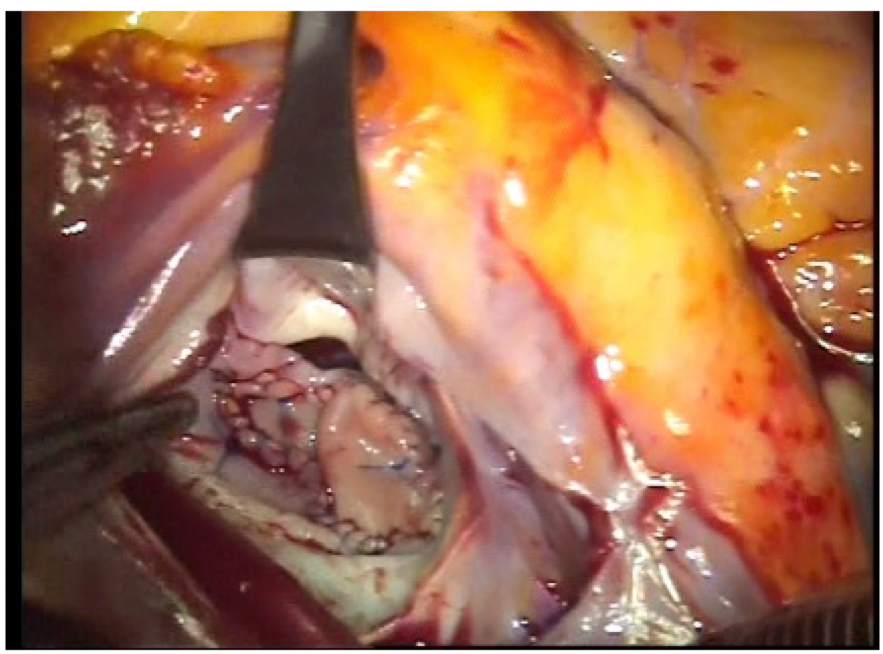


(C)

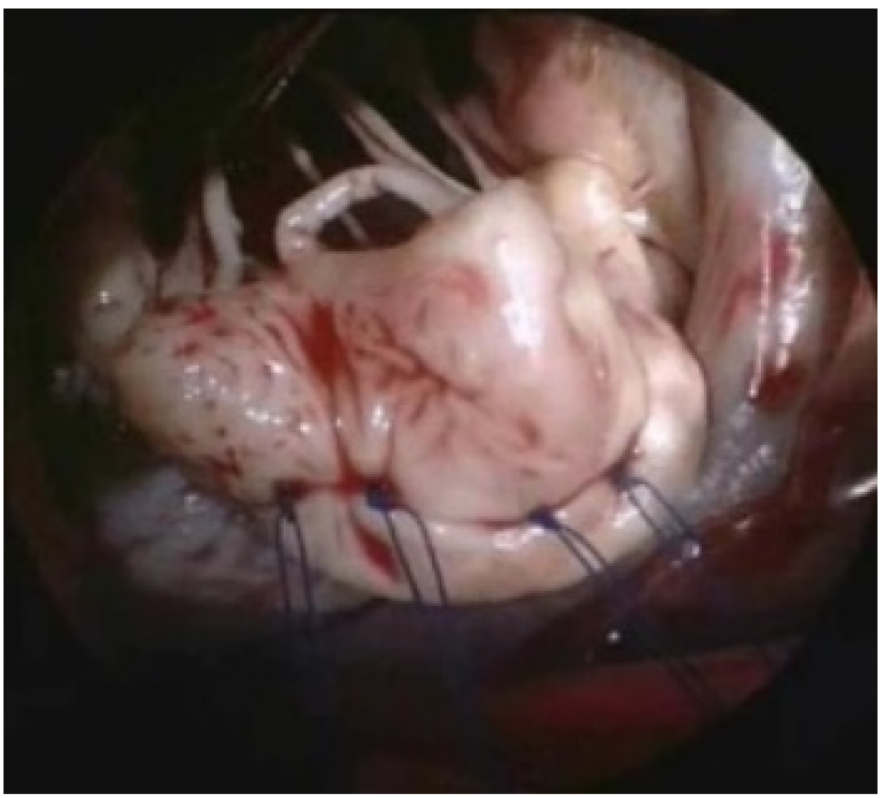




A B C D

Long >30 mm: no action if >15 mm

longitudinal plication



E F

A: the AL is detached 5 mm from the annulus from trigone to trigone. B: the second-order chords (arrows) are evident and cut with a scissor. C: a pericardial patch is sewn to augment AL length. D, patch augmentation of the posterior leaflet with a pericardial patch. E, P2 is long and (F) it is plicated with 4 longitudinal sutures to match the height of the other scallops.

