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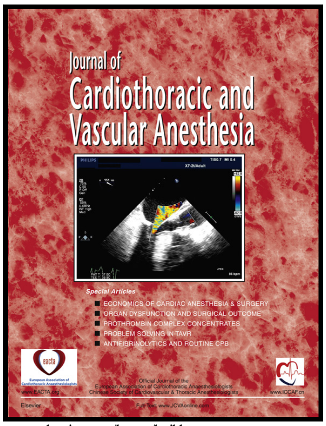

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Aortic Regurgitation in Acute Type A Aortic Dissection: a clinical classification in the era of the functional aortic annulus for the perioperative echocardiographer

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Key Words: functional aortic annulus; aortic cusp; aortic annulus; sinus segment; sinotubular junction; acute type A aortic dissection; intimal flap; aortic regurgitation; mechanisms; three-dimensional imaging; transesophageal echocardiography; coronary dissection; type I; type II; type III; type IV; aortoventricular junction; aortic valve resuspension; Bentall procedure; David V valve –sparing root replacement.

Abstract

The functional aortic annulus offer s a clinical approach for the perioperative echocardiographer to classify the mechanisms of aortic regurgitation in acute type A dissection. Comprehensive interrogation of the functional aortic annulus in this setting by TEE can guide surgical therapy for the aortic root by considering the following important aspects: severity and mechanism of aortic regurgitation; extent of root dissection; and, the pattern of coronary artery involvement. The final choice of surgical therapy should also take into account factors such as patient presentation and surgical experience to limit mortality and morbidity from this challenging acute aortic syndrome. This review explores these concepts in detail within the framework of the functional aortic annulus, detailed anatomical considerations, and the latest literature.

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Introduction

The functional aortic annulus (FAA) has matured as an echocardiographic concept to provide a framework for echocardiographic analysis of the aortic root to guide aortic valve repair both for bicuspid and tricuspid valves.[1-4] The FAA as a complex contains the following major components (refer to Figure 1): the aortic annulus defined as the hinge points of the aortic valve leaflets; the sinus segment with the sinuses of Valsalva and the ostia of the coronary arteries; and, the sinotubular junction where the sinus segment joins the tubular ascending aorta.[4-5]

Acute type A aortic dissection (ATAD) is defined as acute dissection proximal to the aortic arch with or without distal extension (refer to Figures 2 and 3).[5-7] This acute aortic syndrome is a surgical emergency since immediate surgical repair is considered the gold standard to optimize survival from this often lethal disease.[5-7] Since this dissection process will commonly disrupt the integrity of the FAA to result in significant acute aortic regurgitation (AR), the perioperative echocardiographer must assess the severity and mechanism of this AR to facilitate a data-driven approach for surgical management of the aortic root, since aortic valve repair is often feasible in this emergency setting.[5-7] The focus of this expert review is to explore the mechanisms of AR in ATAD as a platform to guide the surgical therapy for the aortic valve in the setting of a multidisciplinary heart team model.[5-7] The severity of AR has already been extensively discussed in a recent guideline by the American Society of Echocardiography and so will not be addressed in this focused analysis for the perioperative echocardiographer.[8]

1. The Functional Aortic Annulus and the Classification of Aortic Regurgitation

The classification of AR has been framed within the concepts of the FAA and aortic cusp mobility (refer to Figure 4).[8] The 3 classes of aortic regurgitation are distinguished by the degree of aortic cusp mobility, analogous to the surgical approach to mitral regurgitation. Type I AR is characterized by normal aortic cusp motion: the associated AR is typically due to dilation of the sinotubular junction and ascending aorta (type Ia), the sinus segment (type Ib), or the aortiventricular junction (type Ic). The second mechanism in type I AR is due to cusp perforation from various etiologies and has been classified as type Id. As illustrated in figure 4, the direction of the AR jet is typically central in types Ia, Ib and Ic whereas in type Id, the AR jet is typically directed away from the culprit cusp.[1-3]

Type II AR is characterized by excessive aortic cusp mobility (refer to Figure 4). As illustrated in figure 4, the jet in type II AR is typically directed away from the culprit cusp. Type III AR is characterized by limited cusp mobility from various etiologies. As illustrated in figure 4, the jet in type III AR is central with symmetrical restriction of cusp mobility. If the pathological process restricts aortic cusp mobility in an asymmetric fashion, the associated AR jet is typically eccentric, as may be seen in bicuspid aortic valve disease. [1-3]

2. **Type IA Aortic Regurgitation in Acute Type A Dissection**

In type Ia AR associated with ATAD, there is acute dilation of the sinotubular junction, defined as the junction between the sinus segment and the tubular ascending aorta (refer to Figures 4-7). This results in a departure from the normal geometry such that the ratio of the sinotubular junction diameter to the root diameter exceeds 1 (the normal ratio is below 1).[11] The aortic cusps are separated in a symmetrical fashion to produce central AR. In ATAD, the surgical repair includes graft replacement of the ascending aorta that restores the integrity of the sinotubular junction (refer to Figure 7). This surgical remodeling of the sinotubular junction restores diastolic coaptation of the aortic cusps to restore valvular competency with disappearance of the central AR, as outlined in figure 7. Even though this mechanism is common in ATAD, it will typically be corrected by the graft replacement of the ascending aorta that is a standard feature of the surgical management for this acute aortic syndrome.[11]

3. **Type IB Aortic Regurgitation in Acute Type A Dissection**

In type Ib AR associated with ATAD, there is acute dissection of the sinus segment in the aortic root with consequent acute dilation in this aortic segment (refer to Figures 8-10). The aortic sups are thus separated in diastole either in a symmetrical fashion with central AR or in an asymmetric fashion with eccentric AI, depending on the extent of the dissection process in the root.[11-12] The extent of the dissection process in the sinus segment of the aortic root can be classified by the perioperative echocardiographer both as a guide to the complexity of aortic root repair and the mechanisms for AR in ATAD (refer to Figure 11).[12]

Extent I acute dissection of the aortic root has been defined as minimal dissection of the sinus segment with preservation of the sinotubular junction.[12] In this setting, preservation of the native aortic root is likely, as illustrated in figure 7, where tubular replacement of the ascending aorta restores integrity of the functional aortic annulus. Extent II has been defined as moderate dissection of the sinus segment to the level of the coronary arteries. In this setting, root repair may or may not be possible, depending on the final pathology and the experience of the surgical team.[12] Extent III has been defined as severe dissection of the entire root down to a level below the coronary arteries. In this setting, aortic root replacement is likely, given the extensive destruction of the native root. Depending on the level of surgical skill and experience, root replacement may be with aortic valve replacement (the Bentall procedure) or with sparing of the the aortic valve (e.g. David V procedure).[13-14] This pragmatic classification can therefore not only guide the surgical decision about root repair versus replacement but also the decision about aortic valve repair versus aortic valve replacement depending on the mechanisms of AR, including type II lesions that will be discussed ahead in a dedicated section.

4. **Type IB Aortic Regurgitation in Acute Type A Dissection: Coronary Dissection Focus**

As outlined, the coronary ostia in the sinus segment are an important landmark to classify the extent of dissection in the aortic root (refer to Figure 11).[12] Coronary malperfusion due to coronary dissection remains an important independent determinant of perioperative mortality in ATAD, as outlined by the Penn Classification of the clinical presentation profiles in this challenging disease.[15-16] The echocardiographic diagnosis of coronary malperfusion in ATAD is manifested by the combination of demonstrated coronary dissection with appropriate regional wall motion abnormalities. The detection of coronary dissection has been further enhanced by the advent of three-dimensional transesophageal echocardiography (3D TEE).[17-21]

Comprehensive interrogation of the aortic root by 3D TEE can precisely characterize the extent of dissection in the sinus segment and the precise relationship of the intimal flap to the ostia of the right and left coronary arteries (refer to Figure 12).[17-18]

Further analysis of the spatial relationship between the intimal flap in ATAD and the coronary ostia has revealed 4 patterns that have been classified as types 1-4 (refer to Figures 13-16). In the type I pattern, the coronary artery arises from the aortic true lumen (refer to Figure 13). In the type II pattern, the coronary artery arises from the aortic false lumen (refer to Figure 14). In the type III pattern, the coronary artery is dissected with extension of the intimal flap into the coronary lumen (refer to Figure 15). In the type IV pattern, the imtimal flap overlies the coronary ostium (refer to Figure 16). In the contemporary era, the perioperative echocardiographer should aim to analyze the extent of dissection in the aortic root with an emphasis on the mechanism of AR and the coronary arteries to guide the surgical intervention for these aortic structures in ATAD.

5. **Type IC and Type ID Aortic Regurgitation in Acute Type A Dissection**

Type 1c AR has been defined as AR associated with normal aortic cusp mobility and dilation of the aortoventricular junction (refer to Figure 4). In ATAD, the intimal tear may extend through the sinus segment below the coronary arteries to the aortic origin, namely the aortoventricular junction, where it will be limited by ventricular myocardium (refer to Figure 17).[22-25] Dilation of the fibromuscular aortic valve annulus does not occur in the acute setting, but rather aortic rupture into the pericardium is the clinical event in ATAD that occurs with further extension of the dissection process at this aortic level (refer to Figure 17). Therefore, as a consequence of the aortoventricular junction, acute type Ic AR does not typically occur in ATAD.

Type Id AR has been defined as AR associated with normal aortic cusp mobility and cusp perforation (refer to Figure 4). The body of the aortic valve cusp has a basal attachment below the level of the aortoiventricular junction, as outlined (refer to Figure

17).[22-23] Thus, cusp damage from intimal dissection is not possible in ATAD at the level of the basal cusp attachment since the dissection process is halted above this level by the aortoventricular junction. Although the commissural attachments of the aortic cusps are at the sinotubular junction and thus involve the aortic intima, ATAD at this level typically results in commissural disruption with aortic cusp detachment and prolapse with excessive cusp mobility to produce type II AR that will be discussed next. In summary, due to the anatomical relationships of the functional aortic annulus, type Ic and type Id AR are not observed in the AR spectrum associated with ATAD (refer to Figure 17), unless they were present before the onset of ATAD.[5;7;11] These two type I mechanisms are thus not described in the discussion of AR mechanism in ATAD.[5;7;11; 26]

6. **Type II Aortic Regurgitation in Acute Type A Dissection**

In type II AR, there is excessive cusp mobility resulting in cusp prolapse (refer to Figure 4). The dissection process in ATAD results in type II AR through detachment of the commissural attachments to result in excessive cusp mobility, cusp mobility and type II AR (refer to Figures 17 -20;).[26] This acute cusp detachment may occur in a symmetric fashion to result in prolapse of multiple cusps with centrally directed AR (refer to Figures 18-19). Alternatively, the dissection process can produce single cusp detachment in an asymmetric fashion to result in eccentric AI that is typically directed away from the affected cusp (refer to Figures 18 -20).

