We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

6,900
Open access books available

186,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

The Degenerative Mitral Valve Regurgitation: From Geometrical Echocardiographic Concepts to Successful Surgical Repair

Gheorghe Cerin, Bogdan Adrian Popa and Marco Diena
The Cardioteam Foundation / San Gaudenzio Clinic, Novara
Italy

1. Introduction

Echocardiography has become within the last years the main tool in the evaluation of the valvulopathies. Surgery plays a key role in the management of the valvular disorders, but it must be underlined that the surgical timing, planning and indication are all widely based on echocardiography. All the guidelines use the echocardiographic criteria to manage the valvular patients. Echocardiography became the main tool for the selection of the patient candidate to valve repair or replacement. The echocardiographic assessment is important in all the valvulopathies, but becomes crucial in the management of patients with mitral insufficiency, candidate to mitral valve repair.

Still, it should be noted, that there is no randomized study comparing the mitral valve repair and mitral valve replacement, and comparisons between the two, using propensity matching or other statistical methods are very difficult. On the other hand there are numerous studies which suggest that the short and long term outcomes of patients undergoing successful mitral valve repair are superior to those undergoing replacement.

Mitral valve repair has been proved to increase additional operative and long-term survival advantages over mitral valve replacement in case of chronic mitral regurgitation. The reduction in the left ventricular pump performance that has been observed after conventional mitral valve replacement, has not been obvious with mitral valve repair, provided that the postoperative contractile state remains pretty similar to the preoperative hemodynamic status. Compared to mitral replacement, mitral valve repair has lower mortality rates and higher long-term survival.. In addition, the thromboembolic and haemorrhagic complications associated with mitral valve reconstruction are also significantly decreased compared to mitral valve replacement. Several studies have reported that approximately 95% of patients are free from thromboembolic complications at 5 to 10 years after surgery. In contrast, 10% to 35% of patients with mechanical prostheses have thromboembolic events within 5 to 10 years after surgery (Bonow, 2011). Thus, the number of mitral valve repairs is expected to increase because the advantages over replacement were also clearly demonstrated by daily practice.

Nowadays, the number of patients undergoing mitral repair surgery is growing worldwide. The STS database proves that in the US, the percentage of patients undergoing mitral valve

repair has increased from roughly 50% in 2000 to nearly 70% in 2007 (Bonow, 2011), for those patients with degenerative mitral regurgitation (excluding mitral stenosis, previous cardiac surgery and other types of surgery other than tricuspid valve procedures). The percentage of patients is expected to increase, considering that roughly 50% of the symptomatic patients with severe mitral regurgitation are still denied surgery. (Mirabel & colab,)

2. The role of echocardiography in the management of degenerative mitral regurgitation

First of all, in patients with degenerative mitral regurgitation, Echo identifies the type of degeneration: Barlow disease, fibroelastic deficiency (FED), hyper-elastic deficiency in Marfan syndrome etc. It is important for the surgeon to know it is important to know the aetiology of mitral insufficiency because some types of degenerative mitral regurgitation, such as FED, are more difficult to repair. Moreover, echo allows the identification of the mechanisms of mitral regurgitation, the alteration of leaflet coaptation and the specific geometrical concepts, which will be addressed further on.

In fact, echocardiography stands out as the only evaluation tool used in mitral valve repair. In dedicated centers, the tight collaboration between the echocardiographer and the surgeon, transformed the mitral valve repair into the gold standard treatment of mitral regurgitation, with over 90-95% of feasibility.

2.1 Standardization of the echocardiographic evaluation

The standardization of the perioperative echo exam is a key element; it allows the identification of specific patterns of lesions which consequently guide the surgical planning and determine the outcome. It may be considered that the standardisation of the echocardiographic lesions is, in fact, the first step to achieve a standardised surgical technique. At the very beginning, when the echocardiography was less powerful, the mitral repair and the surgical strategy were mainly done by direct anatomical assessment performed by the surgeon in the operating theatre, after opening of the left atrium. Over the last decade, due to to a better resolution of the echo machines and the experience of the echocardiographer, the method allowed a reliable assessment of mitral anatomy and lesions, and by doing so, permitted a reliable surgical planning before opening of the left atrium.

During the last decade, 'Cardioteam' has developed its own algorithm of mitral assessment, in order to standardize the lesions and the mechanisms of regurgitation. It uses some of the classically described patterns of lesions, such as mitral valve prolapse, flail, floppy or billowing mitral valve, but also new ones, such as 'undulating mitral valve', 'overturned' valve, 'marginal prolapse' of the anterior leaflet or 'pseudo-cleft' of the posterior leaflet. The application of this algorithm allowed a better understanding of the relationship between the mitral valve geometry and the valve function. This has significantly modified the surgical approach with subsequent improvement of the results.

Technically speaking, preoperative echocardiographic examination has to consider the mitral valve as an eight-component anatomical structure: three pairs of corresponding scallops (A_1-P_1, A_2-P_2, A_3-P_3) and the two commissures (Figure 1). This approach guarantees a better dialog with the surgical team, by mean of structured lesion localizations and standardization of the examination.
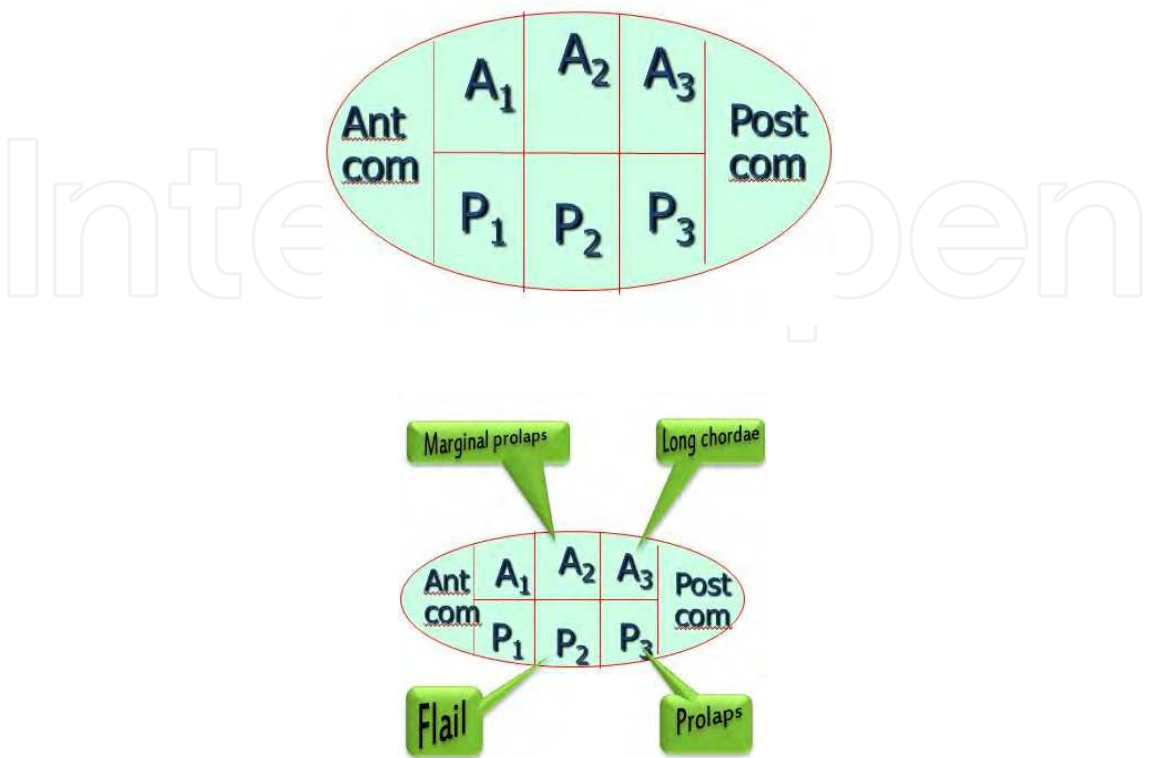
Fig. 1. The mitral valve scheme. The valve is divided into 8 components: three pairs of corresponding scallops (A_1-P_1, A_2-P_2, A_3-P_3) and two commissures. The Echo exam must describe the normality or the abnormalities of each component, assessing the pattern of mitral valve lesion for each one, focusing the attention on the leaflet coaptation.

2.2 The first step of standardization: The prolapsing score

During both transthoracic and intraoperative transesophageal examinations, each scallop must be analysed and a lesion code has to be ascribed: 0-normal, 1-elongated chordae, 2-prolapse, 3-flail and 4-marginal prolapse. The complexity of the valve disorders is expressed by the prolapsing score (PS), namely the ratio between the sick scallops and the total scallops (eg 1/8; 8/8) per patient (Cerin, 2006, 2010).

The echocardiographic message contained within the prolapsing score is fundamental for the surgeon to set the surgical approach. For example, when the echocardiographer states that the prolapsing score is 1/8 or 2/8, the surgical team expects a relatively 'simple' repair to be performed. Consequently, in such a patient the new surgical approaches such as minimally invasive surgery are more likely to be pursued. On the other hand, when the prolapsing score is as high as 8/8, the expected surgical approach will be different, more complex from the technical point of view, therefore more difficult and more likely to be done in classical sternotomy. In the operating theatre, the prolapsing score will be verified and confronted with the echo data Based on the experience of our center, around 75-80% of the echo information obtained from transthoracic exam fits the reality from the operating room.

