Journal of Clinical and Basic Cardiology

An Independent International Scientific Journal

Journal of Clinical and Basic Cardiology 2002; 5 (2), 139-143

Monitoring of Invasive Procedures - The Role of Echocardiography in Cathlab and Operating Room

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FOCUS ON NEW DEVELOPMENTS IN ECHOCARDIOGRAPHY

Monitoring of Invasive Procedures – The Role of Echocardiography in Cathlab and Operating Room

R. Rosenhek, Th. Binder

Echocardiography is now widely applied during cardiac procedures. It is used for haemodynamic monitoring, guiding and immediate assessment of procedural results as well as detection of complications. The present review article focuses on the role of periprocedural echocardiography in the cathlab and in the operating room. Specific aspects of its role in different settings are discussed. Furthermore, a description of the value of echocardiography in newer procedures such as ASD closure, septal ablation or port access surgery is presented. *J Clin Basic Cardiol 2002; 5: 139–43.*

Key words: echocardiography, intraoperative echocardiography, periprocedural echocardiography

Echocardiography is currently an integral part of many cardiovascular and surgical procedures. Its impact on management in interventional cardiology and surgery are well established [1]. Transesophageal echocardiography (TEE) is the method of choice in patients undergoing surgery. Recently intracardiac echocardiography (ICE) has been introduced. This technique could be an alternative to TEE in several settings. TEE provides high-resolution images of cardiac structures and allows visualization of flow abnormalities. It does not interfere with the catheter procedure or with the surgical field. Specifically, it allows haemodynamic monitoring, guiding and immediate assessment of procedural results as well as the detection of complications.

The indications for echocardiography in the cathlab include percutaneous atrial septal defect (ASD) and patent foramen ovale (PFO) closure, valvuloplasty, septal ablation in hypertrophic obstructive cardiomyopathy, lead placement for biventricular pacemakers and the detection of complications during coronary intervention. Indications in cardiac surgery include valve replacement, valve repair, coronary artery bypass graft surgery, operations on the aorta, correction of congenital malformations, cardiac tumours, myectomy and placement of assist devices. Echocardiography is also used in noncardiac surgery to monitor for ischaemia and volume status.

The present article will focus on the role of periprocedural echocardiography in the cathlab and in the operating room and will also discuss its role in newer procedures such as ASD closure, septal ablation and port access surgery.

Practical Aspects

TEE is safe when properly conducted. Serious and even fatal complications are very rare. The major inconvenience of TEE during cathlab procedures is additional patient discomfort and the need for general anaesthesia. Recently ICE has emerged as a new method for the visualization of intracardiac structures. ICE represents a more invasive approach than TEE and requires a sterile field. Transthoracic echocardiography (TTE) cannot be used in the operating room. Alternatively epicardial echocardiography has been applied. However, this technique has not gained wide acceptance. Even though image quality of TTE is inferior to TEE, it is associated with less patient discomfort and does not require anaesthesia.

Cardiac Surgery

Procedure, Technique and Operative Planning

A baseline or so-called prepump study allows monitoring of cardiac function under general anaesthesia and assessment of the underlying pathology. In addition, evaluation of the thoracic aorta is useful for the selection of the cannulation sites. Since cauterization and mechanical manipulation of the heart by the surgeon impairs image quality it is advisable to perform the baseline examination prior to the skin incision. The prepump examination allows the anaesthesiologist and the cardiac surgeon to resolve potential uncertainties related to the surgical procedure.

In addition, intraoperative TEE (IOTEE) can be helpful in quantifying the severity of valvular lesions that might coexist and, thus, aid in the decision whether it is necessary to perform surgery on additional valves.

Intraoperative TEE can provide new information, particularly when no preoperative TEE was performed. This may be the case in patients in whom transthoracic echocardiography, angiography and clinical assessment were felt to be sufficient to determine the need for valve replacement.

There are numerous reports of incidental findings such as masses, thrombi, patent foramen ovale (PFO), atrial septal defects and membranous subaortic stenosis found during heart surgery [2–4]. The detection of these abnormalities is of importance since surgical management may be required (*ie* PFO closure, removal of a thrombus or mass).

The TEE probe is introduced shortly after general anaesthesia following tracheal intubation. The probe is left in place while the patient is in cardiac arrest and on cardiopulmonary bypass. When weaning from the pump and rewarming, IOTEE serves as a monitor of cardiac function and provides information on regional and global function of the ventricle [5]. A postpump examination provides information on the surgical result such as the function of the prosthetic valve(s), the result of valve repair and the repair of congenital defects [6].