PA, patch augmentation; CC, chordal cutting; AL, anterior leaflet.

A-C: from Calafiore et al.[22] with permission.

Table 2 – Mobility of the leaflets.

ANTERIOR LEAFLET POSTERIOR LEAFLET

Normal no action no action

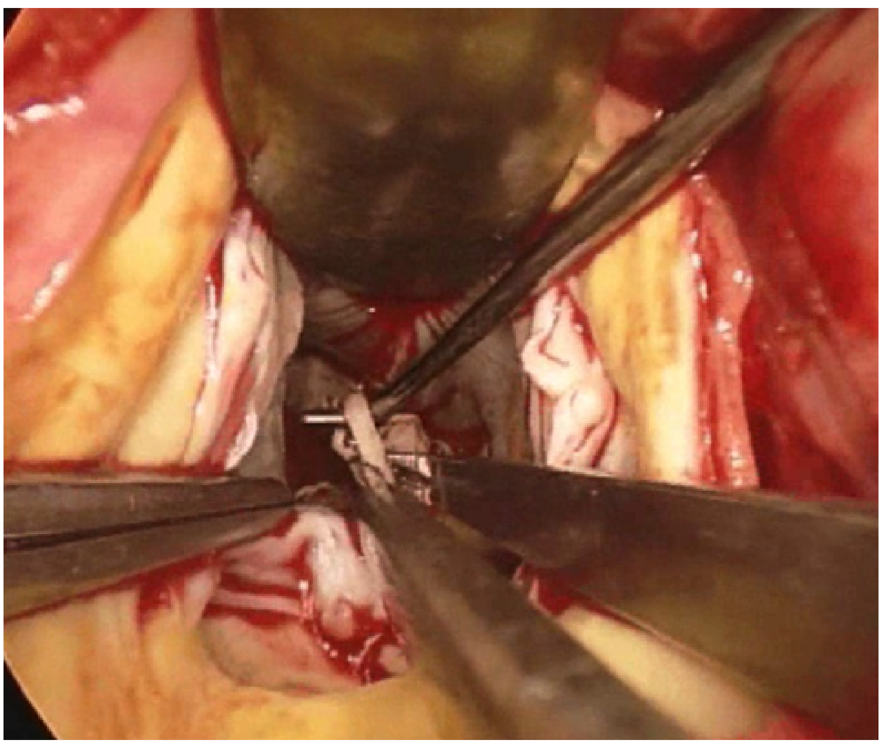
Restricted *at 1st order chords level* no action

PA and CC (see Table 1, A-C)

at the 2nd order chords level

AL<26 mm: PA and CC (see Table 1, A-C)