2.3 The second step of standardization: Evaluation of the mitral valve geometry

The normal mitral geometry is the concept that guides both the evaluation of the various valve lesions and the surgical strategy. This is a key concept, also very helpful in the postoperative assessment of surgical result and for the echocardiographic follow up.

2.3.1 The triangle of coaptation

The central feature of the normal mitral valve geometry is represented by the triangle of coaptation (Cerin, 2006, Tesler 2009). It is usually assessed by two dimensional echocardiography and is delimited by the coaptation point, which is normally sited within the left ventricular cavity, and two other points placed on the septal and lateral mitral annulus (FIG 2). The triangle presents a height, which may be considered the expression of the optimal balance between the elastic and collagen fibres of the mitral valve. In patients with degenerative mitral valve, the height of the triangle of coaptation, which is usually reduced, expresses the excess of elastic fibres.
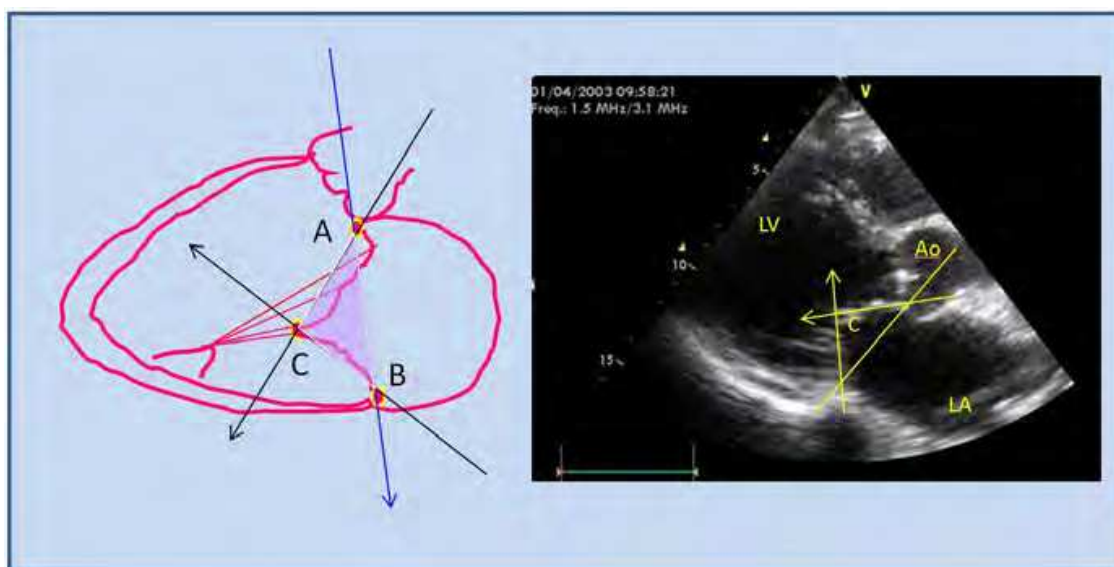

Fig. 2. The concept of triangle of coaptation. The triangle of coaptation is formed by the two points sited on the mitral annulus (A, B) and the coaptation point. The coaptation point (C) is normally situated into the left ventricle. LV – left ventricle; LA – left atrium; Ao – aorta;

At the tip of this triangle, the echocardiographer has to measure the length of leaflet coaptation. The coaptation length and the coaptation height are cornerstone elements used in order to fully describe the valve geometry and to assess the result of the repair.

It may be assumed that from a volumetric and a three dimensional geometrical perspective, the triangle of coaptation corresponds roughly to an asymmetrical tent. In the course of perioperative echocardiographic study, the systematic analysis of the mitral valve apparatus is done, focusing on whether the triangle of coaptation is present or not. The main surgical purpose of repair is achieving a good leaflet coaptation of at least 6mm in length and whenever possible, rebuilding the triangle of coaptation. Due to the increased amount of myxomatous tissue and elastic fibres in the mitral apparatus, the degenerative mitral valve usually loses its normal geometry progressively, alters the triangle of coaptation, presents itself as, elongated chordae or as a truly prolapsing valve.

2.4 The third step of standardization: Check the pattern of mitral valve lesions

In degenerative mitral insufficiency, many types of mitral valve lesions were classically described in the literature: from the classical mitral prolapse or mitral flail, to the billowing or floppy mitral valve. For a true dialogue between the echocardiographer, anaesthesiologist, and surgeon, all the team has to rigorously know the meaning of the most frequent lesions found in these patients. Alongside the well-known classically patterns of lesions, our group identifies some other particular patterns of mitral valve injuries, such as: elongated chordae, marginal prolapse, overturned mitral valve, undulating mitral valve or the mitral valve's pseudo-cleft. The main echocardiographic pattern used for the characterization of the degenerated mitral valve is presented further on.

2.4.1 The pattern of 'elongated chordae'

This pattern defines the situation when the coaptation point is found to be into the left ventricular cavity, immediately below the level of the mitral annulus. It is a borderline situation between a normal aspect of the mitral valve and the mitral prolapse. Usually is not associated with mitral regurgitation. For the surgical planning, it is important to recognise it and indicate it to the surgeon. Sometimes it may interest one or both leaflets (Figure 3), involving one or more scallops. The relatives of patients with truly mitral valve prolapse may sometimes present 'elongated chordae' during the echocardiographic exam, without the classical prolapse.
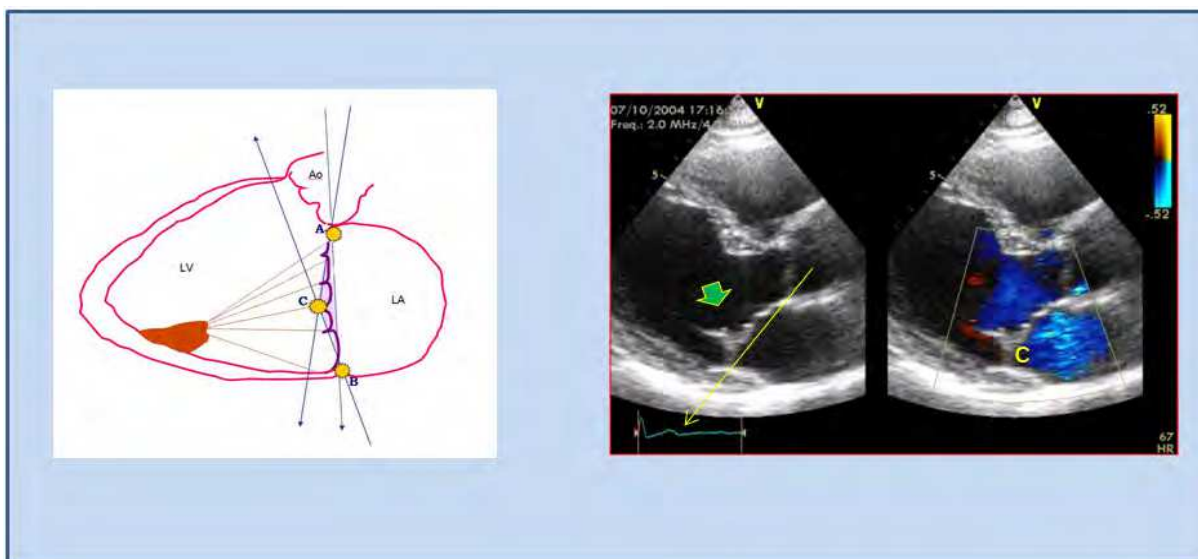

Fig. 3. The pattern of 'elongated chordae'. In the presence of 'elongated chordae', the coaptation point (C) is found into the left ventricular cavity, immediately below or at the level of the mitral annulus. Note the shape of the triangle of coaptation which is flattened. The coaptation height of the triangle has practically disappeared. LV – left ventricle; LA – left atrium; Ao – aorta.