The surgical management of type II AR in ATAD is achieved with aortic valve resuspension in which the commissural attachments are restored at the level of the sinotubular junction (refer to Figures 21-22).[26-28] Multivariate analysis has demonstrated that acute AR in this setting is independently related to the degree of aortic root dissection ($P < 0.0001$) as delineated by perioperative TEE.[28] Given that type II AR in ATAD is typically associated with a dissected sinus segment, it follows that the dissected root may or may not be reparable (refer to Figures 21-22). Complex root repair in this scenario is safe and effective in experienced aortic centers, despite extent II or extent III levels of root dissection (refer to Figure 11).[26-28] If the aortic root has been destroyed in ATAD, the surgical options include root replacement with valve replacement (Bentall procedure) or in highly selected patients, aortic valve preservation in the setting of root replacement (commonly, a David V procedure), as outlined earlier.[11-14] The imperative in this surgical emergency is to save the life of the patient in ATAD – the approach to surgical management of the root and AR must be framed within this overall objective.

7. **Type III Aortic Regurgitation in Acute Type A Dissection**

In type III AR, there is restricted cusp mobility that may be symmetric or asymmetric (refer to Figure 4). In ATAD, type III AR occurs when the intimal flap prolapses through the aortic valve during diastole to restrict cusp mobility (refer to Figures 23-27).[26-28] The AR in this setting is typically centrally directed due to symmetric cusp restriction. The complex intimal flap may also cover the ostium of a coronary artery during diastole to such an extent as to result in malperfusion with coronary ischemia, regional wall motion abnormalities and cardiogenic collapse (refer to Figure 26).[5;7;11; 29] The surgical management for type III AR in ATAD is resection of the intimal flap that is standard part of the surgical therapy for this challenging acute aortic syndrome.

Conclusions

The functional aortic annulus represents a sound clinical framework for understanding the mechanisms of AR in ATAD, as outlined in figure 27. Comprehensive interrogation of the functional aortic annulus in this setting by TEE (including 3D imaging) can provide the data to facilitate surgical planning for the aortic root by analyzing the following aspects in detail: severity of aortic regurgitation; mechanisms of aortic regurgitation; extent of dissection in the sinus segment in relation to the coronary ostia; and the pattern of coronary artery involvement by the intimal flap. Although repair of the aortic valve and root is safe, effective and durable, the final choice of surgical therapy should take into account factors such as patient presentation, echocardiographic evaluation of the proximal thoracic aorta, and surgical experience within the framework of a multidisciplinary heart team model so as to limit mortality and morbidity in this perioperative emergency.

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Figure Legends

Figure 1: The Components of the Functional Aortic Annulus I – aortic valve annulus (leaflet hinge point); II – aortic root at the sinuses of Valsalva (maximal diameter usually midpoint); III – sinotubular junction; IV = proximal tubular portion of the ascending aorta.

(Ao - Aorta; LA - Left Atrium; LV - Left Ventricle).

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Figure 2: The DeBakey and Stanford Classifications for Aortic Dissection. DeBakey I originates in the ascending aorta and can include the entire aorta: Debakey II originates in the ascending aorta and does not propagate; Debakey III originates in the descending aorta and propagates distally with no ascending aorta involvement. Stanford Type A aortic dissection involves the ascending aorta (with or without distal extent). Stanford Type B dissections do not involve the ascending aorta.

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Figure 3: Stanford Type A Aortic Dissection In this midesophageal long axis view of the aortic valve view obtained during aortic assessment with transesophageal echocardiography, there is an intimal flap (arrow), consistent with type A dissection. (LA - Left atrium; ASC'G AO – Ascending Aorta).

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Figure 4: The Classification of Aortic Regurgitation in the Functional Aortic Annulus Era Type I aortic regurgitation is defined as normal aortic cusp motion: types Ia, Ib and Ic are associated with dilation of the ascending aorta, aortic sinus and aortic annulus respectively; type Id is associated with aortic cusp perforation. Type II aortic regurgitation is associated with excessive cusp mobility, typically manifested as cusp prolapse. Type III aortic regurgitation is associated with restricted cusp mobility, typically due to cusp fibrosis and/or calcification.

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Figure 5: Type IA Aortic Regurgitation in Acute Type A Aortic Dissection

This figure depicts the midesophageal long-axis view of the aortic valve. There is dissection of the ascending aorta with extension and consequent acute dilation of the ascending aorta and sinotubular junction. The aortic cusps are thus acutely separated during diastole with lack of coaptation and consequent type Ia aortic regurgitation (refer to Figure 6)

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Figure 6: Type IA Aortic Regurgitation in Acute Type A Aortic Dissection

This figure depicts the midesophageal short-axis view of the aortic valve. There is symmetric diastolic separation of the aortic cusps due to acute type A aortic dissection with acute dilation of the ascending aorta and sinotubular junction. The resulting aortic regurgitation is centrally directed, as illustrated here in short-axis and in long-axis with Figure 5.

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Figure 7: Surgical Management for Type IA Aortic Regurgitation

This figure depicts the normal functional aortic annulus on the far left. In the center panel, there is acute dilation of the ascending aorta and sinotubular junction due to acute type A aortic dissection. There is effacement of the sinotubular junction with symmetric aortic cusp separation with consequent central aortic regurgitation as outlined in figures 5 and 6. Graft replacement of the ascending aorta is depicted in the far right panel with restoration of sinotubular dimensions, a return to normal geometry of the functional aortic annulus and resolution of the aortic regurgitation. (AV – Aortic Valve; STJ – Sinotubular Junction; AA – Ascending Aorta)

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Figure 8: Type IB Aortic Regurgitation in Acute Type A Aortic Dissection

This figure depicts the midesophageal long-axis view of the aortic valve. There is dissection of the ascending aorta with extension into the sinus segment with consequent acute dilation of the aortic root. The aortic cusps are thus acutely separated during diastole with lack of coaptation and consequent type Ib aortic regurgitation (refer to Figure 9). In this figure, the root dissection has dilated the sinus segment in a symmetrical fashion to result in centrally directed aortic regurgitation.

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Figure 9: Type IB Aortic Regurgitation in Acute Type A Aortic Dissection

This figure depicts the midesophageal short-axis view of the aortic valve. There is symmetric diastolic separation of the aortic cusps due to acute type A aortic dissection with acute dilation of the sinus segment. The resulting aortic regurgitation is centrally directed, as illustrated here in short-axis and in long-axis with Figure 8. If there is asymmetric dissection of the sinus segment as illustrated here, the diastolic separation of the aortic cusps may be asymmetric with consequent eccentric aortic regurgitation.

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Figure 10: Type IB Aortic Regurgitation in Acute Type A Aortic Dissection

In this midesophageal long axis view of the aortic valve view obtained during aortic assessment with transesophageal echocardiography, there is an intimal flap (arrow), consistent with type A dissection. The dissection process has extended into the sinus segment to result in acute dilation of the aortic root and aortic regurgitation due to lack of aortic cusp coaptation.

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Figure 11: The Classification of Dissection Extent in the Sinus Segment of the Aortic Root

In panel A, extent 1 is depicted with minimal dissection of the sinus segment with a normal sinotubular junction and minimal aortic regurgitation. In panel B, extent II is illustrated with moderate dissection of the sinus segment to the level of the coronary arteries with disruption of the sinotubular junction and significant aortic regurgitation. In panel C, extent III is demonstrated with severe dissection of the sinus segment below the level of the coronary arteries with disruption of the entire root and significant aortic regurgitation.

(Note to the publisher: This figure is taken from an Elsevier journal as follows -Sun L, QI R, Zhu J, et al. Repair of acute type A dissection: our experience and results. Ann Thorac Surg 91: 1147-1153, 2011– there is thus **no copyright issue** since Elsevier publishes both this source and the Journal of Cardiothoracic and Vascular Anesthesia)

Figure 12: The Analysis of Coronary Involvement in Acute Type A Aortic Dissection

In this 4-panel display of a three-dimensional full volume data set, the midesophageal short-axis and long-axis views of the aortic valve are demonstrated in an orthogonal fashion (red and green planes) at the level of the proximal right coronary artery (arrow). The relationship of the intimal flap (asterisk) to the right coronary artery can thus be clearly characterized by this orthogonal analysis. In this case, the intimal flap (asterisk) is clearly at the level of the right coronary artery but does not appear to be involving the coronary ostium. Therefore, in this case, the extent of aortic root dissection is level II, as outlined in figure 10.

(Note to the publisher: This figure is taken from an Elsevier journal as follows - Sasaki S, Watanabe H, Shibayama K, et al. Three-dimensional transesophageal echocardiographic evaluation of coronary involvenenbt in patients with acute type A aortic dissection. J Am Soc Echocardiogr 26: 837-845, 2013 –

there is thus **no copyright issue** since Elsevier publishes both this source and the Journal of Cardiothoracic and Vascular Anesthesia)

Figure 13: Type I Coronary Involvement in Acute Type A Aortic Dissection

In this display, the midesophageal short-axis and long-axis views of the aortic valve are demonstrated. The relationship of the intimal flap (asterisk) to the coronary artery demonstrates that the coronary artery arises from the aortic true lumen. (T – True Lumen; F – False Lumen; L – Left Coronary Artery; R – Right Coronary Artery)

(Note to the publisher: This figure is taken from an Elsevier journal as follows - Sasaki S, Watanabe H, Shibayama K, et al. Three-dimensional transesophageal echocardiographic evaluation of coronary involvenenbt in patients with acute type A aortic dissection. J Am Soc Echocardiogr 26: 837-845, 2013 – there is thus **no copyright issue** since Elsevier publishes both this source and the Journal of Cardiothoracic and Vascular Anesthesia)

Figure 14: Type II Coronary Involvement in Acute Type A Aortic Dissection

In this display, the midesophageal short-axis and long-axis views of the aortic valve are demonstrated. The relationship of the intimal flap (asterisk) to the coronary artery demonstrates that the coronary artery arises from the aortic false lumen. (T – True Lumen; F – False Lumen; L – Left Coronary Artery; R – Right Coronary Artery)

(Note to the publisher: This figure is taken from an Elsevier journal as follows - Sasaki S, Watanabe H, Shibayama K, et al. Three-dimensional transesophageal echocardiographic evaluation of coronary involvenenbt in patients with acute type A aortic dissection. J Am Soc Echocardiogr 26: 837-845, 2013 – there is thus **no copyright issue** since Elsevier publishes both this source and the Journal of Cardiothoracic and Vascular Anesthesia)