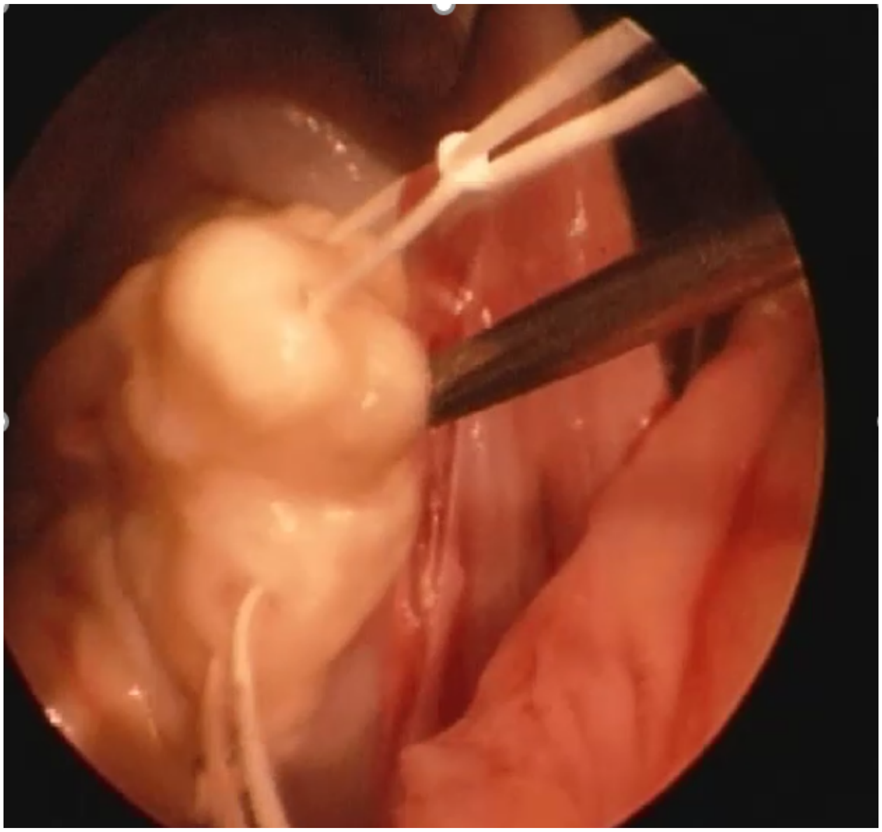
AL[?]26 mm: only CC (aortotomy)