2.4.2 The pattern of 'prolapsing valve'

The pattern of 'prolapsing valve' was classically defined as the presence of the coaptation point into the left atrium, above the level of the mitral annulus (Figure 4). By definition, the

lesion has to be present in PSLAx view, otherwise, due to the shaded shape of the mitral valve, a false diagnose of mitral prolapse may be possible.
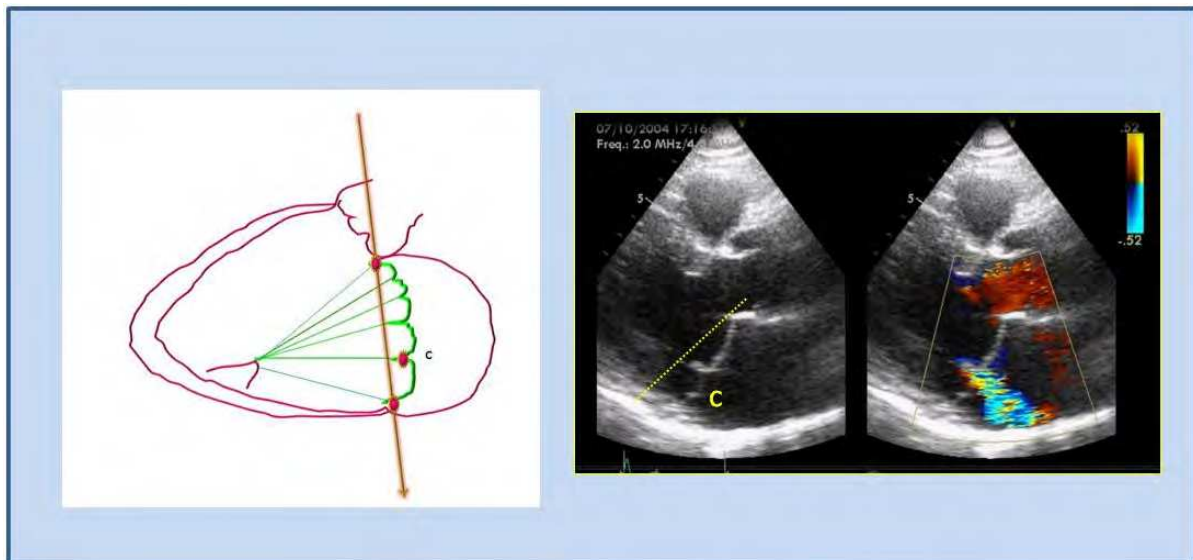

Fig. 4. Prolapsing mitral valve, with both leaflet involvement, shown in the 2D transthoracic parasternal long axis view. Notice the coaptation point (C) sited into the left atrium, behind the virtual line of the mitral annulus.

2.4.3 The pattern of mitral valve flail

It represents the classically loss of leaflet coaptation due to ruptured tendineous chordae. (Figure 5).
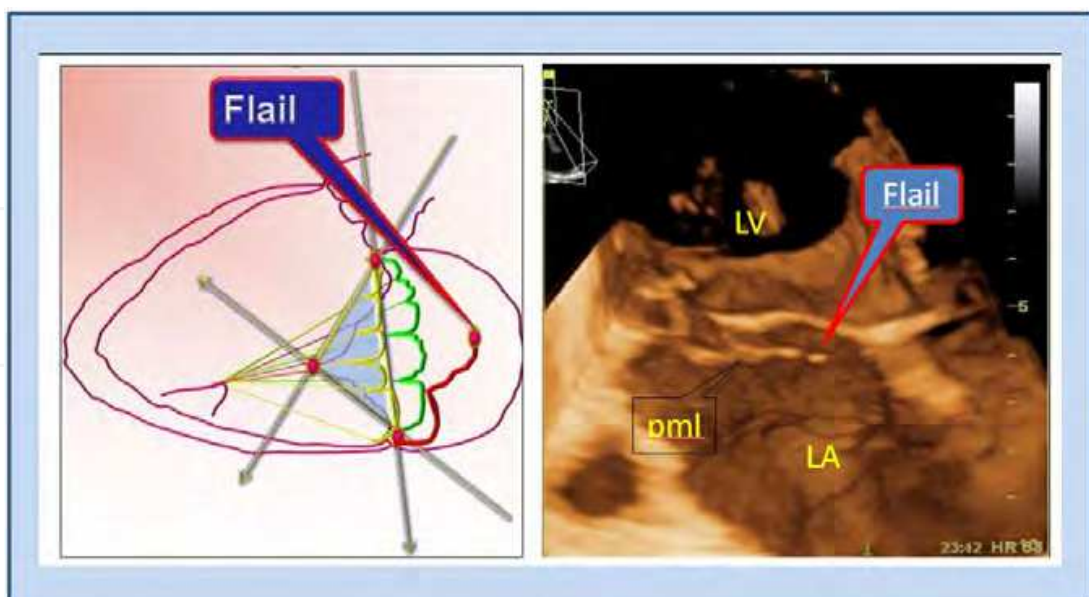

Fig. 5. Flail of the mitral valve shown in the transthoracic parasternal long axis view using real time three-dimensional technique (zoom). The classical lesion usually involves the P_2 scallop of the posterior leaflet, in about 2/3 of the patients with flail mitral valve. LA = left atrium, LV = left ventricle, pml = posterior mitral leaflet.

2.4.4 The pattern of 'marginal prolapse'

The pattern of 'marginal prolapse' is a rare type of mitral lesion, defined as an isolated protrusion of the free border area of one scallop, usually up to the insertion of the second degree chordae. In case of marginal prolapse, the remaining part of the surface of the scallop may be normal, without the displacement of the coaptation point into the left atrium. It is never present as isolated lesion; the marginal prolapse, as a rule, is associated with a P_2 scallop prolapse of the posterior leaflet (Figure 6).
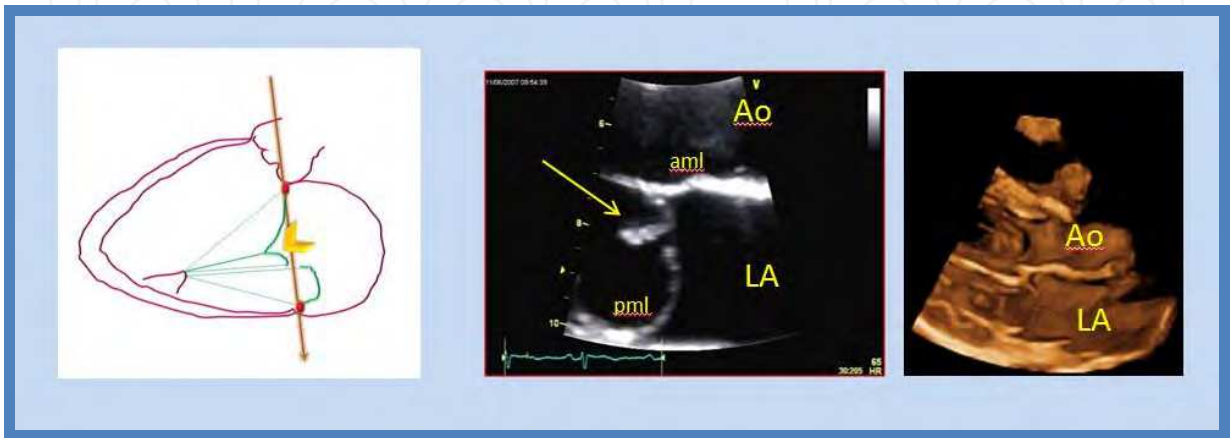

Fig. 6. Marginal prolapse of the anterior leaflet, A_2 scallop (arrow), shown in 2D (zoom) and 3 D Echo. Notice the "stair like aspect" of the anterior leaflet due to the regional prolapse located between the border of the valve and insertion of the second degree chordae (usually strut chordae). This is a hidden and tricky lesion, because its presence may transform the simple mitral plasty of one leaflet, in a complex mitral repair of both leaflets.

2.4.5 The 'undulating mitral valve'

The 'undulating mitral valve' is usually a redundant mitral valve, with excessive tissue, presenting with diastolic fluttering of the free border of both leaflets. In most cases, the prolapsing score is high, approximately 8/8 and as a rule, for the surgeon, it means a complex mitral repair. It is important to underline that the border or a normal mitral valve opens in a linear manner, without diastolic fluttering of the edge.

Fig. 7. Undulating mitral valve. TEE deep trans-gastric short axis view. Notice the undulating aspect of the free borders of the leaflets (much more evident on moving pictures).

2.4.6 The pattern of 'overturned mitral valve'

The pattern of 'overturned mitral valve': this kind of mitral lesion resembles the mitral valve flail as general echocardiographic aspect, but in the 'overturned mitral valve' the chordae are not ruptured (Figure 8). There is only an excessive elongation of the chordae and an obvious prolapse of the mitral valve into the left atrium.
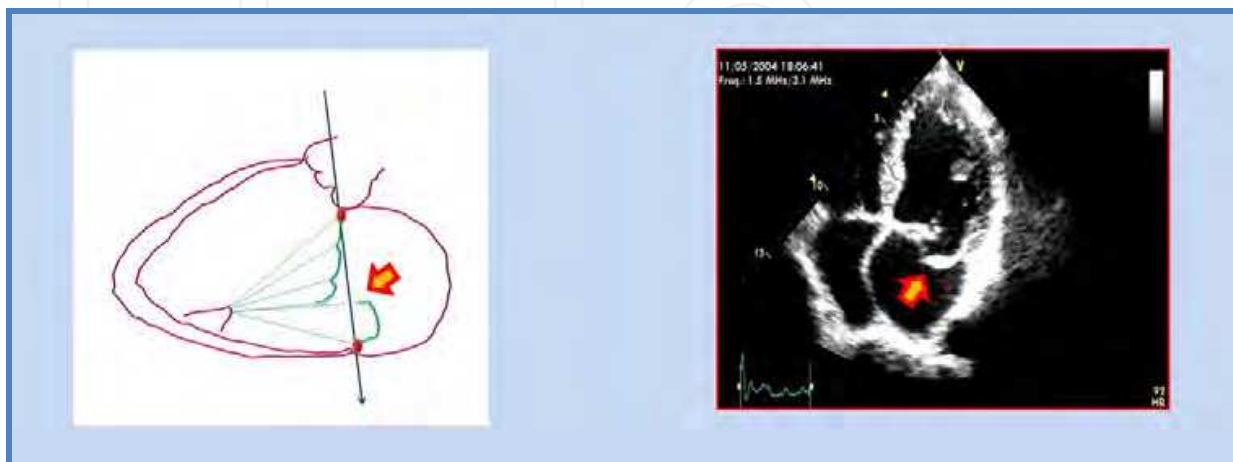

Fig. 8. Transthoracic echocardiography 4 chamber view, showing the obvious prolapse of the posterior mitral leaflet, due to the 'eversion' of the mitral valve. There is a loss of leaflet coaptation due to an excessive elongation of the mitral chordae (verified in the operating theatre).