Figure 15: Type III Coronary Involvement in Acute Type A Aortic Dissection

In this display, the midesophageal short-axis view of the aortic valve is demonstrated. The relationship of the intimal flap (asterisk) to the coronary artery demonstrates that the coronary artery is dissected with the intimal flap extending into the coronary artery. (T – True Lumen; F – False Lumen; L – Left Coronary Artery; R – Right Coronary Artery)

(Note to the publisher: This figure is taken from an Elsevier journal as follows - Sasaki S, Watanabe H, Shibayama K, et al. Three-dimensional transesophageal echocardiographic evaluation of coronary involvenenbt in patients with acute type A aortic dissection. J Am Soc Echocardiogr 26: 837-845, 2013 – there is thus **no copyright issue** since Elsevier publishes both this source and the Journal of Cardiothoracic and Vascular Anesthesia)

Figure 16: Type IV Coronary Involvement in Acute Type A Aortic Dissection

In this display, the midesophageal short-axis and long-axis views of the aortic valve are demonstrated. The relationship of the intimal flap (asterisk) to the coronary artery demonstrates that the intimal flap lies over the ostium of the coronary artery. (T – True Lumen; F – False Lumen; L – Left Coronary Artery; R – Right Coronary Artery)

(Note to the publisher: This figure is taken from an Elsevier journal as follows - Sasaki S, Watanabe H, Shibayama K, et al. Three-dimensional transesophageal echocardiographic evaluation of coronary involvenenbt in patients with acute type A aortic dissection. J Am Soc Echocardiogr 26: 837-845, 2013 – there is thus **no copyright issue** since Elsevier publishes both this source and the Journal of Cardiothoracic and Vascular Anesthesia)

Figure 17: The Anatomy of the Functional Aortic Annulus

The aortic valve annulus is part of the functional aortic annulus complex (A). This annulus is defined as a virtual ring at the level of the hinge points (arrows) of the aortic valve leaflets (B). The plane of these hinge points is below the anatomical plane of the aortoventricular junction where the left ventricular outflow tract myocardium meets the beginning of the aorta. Note that that the basal attachments aortic valve cusps are below the aortoventricular junction and thus are not accessible by aortic dissection. Furthermore, note the commissural attachments of the aortic cusps at the sinotubular junction (RCC – Right Coronary Cusp; NCC – Non-Coronary Cusp; LCC – Left Coronary Cusp)

(Note to publisher: The source for this figure is from an Elsevier journal as follows: Rankin JS, Bone MC, Fries PM, et al. A refined hemispheric model of normal human aortic valve and root geometry. J Thorac Cardiovasc Surg 146: 103-108, 2013 – note that this is also an Elsevier Journal and therefore there is **no copyright issue** for the Journal of Cardiothoracic and Vascualar Anesthesia – both journals are published by Elsevier)

Figure 18: Type II Aortic Regurgitation in Acute Type A Aortic Dissection

This figure depicts the midesophageal long-axis view of the aortic valve. There is dissection of the ascending aorta with extension into the sinus segment with disruption of the commissural attachments of the aortic cusps to cause excessive cusp mobility, cusp prolapse and type II aortic regurgitation. This acute detachment process from aortic dissection may involve multiple cusps in a symmetric fashion to produce centrally directed aortic regurgitation (top panel) or a single cusp in an asymmetric fashion to result in eccentrically directed aortic regurgitation directed away from the involved cusp (bottom panel).

(Note to the publisher: This figure was developed independently by the authors – there is thus **no copyright issue**)

Figure 19: Type II Aortic Regurgitation in Acute Type A Aortic Dissection

This figure depicts the midesophageal short-axis view of the aortic valve. In the left panel, there is symmetric diastolic separation of the aortic cusps due to acute type A aortic dissection with detachment of multiple cusps resulting in centrally directed aortic regurgitation (refer to figure18). In the right panel, there is asymmetric diastolic separation of the aortic cusps due to a dissection process that has resulted in acute detachment of a single cusp resulting in eccentric aortic regurgitation (refer to figure 18).

(Note to the publisher: This figure was developed independently by the authors – there is thus **no copyright issue**)

Figure 20: Type II Aortic Regurgitation in Acute Type A Aortic Dissection

In this midesophageal long axis view of the aortic valve view obtained during aortic assessment with transesophageal echocardiography, there is an intimal flap, consistent with type A dissection, resulting in a true lumen (TL) and a false lumen (FL). The dissection process has extended into the sinus segment with disruption of commissural attachments to result in excessive cusp mobility, aortic cusp prolapse (arrow) and eccentric aortic regurgitation.

(Note to the publisher: This figure is taken from an Elsevier journal as follows - Goldstein SA, Enagelista A, Abbara S, et al. Multimodality imaging of diseases of the thoracic aorta in adults: from the American Society of Echocardiography and the European Association of Cardiovascular Imaging – endorsed by the Society of Cardiovascular Computed Tomography and the Society for Cardiovascular Magnetic Resonance. J Am Soc Echocardiogr 28: 119-182, 2015 – there is thus **no copyright issue** since Elsevier publishes both this source and the Journal of Cardiothoracic and Vascular Anesthesia)

Figure 21: Aortic Valve Resuspension in Acute Type A Aortic Dissection

In this surgical view of the aortic root, there is dissection of the sinus segment that has required extensive reconstruction of the aortic root due to dissection extending down the non-coronary and right coronary sinus. Surgical felt has been utilized to develop a 'neo-media' for the non-coronary sinus (panel A) and the right coronary sinus (panel B – arrow)) for obliteration of the false lumen and a return to normal geometry of the sinus segment. As part of this complex root reconstruction after extensive acute dissection, the aortic valve cusps have been resuspended at the level of the sinotubular junction with sutures anchored outside the aorta with felt pledgets on each side of the right coronary artery (panels A and B) as shown. These commissural sutures have anchored the right-left coronary cusp commissure anterior to the right coronary artery and the right-non-coronary cusp commissure posterior to the right coronary artery. The resuspension of the aortic valve cusps has corrected their acute detachment due to the acute dissection process to restore normal valve geometry, achieve adequate leaflet coaptation in diastole and resolve the acute aortic regurgitation.

(Note to the publisher: This figure is taken from an Elsevier journal as follows - Bavaria JE, Brinster DR, Gorman RC, et al. Advances in the treatment of acute type A dissection: an integrated approach. Ann Thorac Surg 74: S1848-1852, 2002 – there is thus **no copyright issue** since Elsevier publishes both this source and the Journal of Cardiothoracic and Vascular Anesthesia)

Figure 22: Surgical Management in Acute Type A Aortic Dissection

In this surgical view of the proximal thoracic aorta, the complete reconstruction with graft material is demonstrated after acute type A dissection. The aortic root has been preserved after extensive repair with surgical felt for a 'neo-media' and aortic valve cusp resuspension (refer to Figure 21). This radical repair of the sinus segment has restored normal root geometry to correct the acute aortic regurgitation due to type Ib and type II mechanisms (refer to Figure 4). The ascending aorta has been totally replaced with a tubular graft that has been anastomosed to the native reconstructed root to restore normal geometry of the sinotubular junction for correction of aortic regurgitation due to a type Ia mechanism. The ascending aortic graft has been anastomosed distally to the residual native aortic arch in a hemiarch fashion. In this integrated surgical repair, surgical glue has also been applied to reinforce the aortic arch suture line, as illustrated. This example highlights the typical clinical experience, namely that there are multiple mechanisms for aortic regurgitation in acute type A aortic dissection due to complex disruption of the functional aortic annulus.

(Note to the publisher: This figure is taken from an Elsevier journal as follows - Bavaria JE, Brinster DR, Gorman RC, et al. Advances in the treatment of acute type A dissection: an integrated approach. Ann Thorac Surg 74: S1848-1852, 2002 – there is thus **no copyright issue** since Elsevier publishes both this source and the Journal of Cardiothoracic and Vascular Anesthesia)

Figure 23: Type III Aortic Regurgitation in Acute Type A Aortic Dissection

This figure depicts the midesophageal long-axis view of the aortic valve. There is dissection of the ascending aorta with prolapse of the intimal flap through the aortic valve in diastole. There is symmetric restriction of aortic cusp mobility during diastole with lack of coaptation and type III AR.

(Note to the publisher: This figure was developed independently by the authors – there is thus **no copyright issue**)

Figure 24: Type III Aortic Regurgitation in Acute Type A Aortic Dissection

This figure depicts the midesophageal short-axis view of the aortic valve. The intimal flap has prolapsed through the aortic valve in diastole to restrict aortic cusp motion. Resulting in central type III AR.

(Note to the publisher: This figure was developed independently by the authors – there is thus **no copyright issue**)

Figure 25: Type III Aortic Regurgitation in Acute Type A Aortic Dissection

In this midesophageal long axis view of the aortic valve view obtained during aortic assessment with transesophageal echocardiography, there is an intimal flap in the ascending aorta (Ao), consistent with acute type A dissection. The intimal flap has prolapsed through the aortic valve into the left ventricular outflow tract (LVOT) during diastole to result in restricted cusp mobility, and type III central aortic regurgitation.