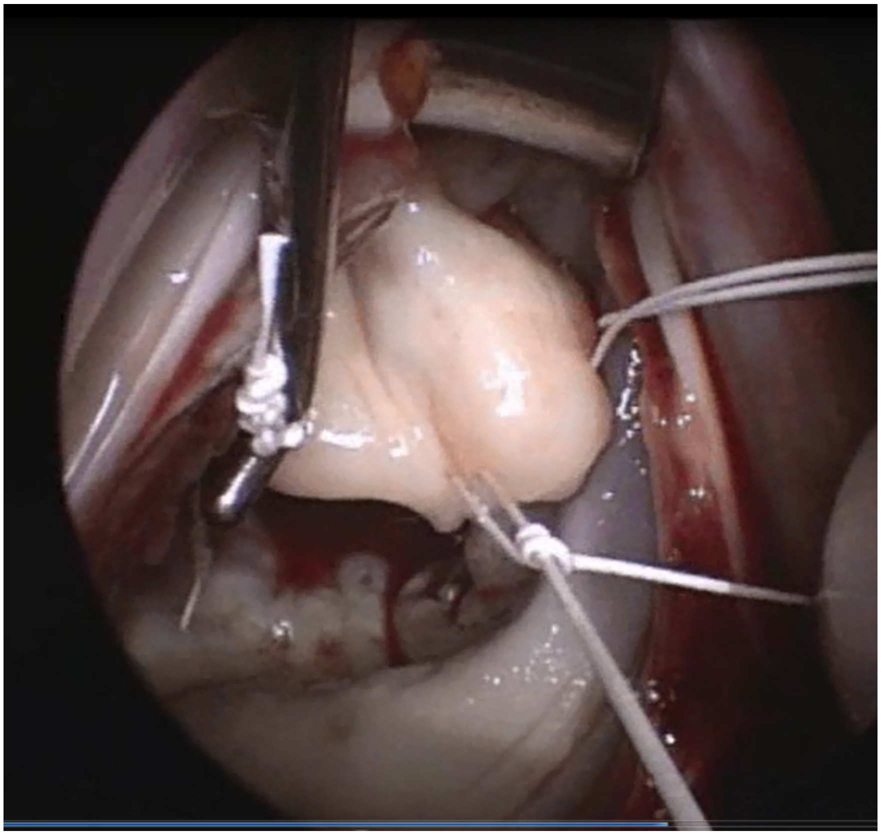


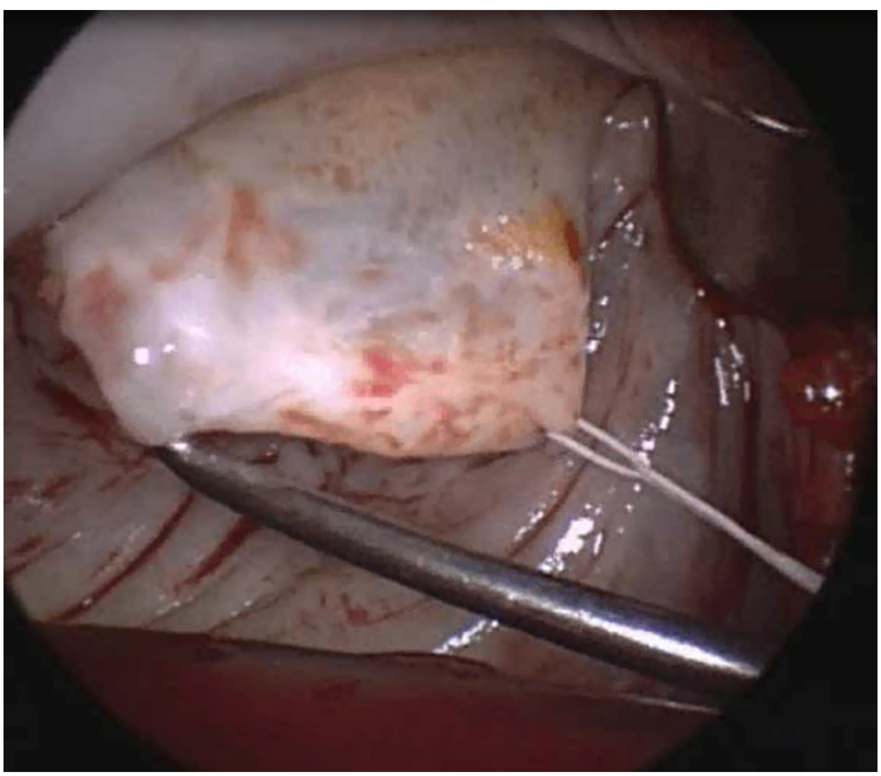
A

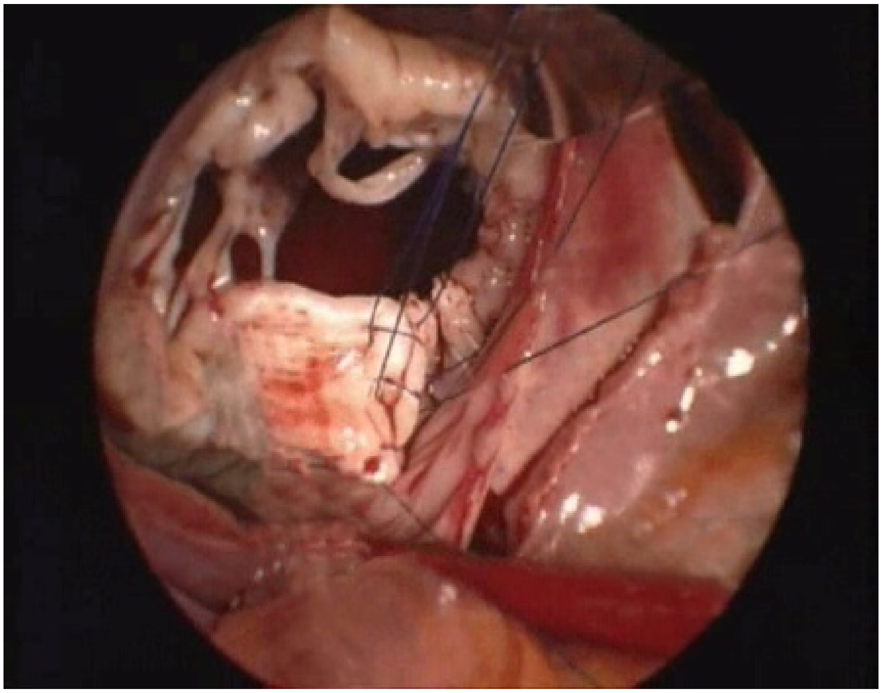
Excessive elongated or ruptured chords elongated chords ruptured chords