2.4.7 The 'pseudo-cleft' of mitral valve

The 'pseudo-cleft' of mitral valve an obvious indentation of the border of the mitral valve, which penetrates deeply into the body of the mitral leaflet. It is pretty difficult to diagnose being visible only during the diastole and has to be integrated with the analyses of the colour Doppler in systole (Figure 9 A,B,C). It is never present as an isolated lesion; it is usually found in old mitral valve P_2 prolapse. A split which resembles a pseudo-cleft develops between the scallops P_2 and P_3 (or P_1).
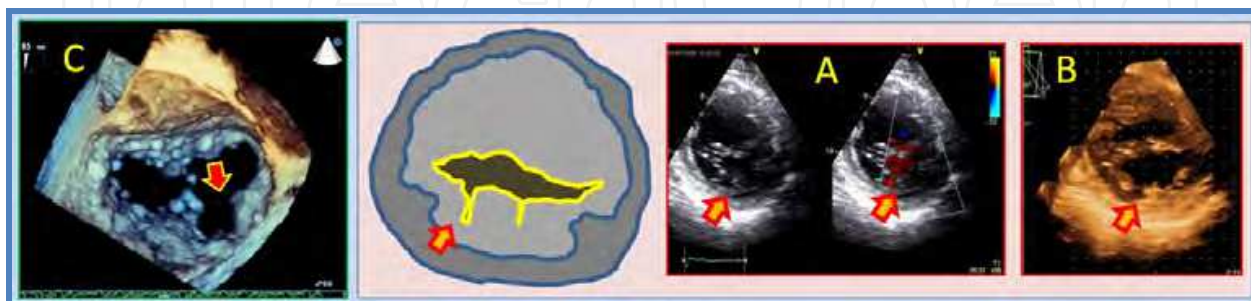

Fig. 9. (A,B,C). Diastolic transthoracic 2D and 3 D echocardiography short axis view (9A,B), showing the crack between P_2 and P_3 in a patient with P_2 prolapse. The figure 9C shows a 3 D transesophageal representation (surgical view) of a pseudo-cleft located between the P_3 and P_2 scallops (red arrow).

2.4.8 The pattern of 'floppy mitral valve'

Represents a redundant mitral valve, usually with both leaflet prolapse. It represents an excessive valve leaflet remodelling, with a 'finger like' transformation of the valve fabrics (Figure 10).

Fig. 10. Transgastric transesophageal intraoperative view of a 'floppy' mitral valve (zoom). Notice the extensive remodelling of the leaflet fabric.

2.4.9 The pattern of 'billowing mitral valve'

Is represented by the protrusion of the leaflet body into the left atrium cavity. As a rule, the coaptation point still remains into the left ventricular cavity (Figure 11). associated with mitral insufficiency, but it is important to indicate it to the surgical team.
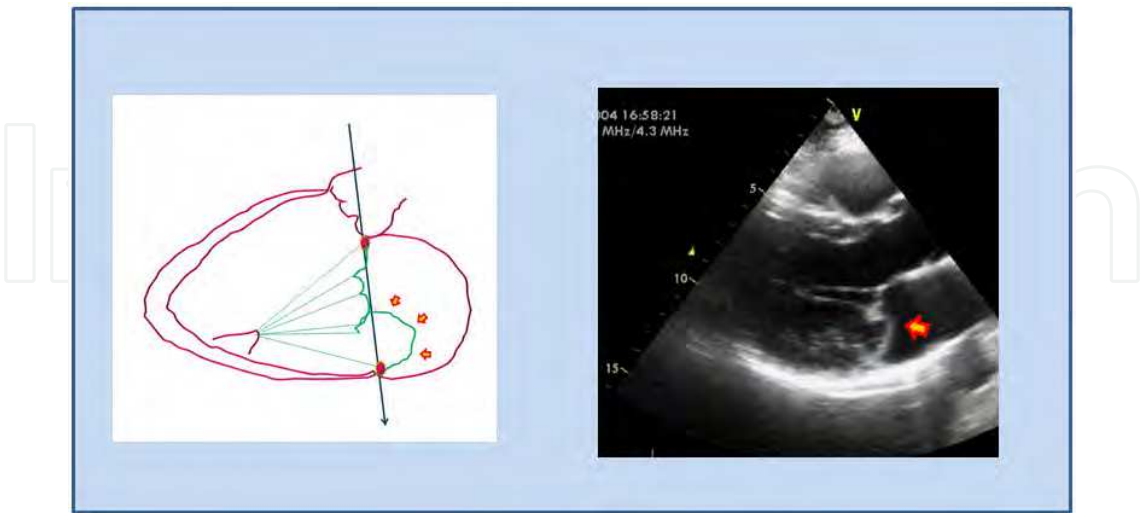

Fig. 11. Billowing mitral valve. PSLAx view of transthoracic exam showing the protrusion of the posterior leaflet (P_2 scallop) into the left atrial cavity. Often the mitral regurgitation may be absent or mild due to a pretty good coaptation, with the coaptation point still sited into the left ventricular cavity.

The final echo report contains coaptation height for each pair of scallops. The assessment of the triangle of coaptation, coaptation length and coaptation height. It represents an integrative scheme which is the synthesis of the various abnormalities found in different areas of the valve (Figure 1).

The mitral annular diameter must be assessed in parasternal long axis view. This measurement corresponds to the septo-marginal diameter of the valve, which is the most important diameter of mitral valve, because the mitral leaflets work in an anterior-posterior plane. The folding of the mitral leaflets depends on this diameter and not on the intercommissural diameter (Figure 12). Keep in mind that the TEE intraoperative measurement of the mitral annulus tends to underestimate it, due to intraoperative hypovolemic status and reduced overload.
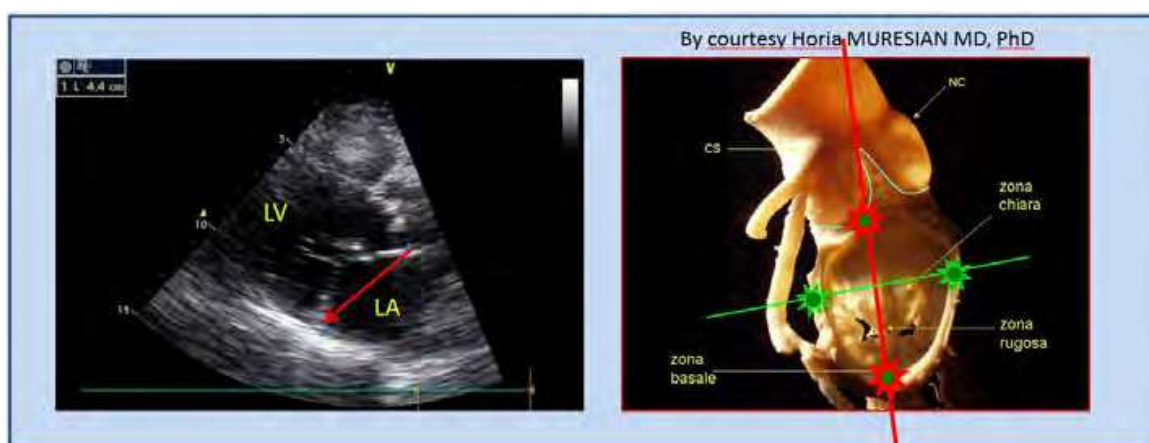

Fig. 12. Correct measurement of the mitral valve annulus in PSLAX view. This diameter corresponds to the septo-marginal diameter of the valve (red diameter on the anatomical photo). The intercommissural diameter (the green diameter in the photo) has to be avoided in the algorithm of decision for surgical planning.

The left ventricular dimensions (as EDØ and EDVolume) and function (LVEF) completes the diagnostic echo algorithm. The severity of mitral insufficiency is mainly quantitatively assessed by calculating the regurgitating volume using the PISA method (proximal isovelocity surface area) and vena contracta. Naturally, all other cardiac structures are carefully described, focusing on associated valvular lesions, mainly on the tricuspide valve. A special attention is paid to the left atrial volume, which may predict atrial fibrillation when measuring around 100ml as volume, or 50mm in diameter (parasternal long axis view). The preoperative assessment should also be focused to identify the patients at high risk to develop postoperative systolic anterior motion: hypertrophic interventricular septum, small left ventricular cavity, hyper dynamic left ventricle (see also 2.6.1 Prepump examination).