In addition, surgical complications, such as left ventricular outflow tract obstruction [7], pericardial or mediastinal haematoma or ischaemia can be detected. Based on these findings, intraoperative TEE permits immediate assessment of the surgical result and, thus, facilitates decision-making

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whether immediate correction of the detected problem is required.

Mitral Valve Repair Surgery
Even though the indication for valve surgery is usually established prior to surgery IOTEE plays an important role in planning of the procedure. Transesophageal echocardiography allows assessment and description of the morphology, location, aetiology, mechanism, and severity of the valvular lesion. These factors are of particular importance in patients with mitral regurgitation where the decision must be made if valve repair opposed to replacement is feasible [8] and which operative technique should be applied.

TEE is superior to transthoracic echocardiography for the quantification of mitral regurgitation. However, it must be considered that altered haemodynamic status during operation can lead to over- or underestimation of mitral regurgitation severity. Two-dimensional imaging and color Doppler allows assessment of the mechanism of mitral regurgitation such as mitral valve prolapse, chordal or papillary muscle rupture, restricted leaflets, leaflet perforation or annular dilatation (Figure 1). IOTEE permits inspection of the entire mitral valve apparatus including the anterior and posterior leaflet, its scallops and the commissures. Thus, the defect can be classified with respect to its extent and location (ie Carpentier classification). IOTEE also provides important information on valve morphology such as the extent of valvular and annular calcification and thickening. Based on these findings the operative strategy (repair vs. replacement) and technique (ie annuloplasty, quadrangular resection and sliding plasty or chordal transfer) can be determined. IOTEE is used for measurements of the annulus and the anterior leaflet, which is helpful in sizing of the annuloplasty ring. Finally TEE allows evaluation of the immediate operative result and assessment of residual regurgitation and left ventricular outflow tract (LVOT) obstruction, which may occur after mitral valve reconstruction when the anterior valve leaflet protrudes into the LVOT. With the aid of Doppler techniques it is further possible to determine the severity of the obstruction and, thus, determine the need for reoperation.

IOTEE has significantly improved the operative outcome and survival in patients undergoing mitral valve surgery. Nevertheless significant operator experience and a thorough understanding of mitral valve anatomy and pathology are required for optimal results.

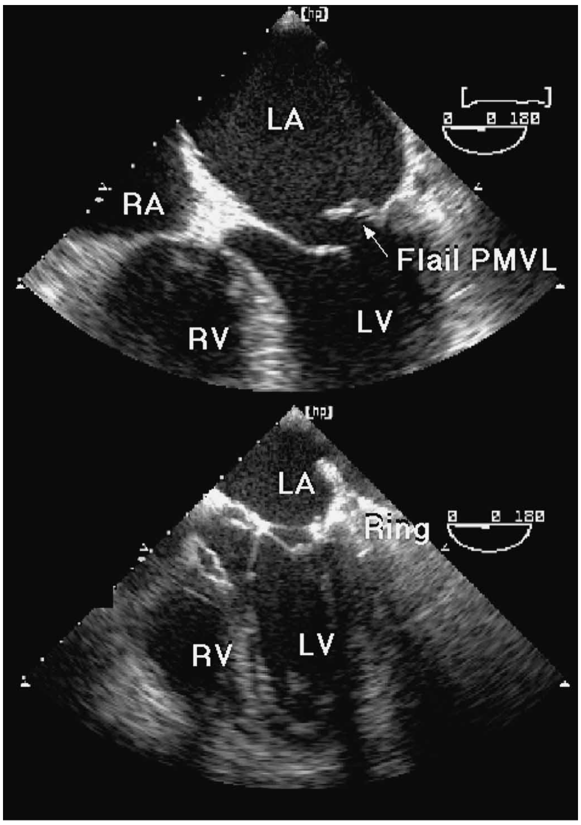

Figure 1. Flail posterior mitral valve leaflet (PMVL) as mechanism of mitral regurgitation (top panel). Immediate postoperative result after mitral valve reconstruction with annuloplasty ring implantation (lower panel). LA = left atrium, LV = left ventricle, RV = right ventricle

Valve Replacement
Measurements of the aortic annulus and the left ventricular outflow tract diameter with IOTEE allows optimal sizing of aortic valve prostheses [9, 10]. If a Ross procedure is attempted, TEE allows assessment of pulmonary valve morphology and function to determine if the valve is suitable as an autograft [11]. IOTEE also permits exact measurements of the aortic and pulmonary annulus, and thus, is able to detect a size mismatch [12].