(Note to the publisher: This figure is taken from an Elsevier journal as follows - Goldstein SA, Enagelista A, Abbara S, et al. Multimodality imaging of diseases of the thoracic aorta in adults: from the American Society of Echocardiography and the European Association of Cardiovascular Imaging – endorsed by the

Society of Cardiovascular Computed Tomography and the Society for Cardiovascular Magnetic Resonance. J Am Soc Echocardiogr 28: 119-182, 2015 – there is thus **no copyright issue** since Elsevier publishes both this source and the Journal of Cardiothoracic and Vascular Anesthesia)

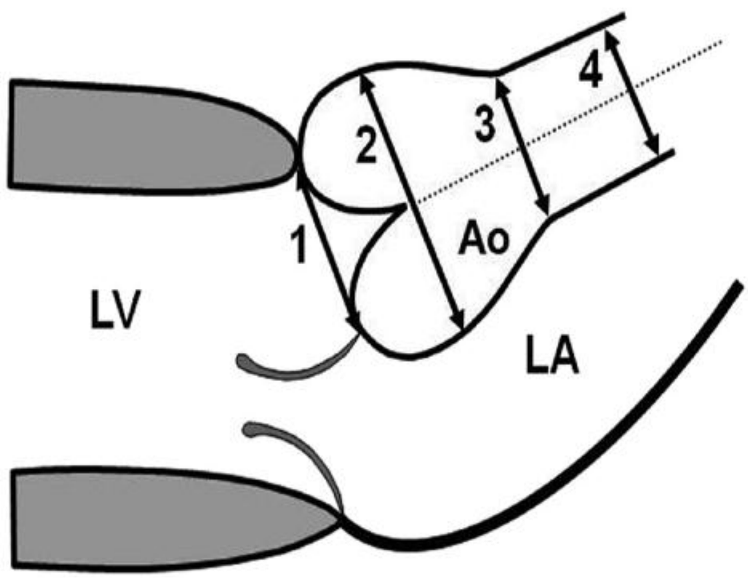
Figure 26: Type III Aortic Regurgitation with Type IV Coronary Involvement in Acute Type A Aortic Dissection

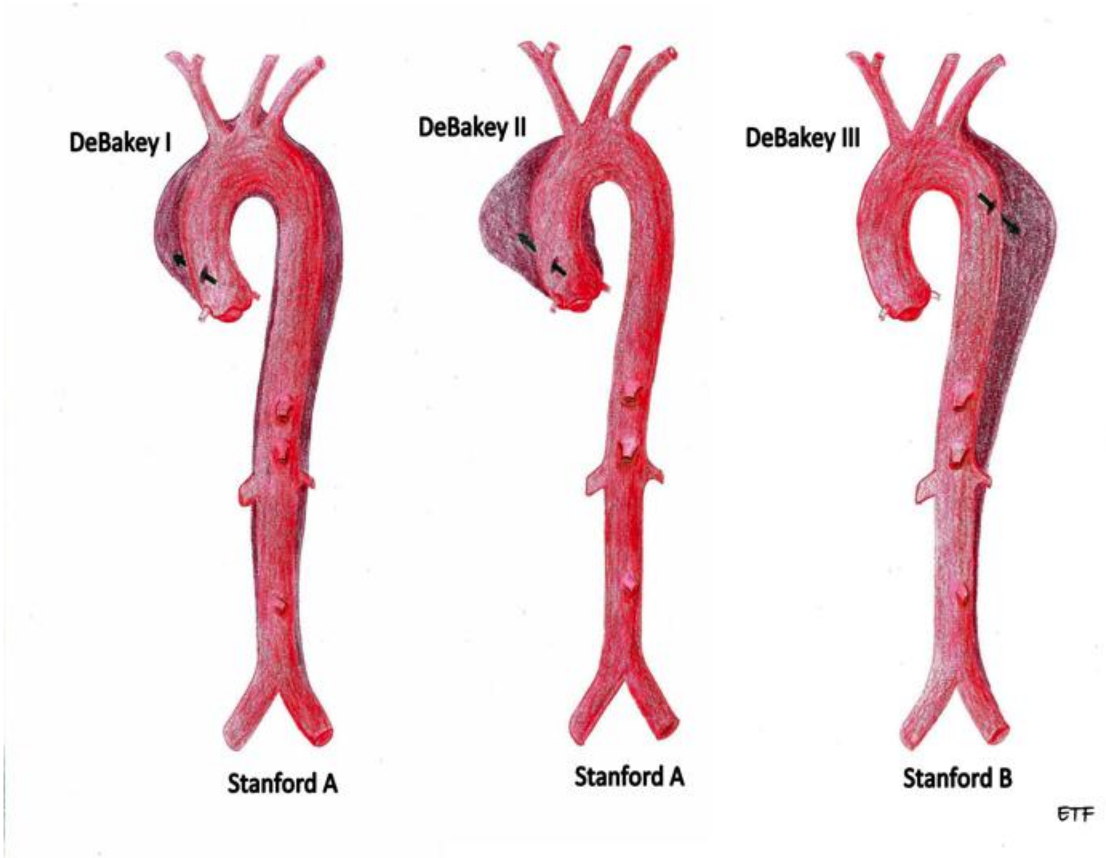
In panel A, the midesophageal short-axis and long-axis views of the aortic valve are demonstrated during three-dimensional transesophageal echocardiographic imaging. There is a complex intimal flap that has prolapsed through the aortic valve in diastole, consistent with acute type A aortic dissection and type III aortic regurgitation. In panel B, the midesophageal short-axis and long-axis views of the aortic valve are displayed after multiplanar reconstruction to analyze the spatial relationship of the intimal flap (asterisk) to the ostium of the left coronary ostium. The relationship of the intimal flap (asterisk) to the coronary artery demonstrates that the intimal flap lies over the ostium of the left coronary artery, as outlined in panel C. In this scenario, there is thus type III aortic regurgitation (refer to Figure 4), and type IV coronary involvement (refer to Figure 16). Given the intermittent left coronary perfusion, the echocardiographer should also evaluate left ventricular systolic function for left coronary ischemia. (LA – Left Atrium; LV – Left Ventricle; T – True Lumen; F – False Lumen; L – Left Coronary Artery; AV – Aortic Valve; Ao – Ascending Aorta; PA - Pulmonary Artery)

(Note to the publisher: This figure is taken from an Elsevier journal as follows - Sasaki S, Watanabe H, Shibayama K, et al. Three-dimensional transesophageal echocardiographic evaluation of coronary involvenenbt in patients with acute type A aortic dissection. J Am Soc Echocardiogr 26: 837-845, 2013 – there is thus **no copyright issue** since Elsevier publishes both this source and the Journal of Cardiothoracic and Vascular Anesthesia)

Figure 27: Mechanisms for Aortic Regurgitation In Acute Type A Dissection

(Note to the publisher: This figure was developed independently by the authors – there is thus **no copyright issue**)

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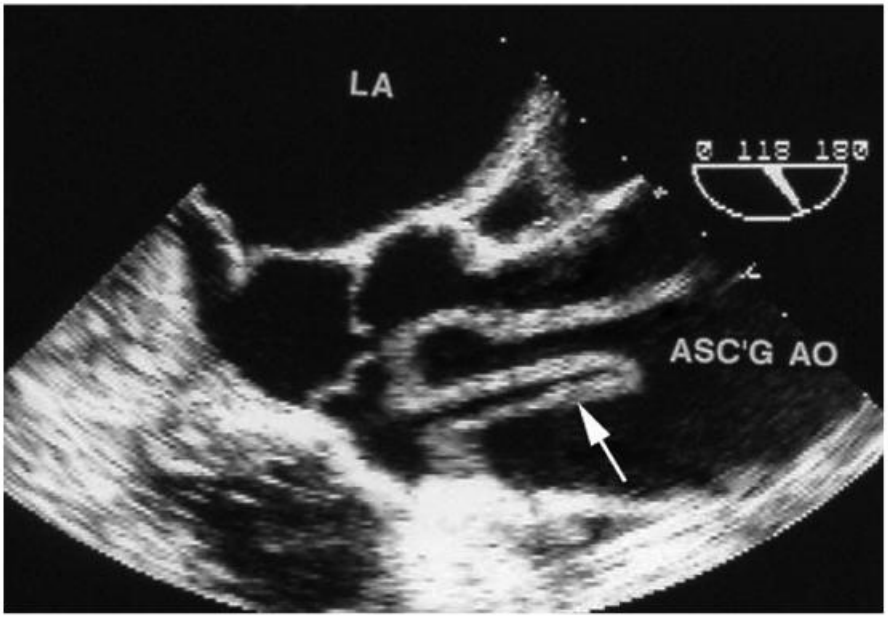
DeBakey II
DeBakey III
Stanford A
Stanford A
Stanford B
ETF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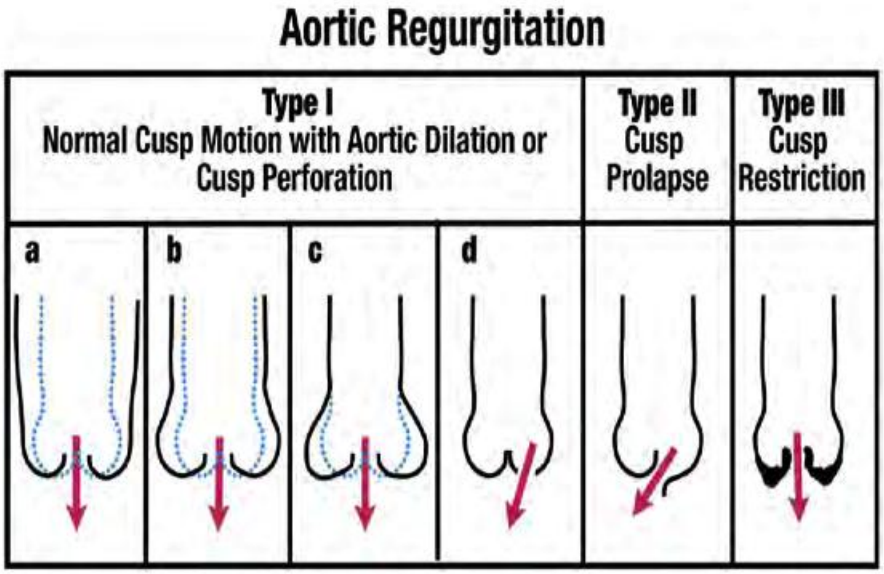
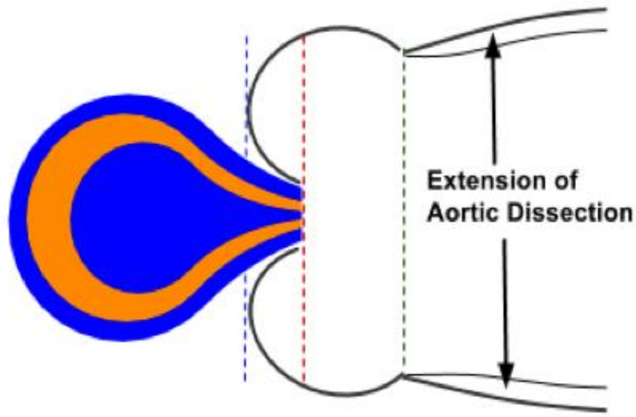

Aortic Regurgitation
Type I
Normal Cusp Motion with Aortic Dilation or Cusp Perforation
Type II
Cusp
Prolapse
Type III
Cusp
Restriction
a
b
c
d