The final report, using the Prolapsing Score and the structured anatomical analysis focused on mitral geometry, allows the surgeon to be aware of the complexity of the lesions and to develop a tailored surgical strategy of repair. In general, the surgical strategy aims to correct mitral regurgitation with a single orifice (achieving a coaptation length of at least 6mm) and, whenever possible, to rebuild the triangle of coaptation by using the PTFE GoreTex chordae and annuloplasty.

The transthoracic echocardiography is almost always sufficient to select the patient candidate to mitral valve repair or replacement. The preoperative transesophageal exam serves to refine the diagnosis, mainly in terms of pseudo-commissures, commissural prolapse, ruptured chordae etc. It is mandatory and the only tool used to assess the outcome of surgery in postoperative period. The transesophageal three-dimensional echocardiography is the best tool in assessing the commissural lesions pre and postoperatively. Thus, the echocardiography is an essential tool in the assessment of mechanism of mitral regurgitation and in choosing the right timing and the proper planning for surgical repair. The surgical strategy is tailored by the prolapsing score and the structural echocardiographic algorithm. The successful repair of mitral valve requires a skilled team: an expert surgeon in valve repair and a dedicated echocardiographer.

2.5 Rebuilding the geometry of the mitral valve: Triangle of coaptation and coaptation length

Generally, the main target of the mitral valve repair is to achieve a minimum of 6mm of coaptation length. Initially, although not specified, this measure referred to the medial corresponding scallops A_2-P_2. As said before, the triangle of coaptation resembles an asymmetrical tent, meaning that the coaptation length varies among different regions of the valve. This fact was intuitive until recently, when studies were available in regard to the definition of the normal values of the coaptation for each valve region. Once three-dimensional echocardiography became available, this type of analysis was possible exclusively on an automatic base.

A recent study has defined the normal values of the coaptation length; these results indicated that the normal coaptation length in zone 1° (corresponding to the scallops A_1/P_1) is about 3.5mm; in zone 2° (scallops A_2/P_2) the coaptation length is round 6.2mm and finally in zone 3° (scallops A_3/P_3) the coaptation length seems to be slightly inferior to zone 1°, around 3.2mm. The authors also indicated that the contribution at coaptation of the anterior and posterior leaflets is not symmetrical. The anterior leaflet seems to have a major involvement compared to the posterior one in all the regions of the valve. This underlines the importance of the functional reserve of the anterior leaflet (Gogoladze, 2011).

Another recent study has proposed a new measure for the coaptation length, namely the coaptation length index, which represents the ratio between the coaptation length and the end-systolic annular septal-lateral diameter (Shudo, 2010). Lately, echocardiographic indexation of all measures (generally to the BSA), has gained much consideration. From this perspective, the new index looks promising but needs further investigation in order to establish its real practical value.

2.6 Evaluation of mitral regurgitation

Doppler echocardiography is the most common technique used for detection and evaluation of severity of valvular regurgitation. Several indexes have been used to assess the severity of regurgitation. The following paragraphs will make a brief description of the main indexes used in clinical practice, with their advantages and limitations. Surgery is addressed to patients with severe mitral degenerative regurgitation, and the quantification of the mitral insufficiency is a crucial point in the algorithm of decision. In the case of moderate mitral insufficiency, the surgery is considered only in patients with ischemic mitral regurgitation.

2.6.1 Proximal isovelocity surface area (PISA) or flow convergence

In most patients, PISA was the method of choice for the quantification of mitral regurgitation. As already extensively described, the PISA method is derived from the hydrodynamic principle stating that, as blood approaches a regurgitant orifice, its velocity increases, forming concentric roughly hemispheric shells of increasing velocity and decreasing surface area.

Colour flow mapping offers the ability to visualise one of these hemispheres that corresponds to the Nyquist limit of the instrument. If a Nyquist limit can be chosen at which the flow convergence becomes hemispheric in shape, the flow rate through the regurgitant orifice (ml/s) may be calculated as the product of the surface area of the hemisphere and the aliasing velocity. Assuming that the maximal PISA radius occurs at the time of peak regurgitant flow and peak regurgitant velocity, the maximal EROA is derived. The regurgitant volume can be estimated as EROA multiplied by the velocity time integral of the regurgitant jet. Since the PISA calculation provides an instantaneous peak flow rate, EROA by this approach is the maximal EROA and may be slightly larger than EROA calculated by other methods (Bargiggia, 1991).

As indicated by the guidelines of evaluation of valve regurgitation, the measurement of PISA by Colour Flow Mapping was done by adjustment of the aliasing velocity until a well-defined hemisphere was apparent. This was generally done by shifting the baseline towards the direction of flow, by lowering the Nyquist limit, or both. This has been shown to improve the reliability of the measurement (Zoghbi, 2003).

Despite the fact that it became the preferred method for evaluation of mitral regurgitation, the PISA method is far from being perfect. As with any other technique, limitations exist, e.g.: it is more accurate for central jets than for eccentric jets and for regurgitation with a circular orifice. If the image resolution allows a good visualisation of the flow convergence, and a Nyquist limit can be chosen in order to obtain a hemispheric shape of the convergence, it is easy to identify the aliasing line of the hemisphere. However, it can be difficult to judge the precise location of the orifice and the flow convergence shape. Any error introduced is then squared, which can markedly affect the resulting flow rate and EROA. Attention should be paid to remain as parallel as possible with the Doppler beam. In every day practice, the main error in grading the mitral insufficiency occurs with the eccentric jets. Fig 13 (A,B).

Fig. 13. (A,B). Simultaneous transthoracic PSLAX view and apical three chamber view showing an eccentric regurgitant jet in anterior mitral prolapse.

2.6.2 Color flow mapping

Mitral regurgitation has been most frequently evaluated through the Colour Doppler method. As all the guidelines use echocardiographic criteria to indicate surgery in valvular patients, the echocardiographer must be aware of the drawbacks of the echocardiographic criteria used to send the patients in the operating room.

For example, the maximal jet area correlates well with the semi quantitative angiographic grade of severity. However, only limited correlation is observed with quantitative measures of regurgitant volume and fraction. In addition, maximal jet area is not predictive of hemodynamic abnormalities, such as an elevated pulmonary capillary wedge pressure or reduced forward stroke volume. The regurgitant jet geometry, the physiologic variability, and the instrument settings are presumably some of the factors that may explain this reduced correlation with angiography.

Given the three-dimensional shape of the regurgitant flow, in all scanning sections, the regurgitant jet area will depend on the geometry and direction of the jet. Colour flow Doppler mapping of free regurgitant jets that are unbounded by surrounding structures may lead to overestimation of severity due to entrainment of adjacent fluid by the high-velocity jet. In contrast, the area of an eccentric jet is only 40% of the area of a free jet with the same regurgitant fraction. Eccentric jets are influenced by adjacent constraining surfaces, so that area measurements correlate poorly with regurgitant volume. It is also important to remember that the colour flow map of a regurgitant jet represents the spatial distribution of velocities and is not a direct measure of volume flow rate. Although colour Doppler jet area increases with regurgitant volume, this relationship is not linear because it is highly influenced by driving pressure, compliance of the receiving chamber, and the size and shape of the regurgitant orifice (Otto, 2002).

2.6.3 Vena contracta

It is one of the preferred echocardiographic indexes for its efficacy and its simplicity. The vena contracta is the narrowest portion of a jet that occurs at or just downstream from the orifice (Baumgartner, 1991). It is characterized by high velocity, laminar flow and is slightly smaller than the anatomic regurgitation orifice due to boundary effects.

The cross-sectional area of the vena contracta represents a measure of the effective regurgitant orifice area (EROA), which is the narrowest area of the actual flow. The size of the vena contracta is independent of the flow rate and driving pressure for a fixed orifice. However, if the regurgitant orifice is dynamic, the vena contracta may change with hemodynamics or during the cardiac cycle. Comprised of high velocities, the vena contracta is considerably less sensitive to technical factors such as PRF compared to the jet in the receiving chamber. To specifically image the vena contracta, it is often necessary to angulate the transducer out of the normal echocardiographic imaging planes, such that the area of proximal flow acceleration, the vena contracta, and the downstream expansion of the jet can be distinguished. It is preferable to use a zoom mode to optimize visualization of the vena contracta and facilitate its measurement. The Colour flow sector should also be as narrow as possible, with the minimal depth, so as to maximize lateral and temporal resolution.

Because of the small values of the width of the vena contracta (usually <1cm), small errors in its measurement may lead to a large percentage error and misclassification of the severity of regurgitation. Therefore, it is very important to acquire accurate primary data and measurement (Zoghbi, 2003).

The vena contracta method for assessing mitral regurgitation by colour Doppler echocardiography overestimates true mitral regurgitant orifice, it is markedly influenced by flow rate and the ultrasound system that is used. However, a diameter of a vena contracta over 8mm has a very good sensitivity and specificity for discriminating severe from non-severe mitral regurgitation (Zoghbi, 2003). The estimation of the diameter of the vena contracta is considered to have a good reproducibility of 10-15% (Margulescu, Brickner).