artificial chords scallops suture U technique and scallops suture









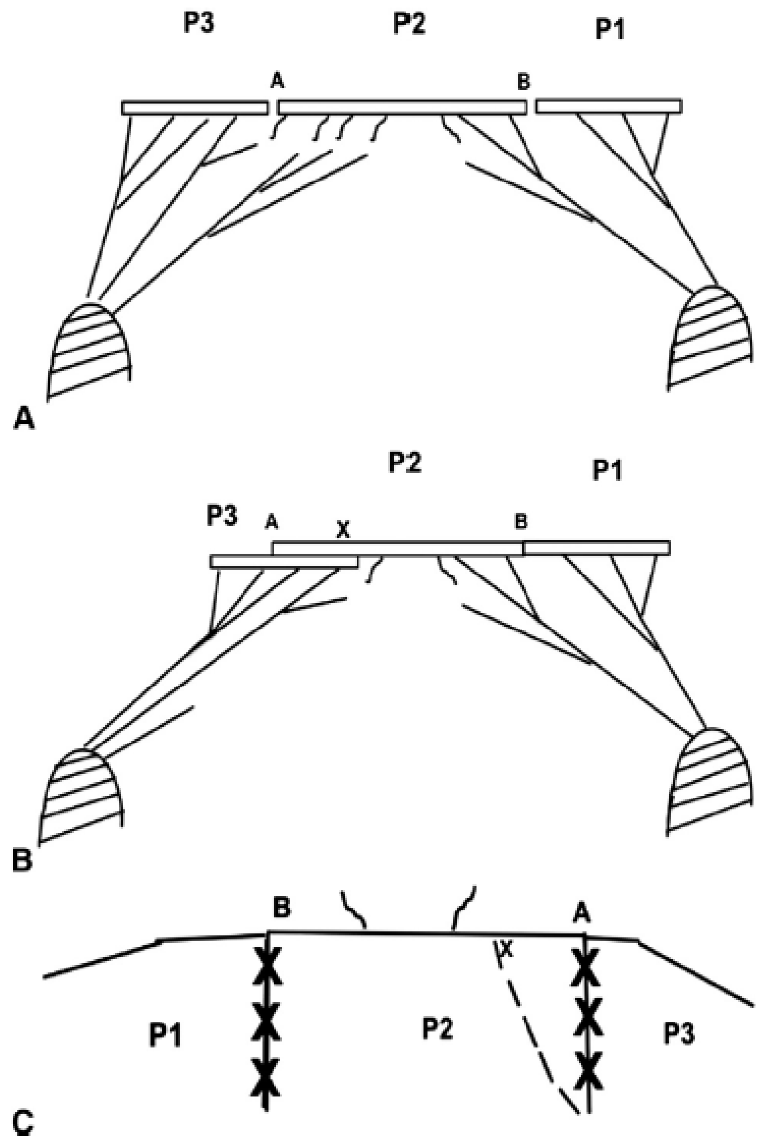


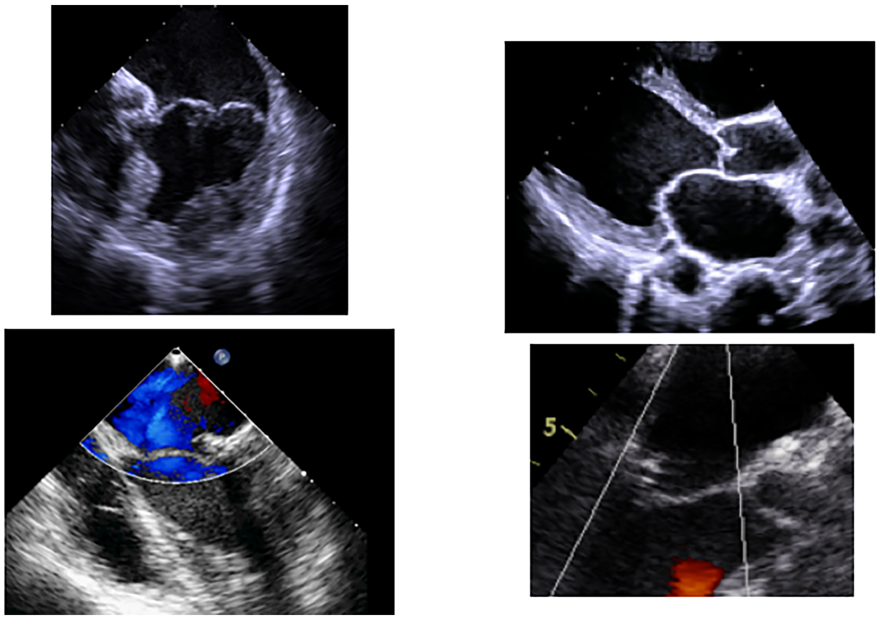
FIGURE 2. A, P2 chordae are ruptured, mostly close to P3. B and C, P3 is sutured below P2 so its chordae will support part of P2. A portion of P2 remains without chordae. x, This suture will define the position of P3 below P2.