Extension of
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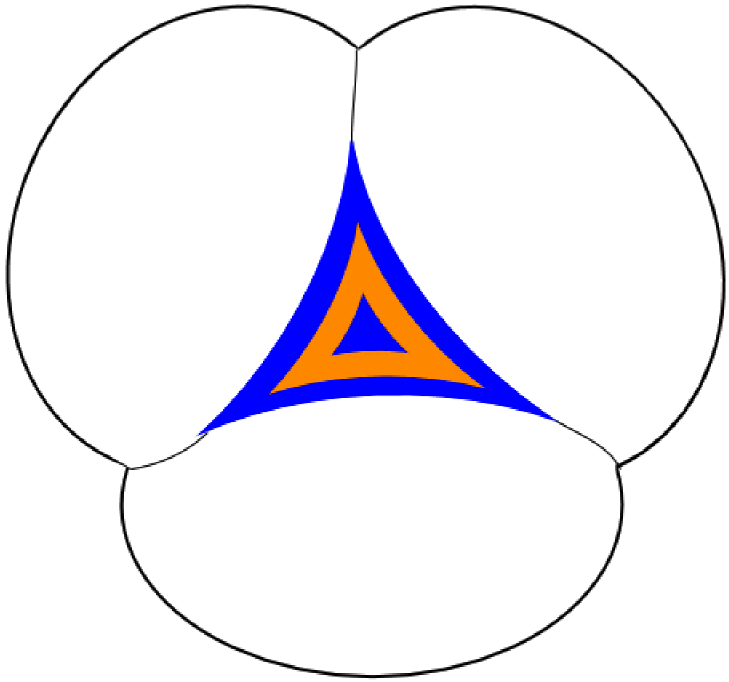
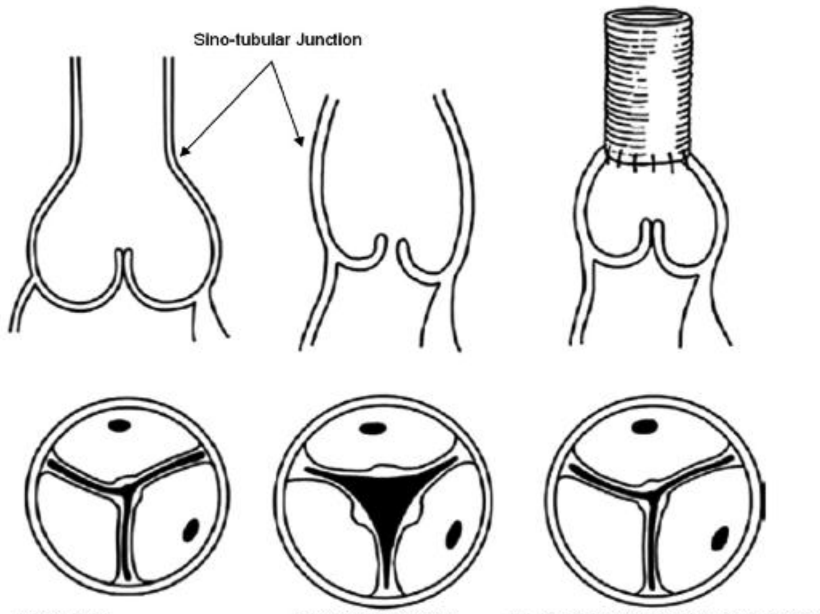
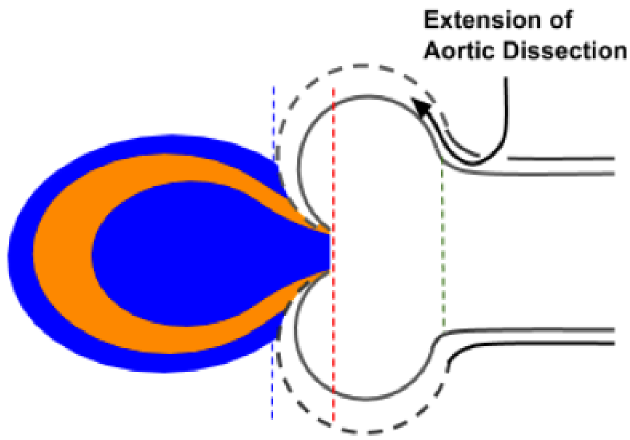



Sino-tubular Junction
Normal AV
AI with STJ dilatation
AV after STJ repair and AA replacement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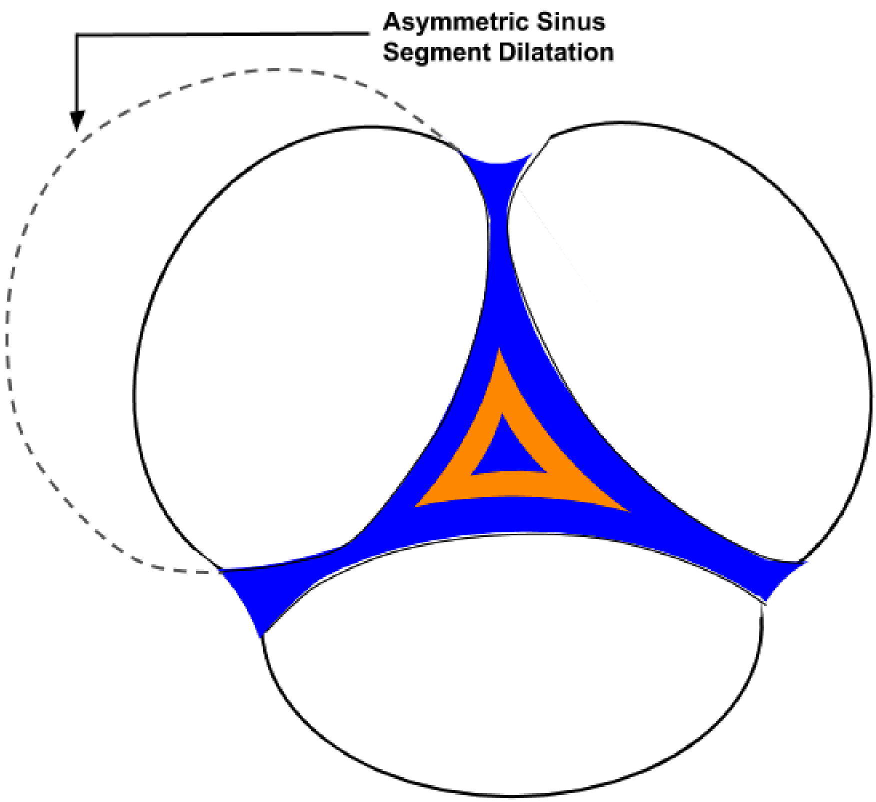
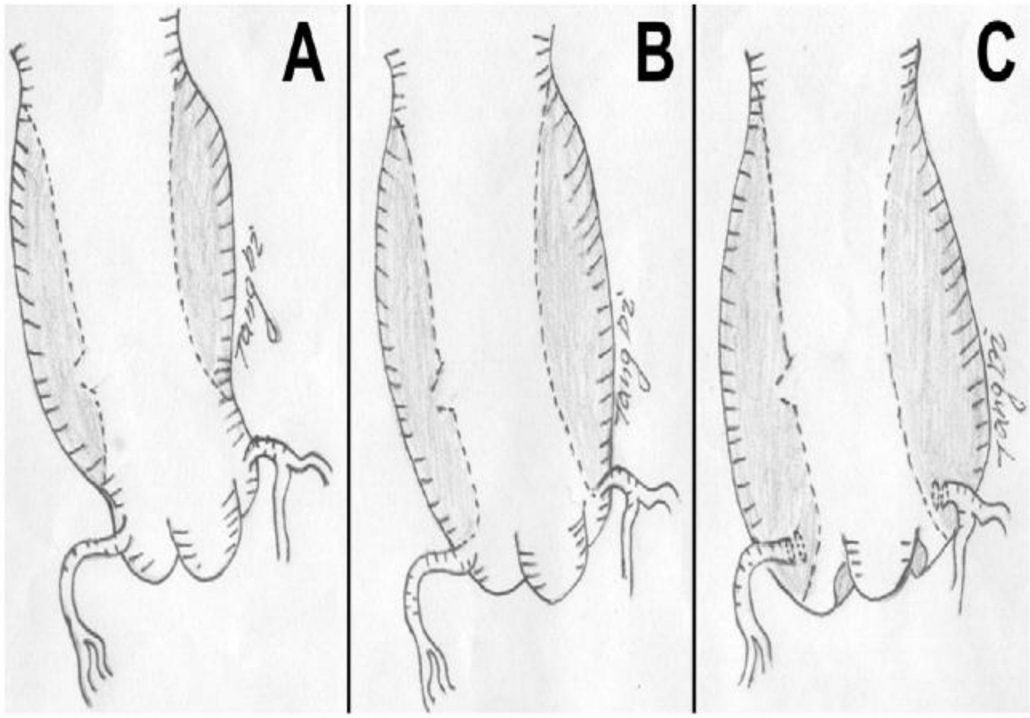

Asymmetric Sinus
Segment Dilatation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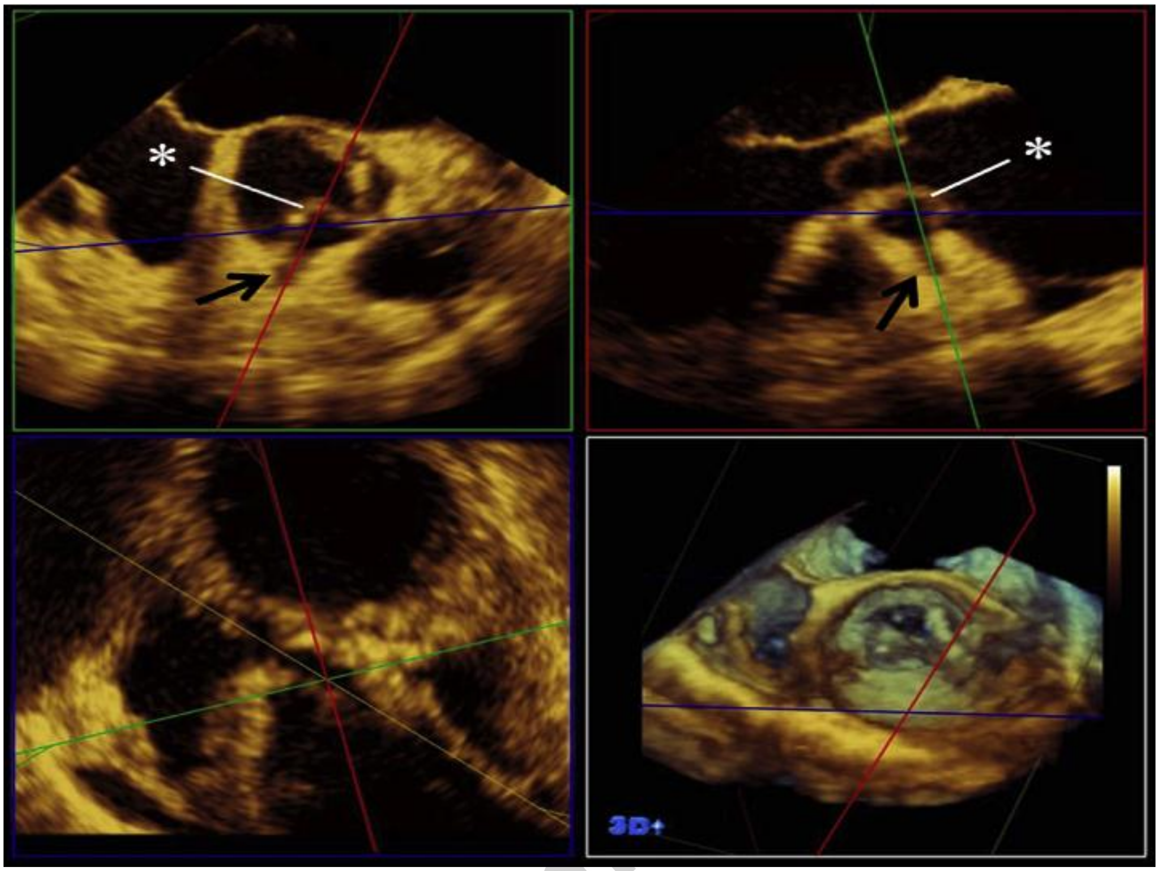