2.7 Intraoperative assessment of mitral regurgitation

The intraoperative echocardiography may be performed using the transesophageal or sometimes the epicardial method. In our practice we used almost exclusively the former. The epicardial approach may be used in paediatric cardiac surgery, when the adult TEE probe is too large and the paediatric TEE probe is not available.

2.7.1 Prepump examination

During the intraoperative transesophageal echocardiography, the evaluation of the severity of mitral regurgitation should be performed following the same steps and methodology as in all other echocardiographic examinations. It was observed that the degree of mitral regurgitation assessed by TEE in the operating theatre appears less severe in respect to the transthoracic exam. The team (anaesthesiologist, cardiologist and surgeon) has to be aware of the complexity of the changes induced by the general anaesthesia and the opening of the thorax and pericardial cavity. It also needs to be taken into account the loading condition of the heart, in term of the preload and afterload. Therefore, prepump TEE examination should not be used to assess the severity of the regurgitation, but mainly to assess its mechanism and the valve anatomy.

Important items on the preoperative echocardiographic check-list are the valve anatomy and the analysis of the coaptation: Does it exists? Is it absent or only reduced? In what valve sector is the coaptation missing or reduced? Why? Is there a prolapsed valve or flail? How much does each segment prolapse in regard to the mitral annular plane?

The answer to these final questions is essential for the surgeon who needs to perform a mitral valve repair. The correct evaluation of the entity of prolapse in tele-systole and in all segments may assist the surgeon in the decision of the length and position of the Gore-Tex neochordae they might need to use in order to correct the prolapse. In the operating theatre, the echocardiographer should measure the distance between the free border of the prolapsing scallop and the mitral annulus plane or the free border of the non-prolapsing scallop (Fig 14). This may be of great importance in measuring the length of the artificial chordae, but the experience of the surgeon remains the most important factor that will determine the final result.
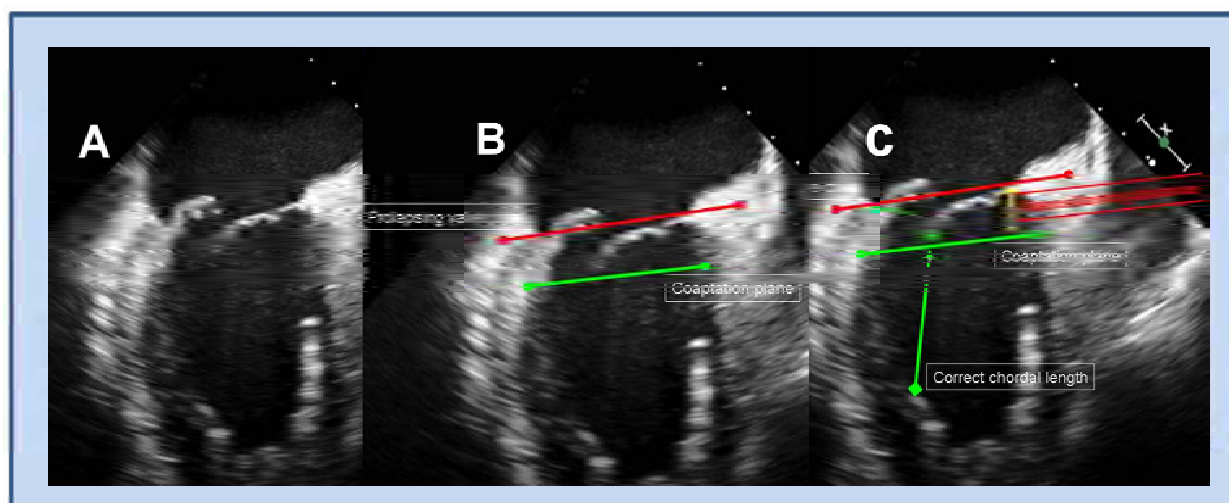
Fig. 14. (A,B,C). Intraoperative echocardiographic measurements showing prolapsed with flail of the posterior mitral leaflet (14A). The red line indicates the prolapsing plane; the green indicates the targeted coaptation plane (14B). Measuring the distance between the targeted position of the P2 scallop plane and the tip of the papillary muscle helps the surgeon decide the length of the neochordae (14C).

The preoperative echocardiographic examination must be performed under normal or near normal loading conditions. If hypovolemia were present, not only the severity of mitral regurgitation might be underestimated, as stated before, but also a false prolapse of various segments might erroneously be described. Often, a false prolapse may be encountered at the level of the anterior mitral leaflet (scallops A_2 and A_3) when, in fact, the lesion, usually flail, eversion or extreme prolapse, is typically located on the posterior leaflet. In order to avoid this risk, the echocardiographer should bear in mind the diagnosis of the preoperative transthoracic examination and carefully compare it to his own findings. One should not forget that most of the times the transesophageal examination confirms most of the elements from the transthoracic exam. By using the new harmonics echocardiographic machines, approximately 2/3 of the lesions found in transthoracic examination will be confirmed by TEE exam. The mitral annulus might also be underestimated when hypovolemia is present. This is the case in the operating room when the prepump exam is performed. In our experience the transthoracic measurement of the mitral annulus should always be taken into account when the surgical strategy is discussed with the surgeon.

It is important to remember that mitral regurgitation is dynamic and is affected by loading conditions. Reduction of afterload or intravascular volume at the time of the operation may reduce the true severity of the regurgitation. When mitral regurgitation is less significant than expected, the intravascular blood volume should be expanded and systemic vascular resistance should transiently be increased, by using repeated boluses of IV phenylephrine. The velocity of mitral regurgitation, and therefore display of its jet by Colour Doppler, depends on the pressure difference between the left atrium and left ventricle, which is higher in the presence of hypertension. The size of the jet in the left atrium is also very sensitive to changes in colour gain (directly proportional) and pulse repetition frequency (PRF) (inversely proportional). In any case, remember that the true assessment of the degree of mitral regurgitation is done by transthoracic exam.

The use of three-dimensional echocardiography for the evaluation of the mitral valve disease is rapidly evolving, especially in conjunction with the transesophageal echocardiography. One of the explanations of this extensive use is that the mitral valve rends itself to detailed 3D imaging from the left atrial perspective, as viewed by the surgeon (Shah & Raney, 2011). In our experience, three-dimensional echocardiography allows a reliable 'volumetric' evaluation with an excellent perspective on the whole mitral valve complex. Moreover, it permits an accurate (even more than the 2D echo) localisation of the various lesions. Still, the resolution and quality of the 3D images do not match those of the 2D echo.

2.7.2 Prepump examination: Risk of systolic anterior motion

Another important mission of the prepump examination is the identification of patients at risk for systolic anterior motion (SAM) of the anterior leaflet and subsequent functional mitral regurgitation. Fig 15 (A,B,C). The selection of patients at risk for SAM is already possible with the transthoracic approach. These patients usually have a small and /or hyper dynamic left ventricle, hypertrophy of the inter-ventricular septum, large posterior mitral leaflet, small mitral annulus and "narrow" LVOT (revealed by a reduced distance between the inter-ventricular septum and the coaptation line). One elegant study has indicated which could be the two echocardiographic indexes that may identify the patients at risk for SAM after surgery: the first is the ratio between the anterior and the posterior mitral leaflet (AL/PL) inferior to 1.3; the second is the distance from the coaptation line to the inter-ventricular septum (C-Sept) equal or inferior to 2.5cm. (Maslow, 1999).
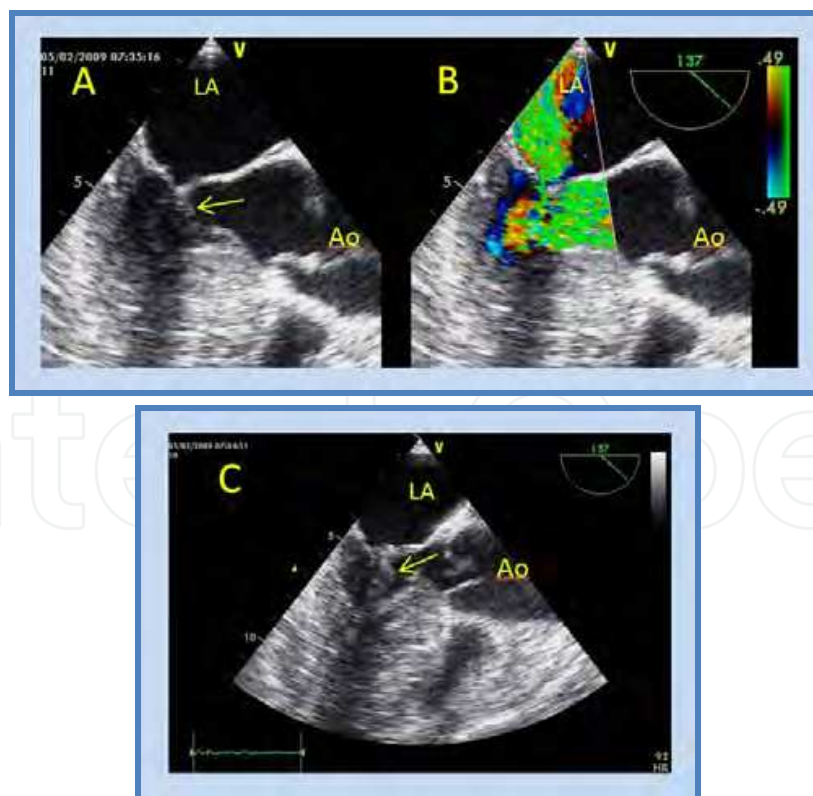

Fig. 15. (A,B,C). Postoperative transesophageal 2D exam showing the presence of SAM at the level of the anterior mitral leaflet (15 A, C, arrow) and the presence of severe mitral regurgitation (15 B).