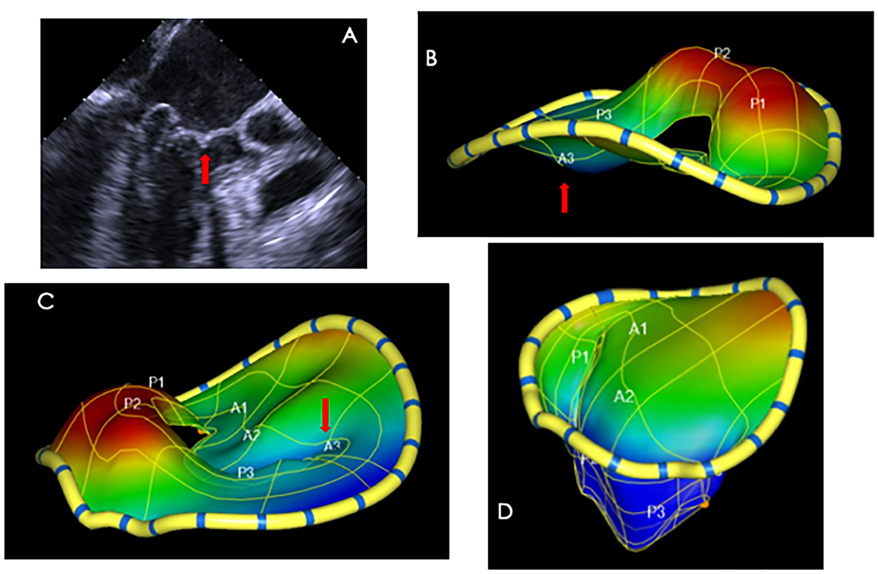
B C D E F

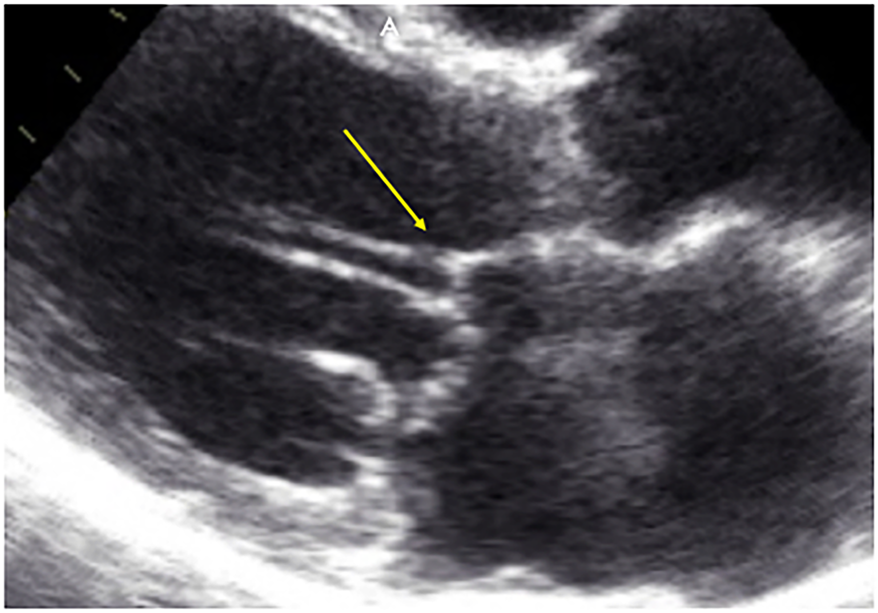
A, the transaortic approach allows to see clearly the second-order chords, which can be easily cut. B, the AL is pulled up at the maximum and the distance between the border and the knot is set at 5 mm over the AL edge. A nerve hook is used for adjustments. In case of chordal rupture, the height of the knot is set at the same height of another artificial chord (if the neighbour native chords are elongated) (C) or 5 mm over the border of the AL (if the native chords are not elongated) (D). E, in case of elongation of the PL chords, the scallops are sutured together, to receive reciprocal support. F, P2 chordae are ruptured, mostly close to P3 (A). P3 is sutured below P2 so its chordae will support part of P2 (B). A portion of P2 remains without chordae. The scallops are anyway sutured together (C). x, this suture will define the position of P3 below P2.