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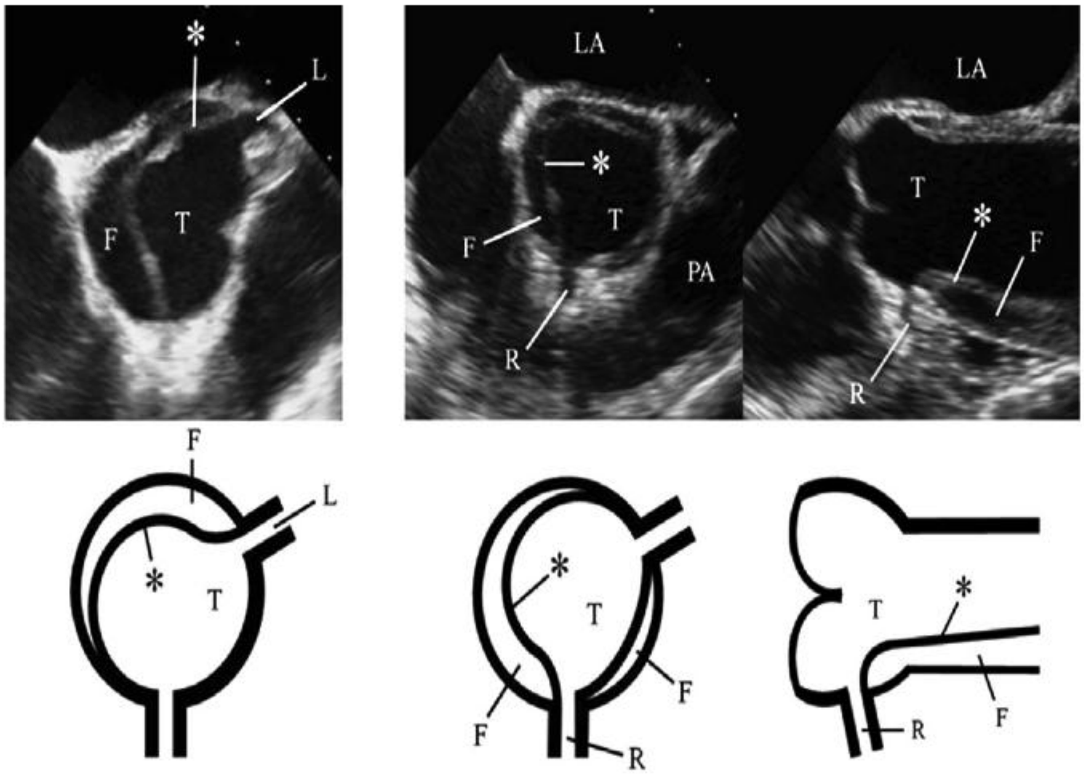
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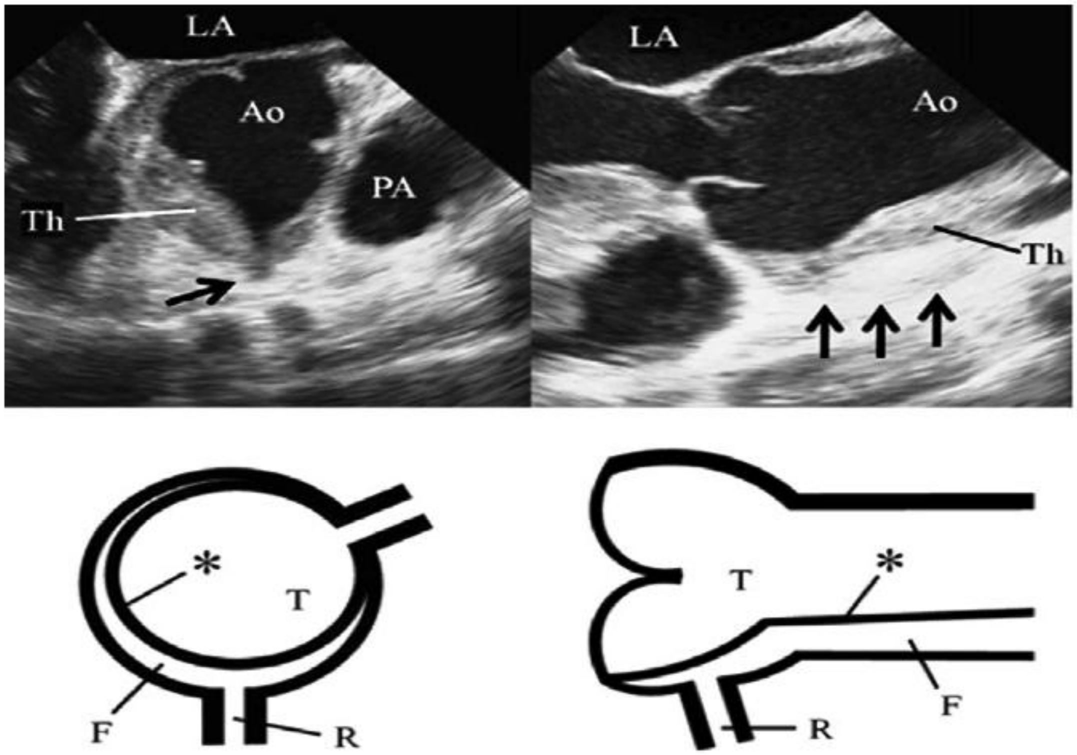
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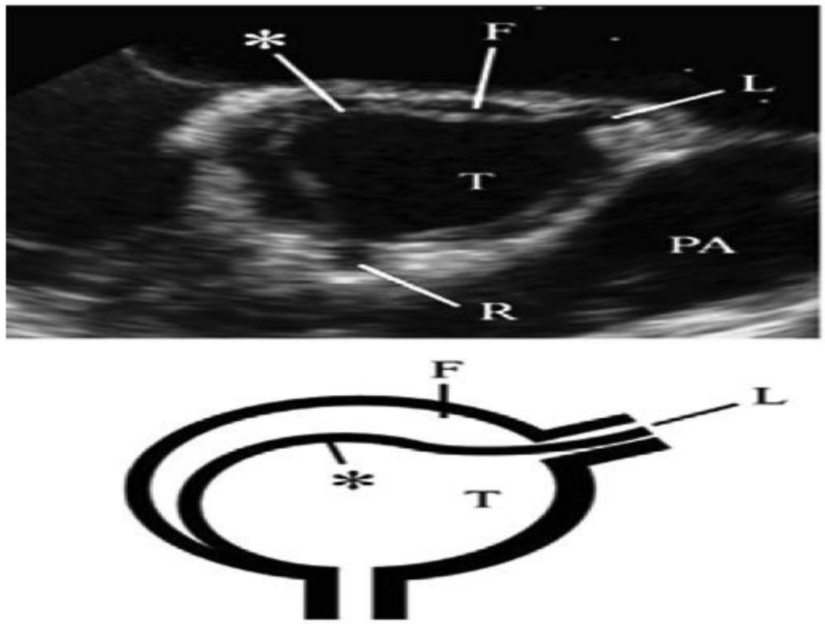
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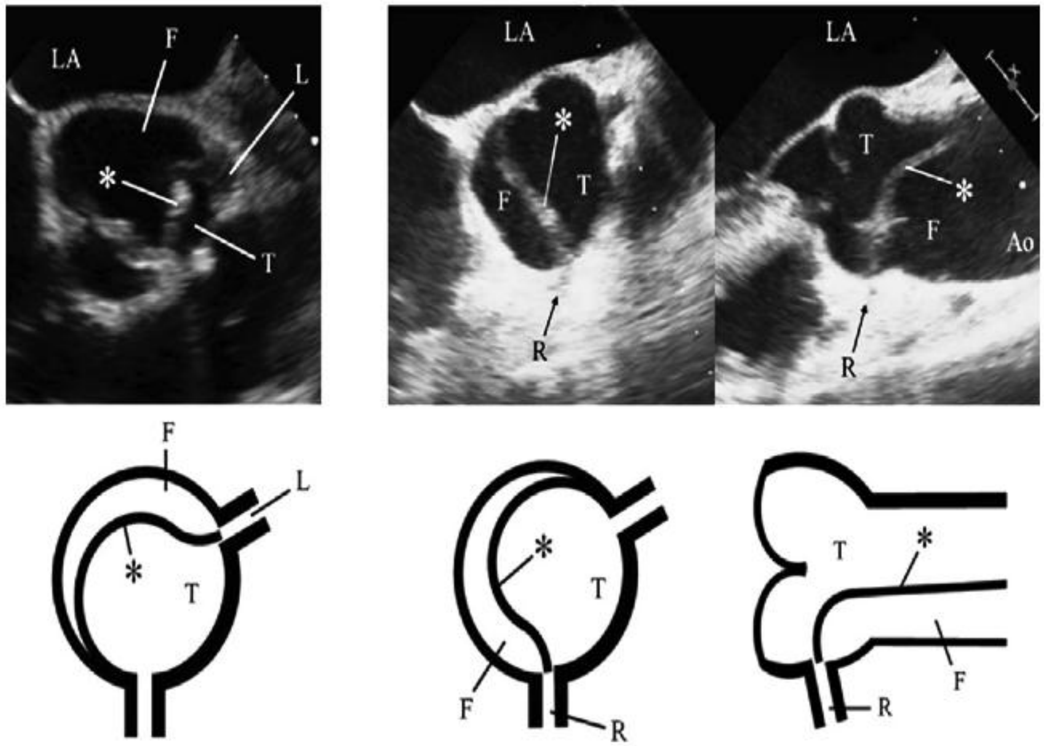
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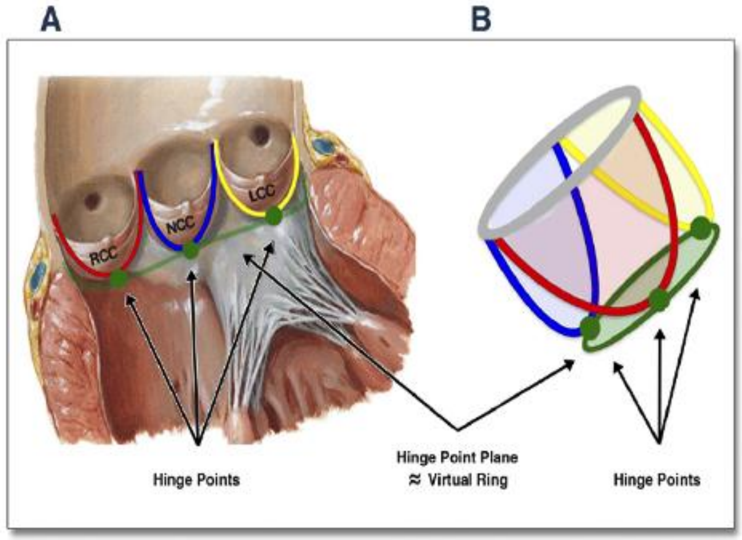
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B
RCC
NCC
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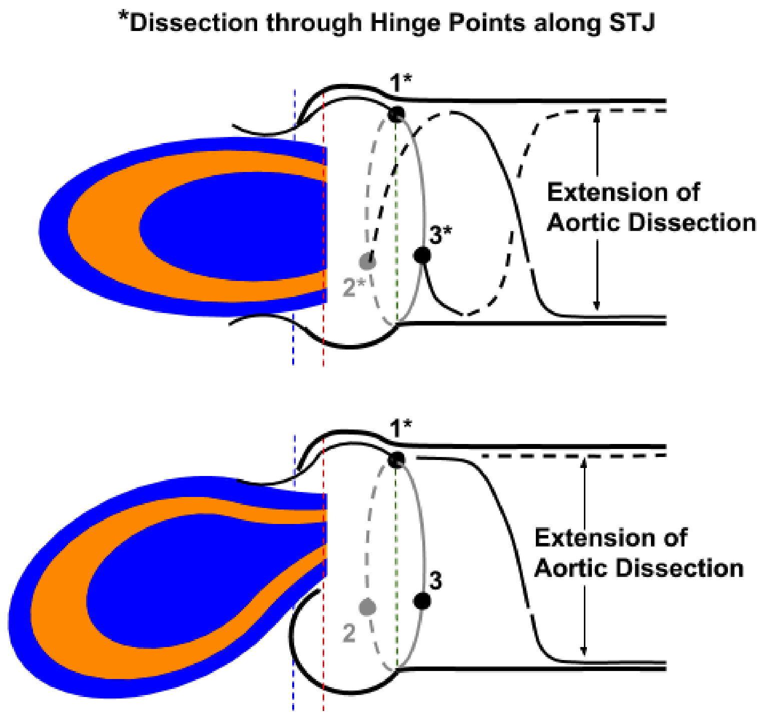
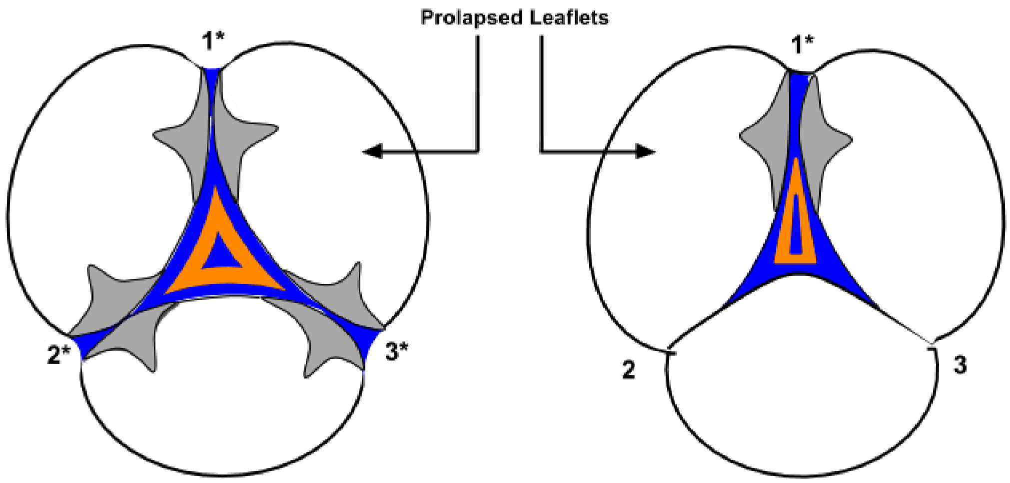
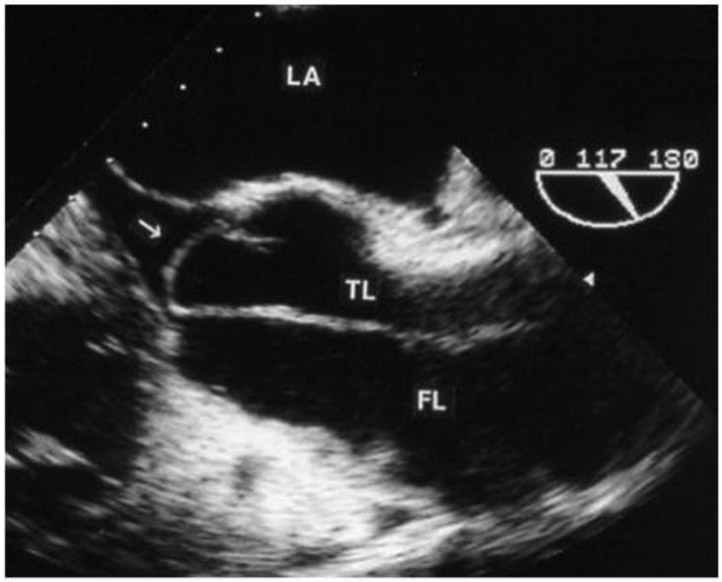
Hinge Points
Hinge Point Plane
≈ Virtual Ring
Hinge Points