For this category of patients, in order to avoid SAM, the surgeon must be informed and aware of each element stated above (e.g. hypertrophic septum associated or not with large posterior leaflet and / or small mitral annulus etc) and the surgical approach should be tailored accordingly. If SAM should appear, its management consists of volume expansion, withdrawal of positive inotropic agents and sometimes use of short acting betablockers like esmolol. However, there is one type of SAM which is irreversible, having a 'surgical mechanism': in case of large P_2 quadrangular resection without sliding plasty. This situation calls for a second run pump, to perform the sliding. This is particularly why the echocardiographer has to be aware of the surgical technique in the given case.

Left ventricular outflow tract obstruction caused by SAM has been described as a complication of mitral repair. It has generally been attributed to the implantation of an annuloplasty ring or to various surgical techniques that alter the normal systolic narrowing of the antero-posterior diameter of the mitral annulus, or due to the displacing the mitral coaptation level towards the interventricular septum. The period immediately after cardiopulmonary bypass is the most crucial time for the development of SAM. This is due to reduced peripheral vascular resistance associated with hypovolemia and hypotension, which have a particular impact when the left ventricular cavity is small. This adverse effect is determined by a hyper dynamic state (increased kinetic energy of blood flow induced by catecholamines), associated with left ventricular hypovolemia.

Mild degrees of LVOT dynamic obstruction after mitral valve repair often respond favourably to conservative treatment, as stated before: discontinuing inotropic agents in order to decrease contractility and heart rate, volume loading to increase preload, and augmenting afterload with pure α-agonists (such as phenylephrine) (Benea, 2005). If these measures prove inadequate, reoperation upon the mitral valve—including the performance of a sliding plasty or folding reconstruction that reduces the antero-posterior height of the posterior leaflet, the implantation of an annuloplasty ring of a larger size or the removal of the annuloplasty ring—may prove necessary. In refractory cases, even prosthetic mitral valve replacement has been reported.

2.7.3 Tailored surgical strategy

Based on the Prolapsed Score and on the structured echocardiographic analyses of the mitral valve, the surgical strategy has to be personalised. In order to choose the right surgical approach and to be able to interact with the surgeon, the echocardiographer needs to know the surgical techniques suitable for the given case. Building a trust-based relationship between the surgeon and the echocardiographer is crucial for the surgical result. Each case has to be discussed by the surgical team prior to the operation.

This approach allows the surgeon to make two types of surgical planning, both necessary: one is the planning with 'the closed atrium', meaning the mental planning based on the echocardiographic findings. The other one is performed after the left atrium was opened and the valve is directly inspected. In our experience the two coincide in most of the cases, due to standardization of the echo exam, to the presence of the echocardiographer in the operating room and due to the dialogue with the surgical team.

Recently, the importance of performing the mitral valve repair using the most 'physiological' approach has become crucial. Single valve orifice but also posterior mitral

leaflet mobility became cornerstone principles that guide the mitral repair in our centre. The classical techniques of repair included the quadrangular resection of the posterior mitral leaflet and ring annuloplasty, which inevitably led to a rigid posterior leaflet (Verma, NYJM 2009). Lately, many surgeons have chosen to perform the triangular resection (instead of quadrangular) in order to guarantee a higher mobility of the posterior leaflet and thus an increased anatomical and functional leaflet reserve, convinced that this will subsequently achieve a better and longer lasting coaptation.

In conclusion, we may assume that the importance of the preoperative transesophageal examination is given by the accuracy in identifying the mechanism of mitral regurgitation and valve anatomy (flail, prolapse, loss of coaptation, perforation and so on), and by describing the geometry of the mitral apparatus. There is a close correlation between valve geometry and function. The Colour Doppler mapping might underestimate the entity of the regurgitant flow; thus, the prepump echocardiographic evaluation needs to rely more on valve geometry and regurgitant mechanism, and less on the Colour flow Doppler.

2.7.4 Postpump examination

In most cases, with an experienced surgeon, mitral valve repair leads to a competent mitral valve with mild or no residual mitral regurgitation. However, there are potential complications of mitral valve repair that are readily recognized by postpump intraoperative echocardiography. Many of these complications may not be apparent clinically or may take longer to accurately diagnose without echocardiography. If left untreated, these complications may interfere with the long-term success of the procedure and require early re-operation (Otto, 2003). In fact, the trust-based relationship between the echocardiographer and the surgeon is tested when a second run pump is needed. In case of debatable "moderate" mitral regurgitation, the team has to focus on the mitral coaptation (and geometry) rather than on the Colour Doppler analyses. Remember to avoid the hypovolemic status.

Transesophageal echocardiography is practically the only method used immediately after weaning from the cardiopulmonary bypass in order to assess the result of the mitral repair. It must rapidly answer some essential questions about the repaired valve. The most important task of the transesophageal echocardiography is to analyze the postoperative mitral valve geometry and function, focusing on leaflet coaptation.

 It may occur that immediately after weaning the patient off the cardiopulmonary by-pass, the echocardiographer declares the success of the repair after analyzing only some of the available views, usually the mid-esophageal 0° or distal-esophageal 135°, where only scallops A_2 and P_2 are evaluated. The postoperative transesophageal examination has to be performed using the same algorithm that was used during the preoperative evaluation. One has to bear in mind that the triangle of coaptation remains the goal of a typically functioning reconstructed valve. It should be taken into consideration that the reconstruction of the coaptation triangle is not always possible. When present, the echocardiographer has to search for it in all the segments of the valve: from the anterior commissure and corresponding scallops A_1/P_1, P_2/A_2 and of course the medial scallops A_3/P_3 and the posterior commissure.

After surgical repair, the essential issue is that the coaptation point must be dragged within the left ventricle, underneath the mitral annular plane (Figure 15). In the normal mitral valve, this type of coaptation expresses the physiological equilibrium between the collagen and elastic fibres, which confers the right balance between the elasticity and resistance of the valve. Same should be true about the repaired mitral valves, which will most probably remain elastic and long-lasting when their geometry satisfies the mentioned criteria.

Fig. 16. TEE postoperative aspect of complex mitral valve repair. Notice the rebuilding of the triangle of coaptation (arrows) and the classical 'smile' aspect of the mitral valve on the intraoperative photo (middle). LA = left atrium.

Even if already stated, it should be underlined that the triangle of coaptation and the coaptation length need to be carefully assessed in all the regions of the mitral valve before expressing the final judgement on the real immediate outcome of the repair. Keep in mind possible traps. The surgeon's "hurry" to know the results of repair; do not express any conclusions before appropriate ventricular loading conditions are achieved. Do not start the post-operative assessment by Colour Doppler. The most important thing is to assess the length of coaptation and valve geometry.

In order to correctly assess the valve geometry, the loading conditions should be optimal: hypovolemia should be avoided as it may underestimate a potential residual mitral regurgitation or label as 'prolapsing' an otherwise normal valve leaflet. We have stated about the prepump exam that the importance of the Doppler techniques for the evaluation of the severity of the mitral regurgitation was lower than the importance of the geometrical analysis. This does not mean that Color Doppler mapping shouldn't be performed but it should integrate the geometrical analysis and not replace it. These details are essential to the surgeon. The outcome depends on that. This statement is also true about the post-pump examination. Geometry is more important than colour (meaning Colour Doppler mapping).

Whenever the result of the repair is suboptimal and there is residual mitral regurgitation, the echocardiographer must be able to rapidly identify the true mechanism of mitral regurgitation. The problem may vary from residual prolapse or restriction of one or more valve sectors - presumably due to incorrect neo-cordal length, residual marginal prolapse if left untreated, oversized annuloplasty ring, persistence of pseudo-commissures, etc. In these cases further surgery with a second run pump might be needed. Rarely, the mitral valve problem may be a consequence of a ventricular dysfunction when a post-pump contractility

issue may appear. This should also be clearly pointed out by the post-pump echocardiographic examination. In this case, further surgery for the mitral valve might not be needed, but only ventricular assistance.

The main problem with residual mitral regurgitation arises in patients with moderate insufficiency. In loose teams, the surgeon tends to underestimates the importance of the mitral regurgitation. Because the echocardiography is a semi quantitative method, in every day practice the surgeon will go easier to the second run pump only if the echocardiographer was able to 100% accurately identify the preoperative lesions, compared to the intraoperative findings. Therefore, an excellent preoperative assessment will bond the team, creating a trustful relationship between the surgeon and the echocardiographer.