PA, patch augmentation; CC, chordal cutting; AL, anterior leaflet; PL, posterior leaflet.

F, from Calafiore et al[12], with permission.



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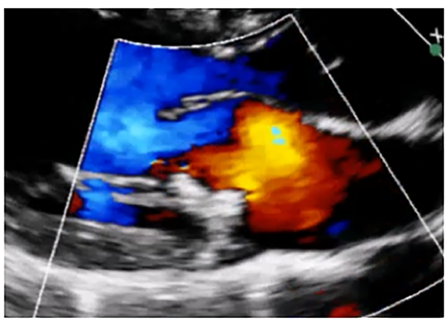

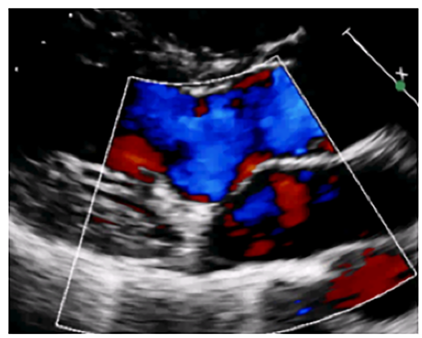

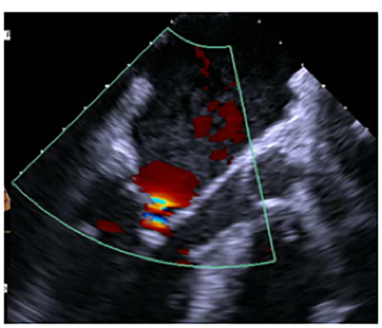

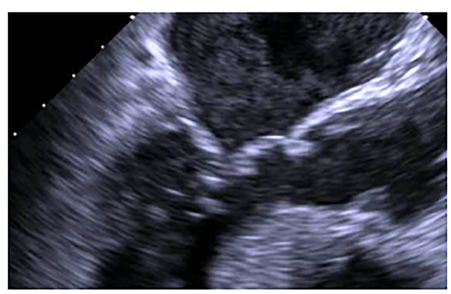

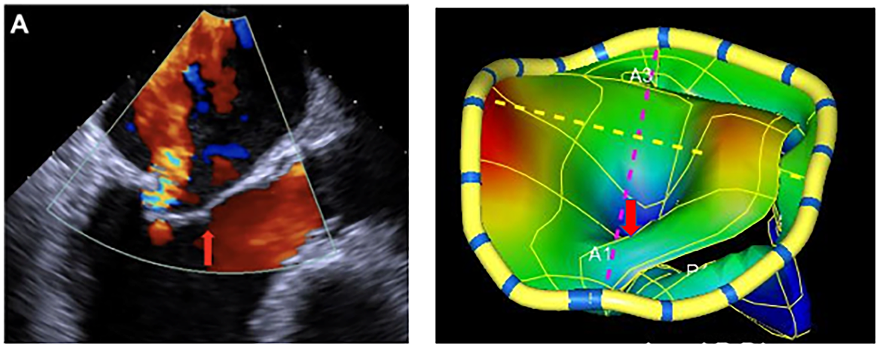
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