*Dissection through Hinge Points along STJ
1*
3*
2*
Extension of
Aortic Dissection
1*
3
2
Extension of
Aortic Dissection


Prolapsed Leaflets
1*
2*
3*
1*
2
3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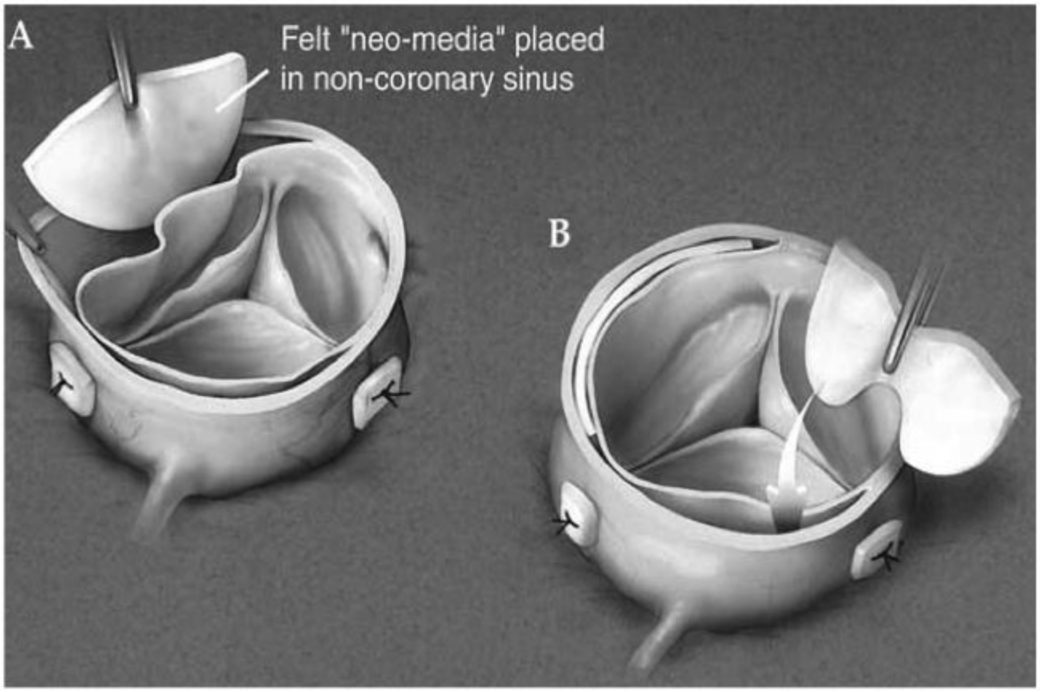
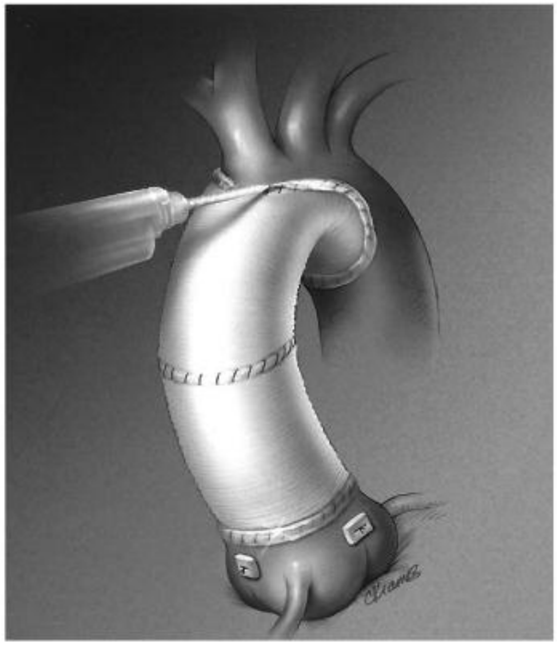
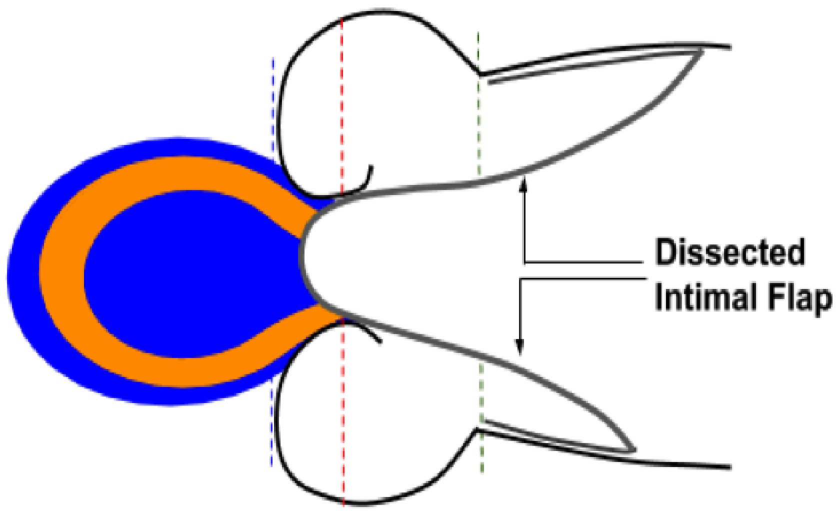