The evaluation of the outcome after mitral repair has been done mainly using the Colour Doppler mapping. When the residual regurgitation is absent or of mild degree, the result is judged as adequate. Generally, superior degrees of residual regurgitation, naturally correlated with the coaptation and geometrical analysis, indicate the need for a second pump run. In selected cases (e.g. old patients or significant comorbidities), moderate or more than moderate residual regurgitation might be accepted when the risk of a second pump run to correct the valvular problem exceeds the potential benefit for the patient.

The annuloplasty ring is used in almost all operated patients. From an echocardiographic technical perspective this might determine difficulties in the postoperative evaluation of the repaired mitral valve when performing the distal esophageal long axis views. Usually, the presence of the annuloplasty ring might 'hide' the mitral valve leaflets by posterior shadowing immediately after surgery. To overcome this problem a valid solution could be the evaluation from the deep transgastric short-axis and long axis views.

3. Conclusion

The standardization of the preoperative, intraoperative and postoperative echocardiographic examination is crucial for the skilled dialogue with the surgical team and for the results. As the surgery of degenerative mitral insufficiency is somehow standardised, echocardiography should also be as standardised as possible. The use of a specific pattern of lesion confers better and tailored surgical planning, adapted to each given case. Use of different types of patterns such as mitral valve flail, undulating valve or marginal prolapse facilitates the dialog with the surgeon.

Alongside specific patterns of lesions, a crucial point in surgical repair is the evaluation of the mitral geometry. Apart from the three dimensional echo, the main tool in assessing the mitral valve geometry by 2 D echocardiography, is the coaptation triangle.

The echocardiographer must consider the mitral valve as an eight-element anatomical structure, and separately assess each segment. The preoperative exam has to be done based on a structural echocardiographic algorithm and finally expressed as a prolapsing score.

By using this strategy, the mitral valve repair is feasible, with excellent results.

In dedicated centres, the mitral valve repair for degenerative disease is possible with more than 95% rate of success. The use of the triangle of coaptation, coaptation length and

coaptation height as geometric echocardiographic concepts aiming to restore the mitral valve shape and coaptation, is a crucial point to improve the surgical planning and results.

4. Acknowledgements

## 5. References

Bargiggia, GS.; Tronconi, L.; Sahn, DJ.; Recusani, F.; Raisaro, A. & De Servi, S. A new method for quantitation of mitral regurgitation based on color flow Doppler imaging of flow convergence proximal to regurgitant orifice. *Circulation.* Vol 84. No 4 (October 1991); pp. 1481-9, ISSN 1524-4539.

Baumgartner, H.; Schima, H. & Kuhn, P.; Value and limitations of proximal jet dimensions for the quantitation of valvular regurgitation: an in vitro study using Doppler flow imaging. *Journal of the American Society of Echocardiography*, Vol 4, (Jan-Feb 1991), pp. 57-66

Benea, D.; Cerin, G.; Diena, M. & Tesler, UF. Pharmacologic Resolution of Functional Out flow Tract Obstruction after Mitral Valve Repair. *Texas Heart Institute Journal*, Vol 32, No 4. (October 2005), pp. 563–566, ISSN 0730-2347

Bonow, R. (2011). Valvular heart disease: Patient needs and practice guidelines. *Aswan Heart Center Science & Practice Series*, Vol 1 (April 2011), pp. 20-29, ISSN 2220-2730

Brickner ME, Willet DL, Irani WN-Assesement of Mitral RegurgitationSeverity by Doppler Color Flow Mapping of the Vena Contracta. Circulation 1997;95:636-642

G Cerin, M Diena, G Lanzillo, S Casalino, A Zito, D Benea, U Filippo Tesler. Degenerative mitral regurgitation - surgical and echocardiographic consideration for repair. Romanian Journal of Cardiovascular Surgery, 5 (3), pp. 131-39, 2006.

Cerin, G.; Popa, BA.; Benea, D.; Lanzillo, G.; Karazanishvili, L.; Casati, V.; Popa, A.; Novelli, E.; Renzi, L. & Diena, M. The triangle of coaptation: a new concept to enhance mitral valve repair through reshaping the native geometry. *World Congress of Cardiology Scientific Sessions,* Beijing, China (June 2010)

Gogoladze, G.; Dellis, SL.; Donnino, R.; Ribakove, G.; Greenhouse, DG.; Galloway, A. & Grossi E. (April 2011). Analysis of the mitral coaptation zone in normal and functional regurgitant valves. *The Annals of Thoracic Surgery*, Vol 89, Issue 4, pp. 1158-1161

Hall SA, Brickner ME, Willett DL, Irani WN, Afridi I, Grayburn PA – Assessment of Mitral Regurgitation Severity by Doppler Color Flow Mapping of the Vena Contracta. Circulation. 1997; 95:636-642).

Maslow, DA.; Regan, MM.; Haering, MJ.; Johnson, RG. & Levine RA(1999). Echocardiographic predictors of left ventricular outflow tract obstruction and systolic anterior motion of the mitral valve after mitral valve reconstruction for myxomatous valve disease. *Journal of the American College of Cardiology*, Vol 37, No 7, (December 1999), pp. 2096-2104, ISSN 0735-1097

Mirabel, M; Iung,B, Baron, G; Messika-Zeitoun, D & Détaint, D. Surgical referral in symptomatic mitral regurgitation: greater compliance with guidelines is needed *European Heart Journal* 2007, 28, 1358-1365

Jean-Louis Vanoverschelde, Eric G. Butchart, Philippe Ravaud and Alec Vahanian. What are the characteristics of patients with severe, symptomatic, mitral regurgitation who are denied surgery? Euro Heart J 2007, 28, 1358-1365

Margulescu, AD; Cinteza, M & Vinereanu, D (2006). Reproducibility in echocardiography:

clinical significance, assessment, and comparison with other imaging methods. *Mædica A Journal of Clinical Medicine*, Vol 1, No 7, (2006), ISSN1841-9038

Otto, C. (2002) *The Practice of Clinical Echocardiography, 2nd Edition,* W. B. Saunders Company, ISBN 0-7216-9204-4, Philadelphia, USA

Shah, PM. & Raney, AA. Impact of 3D echocardiography on mitral valve surgery. *Aswan Heart Center Science & Practice Series*, Vol 1 (April 2011), pp. 36-44, ISSN 2220-2730

Shudo, Y.; Matsue, H.; Toda, K.; Hata, H.; Fujita, S.; Taniguchi, K. & Sawa, Y. A simplified echocardiographic measurements of direct effects of restrictive annuloplasty on mitral valve geometry. *Echocardiography,* Vol 27, No 8, (September 2010), pp. 931-936, ISSN 0742-2822

Tesler, UF.; Cerin, G.; Novelli, E.; Popa, A. & Diena, M. Evolution of surgical techniques for mitral valve repair. *Texas Heart Institute Journal*, Vol 36, No 5. (November 2009), pp. 438-4, ISSN 0730-2347

Subodh Verma, and Thierry G. Mesana, Mitral-Valve Repair for Mitral-Valve Prolapse. N Engl J Med 2009; 361:2261-9.

Zoghbi, A. et al (2003). Recommendations for evaluation of the severity of native valvular regurgitation with two-dimensional and Doppler echocardiography. *Journal of the American Society of Echocardiography.* Vol. 16, No 7, (July 2003), pp. 777-802, ISSN 0894-7317
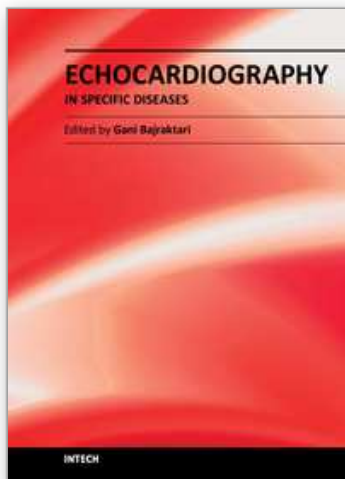
Echocardiography - In Specific Diseases

Edited by Prof. Gani Bajraktari

The book "Echocardiography - In Specific Diseases" brings together contributions from well- known researchers from around the world, some of them specialized in imaging science in their clinical orientation, but also representatives from academic medical centers. Each chapter is structured and written to be accessible to those with a basic knowledge of echocardiography but also to be stimulating and informative to experts and researchers in the field of echocardiography. This book is primarily aimed at cardiology fellows during their basic echocardiography rotation, fellows of internal medicine, radiology and emergency medicine, but also experts in echocardiography. During the past few decades technological advancements in echocardiography have been developing rapidly, leading to improved echocardiographic imaging using new techniques. The authors of this book tried to explain the role of echocardiography in several special pathologies, which the readers may find in different chapters of the book.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Gheorghe Cerin, Bogdan Adrian Popa and Marco Diena (2012). The Degenerative Mitral Valve Regurgitation: From Geometrical Echocardiographic Concepts to Successful Surgical Repair, Echocardiography - In Specific Diseases, Prof. Gani Bajraktari (Ed.), ISBN: 978-953-307-977-6, InTech, Available from: http://www.intechopen.com/books/echocardiography-in-specific-diseases/the-degenerative-mitral-valve-regurgitation-from-geometrical-echocardiographic-concepts-to-successfu

INTECH
open science | open minds