A
Felt "neo-media" placed
in non-coronary sinus
B

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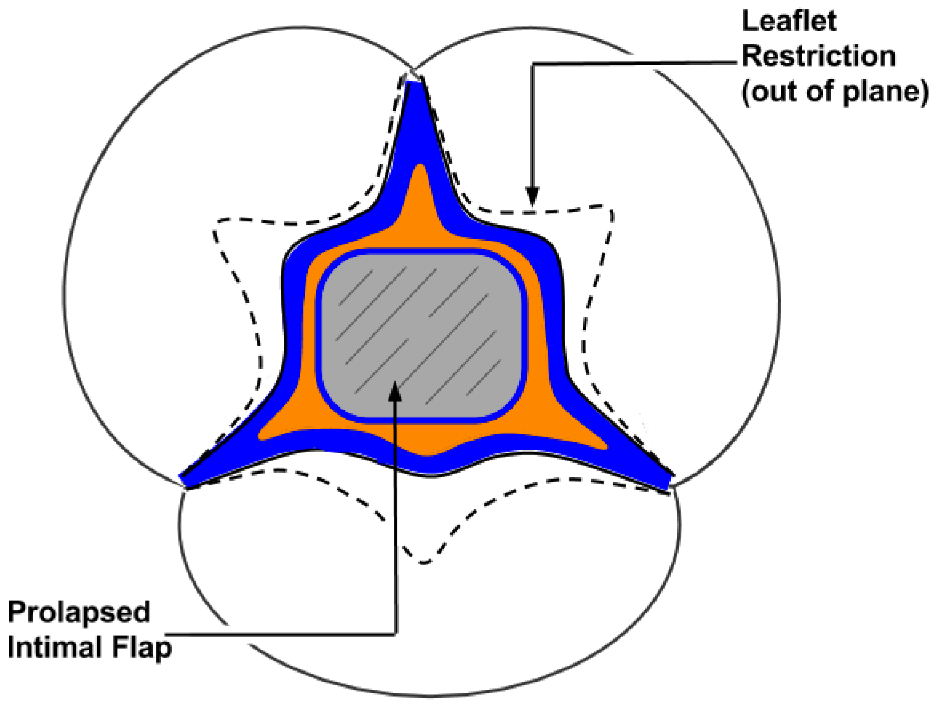
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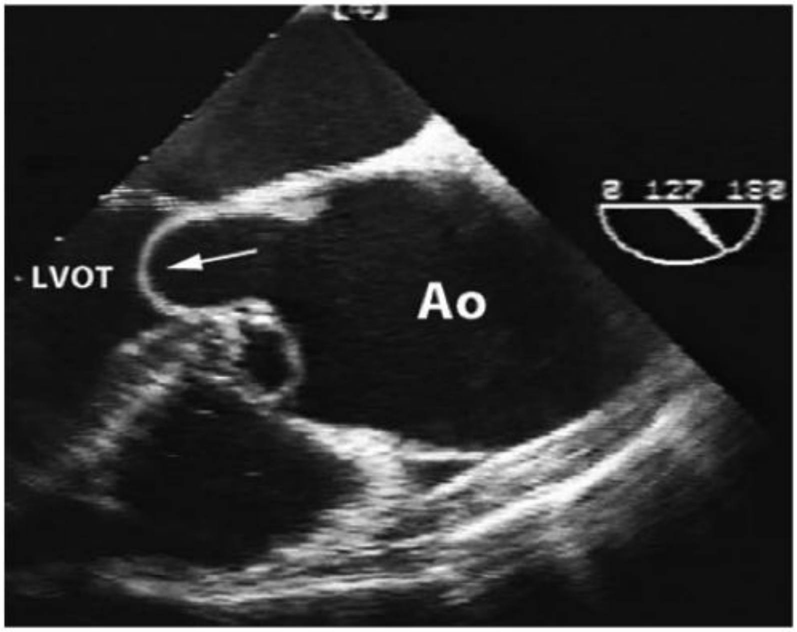
Restriction
(out of plane)
Prolapsed
Intimal Flap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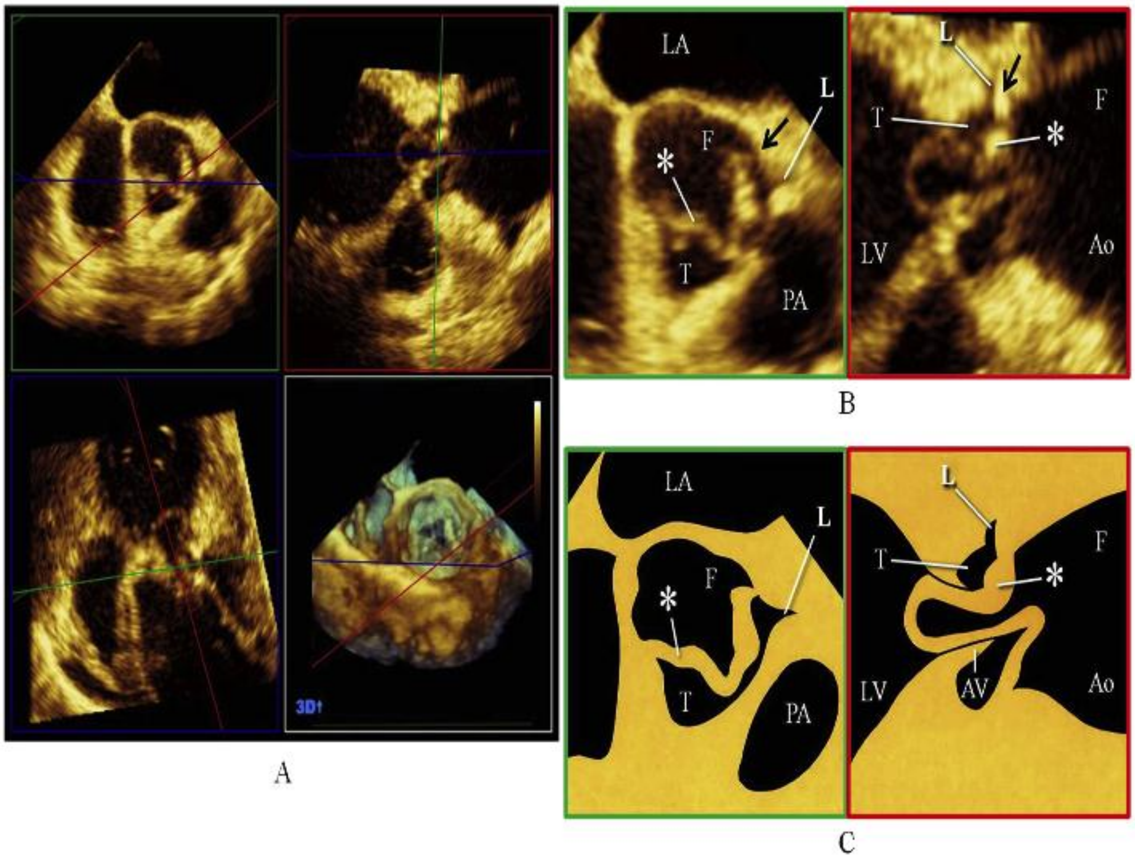
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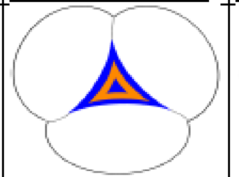
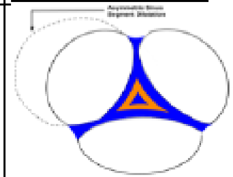
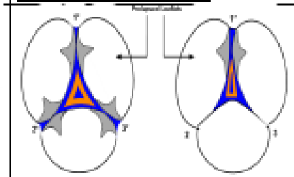
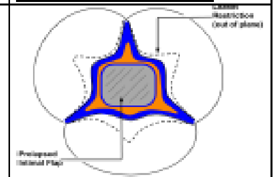
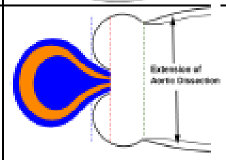
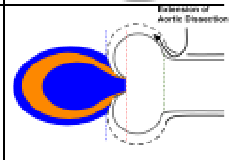
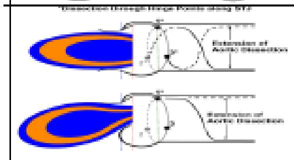
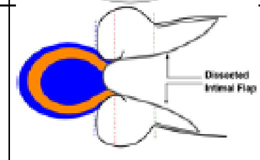
	Type IA Aortic Regurgitation	Type IB Aortic Regurgitation	Type II Aortic Regurgitation	Type III Aortic Regurgitation
Short Axis Aortic Valve View				
Long Axis Aortic Valve View				
Regurgitation	Typically Central	Typically Central – may eccentric depending on extent of sinus segment dissection	Typically Eccentric – directed away from prolapsed aortic cusp. May be central if multiple cusps involved.	Typically Central
Mechanism	Dilated Sinotubular Junction	Dilated Sinus Segment – may involve one or more sinuses of Valsalva	Aortic Cusp Prolapse - due to disruption of cusp attachments to aortic wall	Diastolic Cusp Restriction – due to intimal flap prolapse
Surgical Management	Restoration of normal geometry at level of sinotubular junction with ascending aortic graft	Sinus segment repair and/or replacement to restore normal geometry	Surgical Options Include: 1. Aortic valve resuspension in a repaired root 2. Aortic valve and root replacement (Bentall procedure) 3. Aortic valve reimplantation (David V procedure)	Resection of intimal flap