Paravalvular Regurgitation
Paravalvular leaks are by far the most frequent causes of regurgitation after valve replacement. TEE using color Doppler has a high sensitivity for the detection of paravalvular leaks [13, 14] (Figure 2). Paravalvular regurgitation must be distinguished from normal "functional" regurgitation of mechanical prosthetic valves. Quantification of paravalvular regurgitation is performed using color Doppler under off-pump conditions. The degree of valvular regurgitation may be underestimated by intraoperative transoesophageal echocardiography due to the effects of general anaesthesia and altered loading conditions [8, 9, 15, 16]. Thus, the patient's volume status should be normalized and the peripheral systolic blood pressure and the pulmonary artery systolic pressure must be considered when quantifying mitral and tricuspid regurgitation.

Exact localization of the leak(s) allows the surgeon to rapidly find the defect if correction of the paravalvular regurgitation is necessary [17].

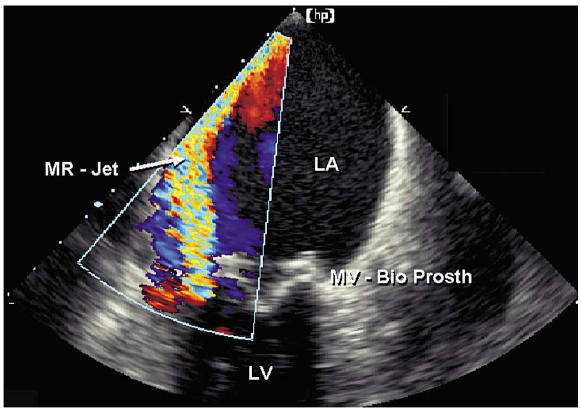

Figure 2. Large paravalvular leak detected by color Doppler echocardiography in a bioprosthetic mitral valve (MV-Bio Prosth). LA = left atrium, LV = left ventricle

Outflow Tract Obstruction
Inappropriate anterior mitral leaflet preservation during mitral valve replacement may cause left ventricular outflow tract (LVOT) obstruction [18]. LVOT obstruction is also related to the strut height and orientation of the prosthesis [19]. Significant outflow tract obstruction can also occur in the presence of hypertrophy and hypovolaemia after aortic valve replacement following aortic stenosis and sudden afterload reduction. Preserved subvalvular structures and mitral valve leaflets after mitral valve replacement can also result in outflow tract obstruction.

TEE allows detailed anatomic imaging of both discrete and complex forms of LVOT obstruction. It is possible to visualize systolic narrowing of the left ventricular outflow tract caused by a bulging septum or an inappropriately aligned strut as well as systolic anterior motion of the preserved anterior mitral leaflet. Doppler techniques provide additional information regarding the site, mechanism, and severity of the obstruction [20]. Color Doppler demonstrates turbulent flow within the LVOT as an indication of elevated flow velocities. CW-Doppler studies using a deep transgastric long axis view (which allows parallel alignment of the Doppler beam to the outflow tract) is performed to determine the pressure gradient across the outflow tract using the Bernoulli equation).

Surgery in Infective Endocarditis
Severe acute endocarditis can be associated with major destruction of the annulus, the presence of abscesses, pseudoaneurysms, valve perforations, periannular distention or even ventricular-aortic disconnection, which can be detected by TEE [21–23].

Furthermore, IOTEE can guide surgical management, which usually requires radical resection of the abscess and inflamed tissues and reconstruction of the affected structures (*ie* intervalvular fibrosa, outflow tract, mitral- or aortic annulus) or even extra-annular implantation of the prosthesis [24–27].

Visualization of the extent of infection using IOTEE is also important to determine the type of prosthesis, which should be used (*ie* homograft with or without aortic root replacement). In addition, IOTEE allows assessment whether repair of the infected valve or prosthesis is feasible [28, 29]. Finally, IOTEE permits immediate assessment of the surgical results and the detection of residual fistulous communications or paravalvular leaks [30].

Minimal Invasive Surgery
The first use of port access surgery in cardiac surgery has been described in 1996. Since the introduction of the closed-chest minimally invasive heart surgery using the Port-Access system a variety of monitoring techniques including fluoroscopy have been described. Several studies have recently shown that IOTEE is superior to fluoroscopy and can now be considered the imaging modality of choice in port access surgery [31]. As the technique of minimally invasive surgery expands into more complex interventions, the importance of IOTEE is expected to increase [32].

IOTEE allows direct visualization of valve structures, the coronary sinus, the right atrium, the superior vena cava, and the thoracic aorta and is, thus, ideal to monitor the procedure. IOTEE is used for correct positioning of the coronary sinus catheter, venous cannula, endopulmonary vent catheter and endoaortic occluder. After balloon inflation, its proper positioning and function during endo-aortic occlusion, sufficient delivery of cardioplegia into the coronary ostia, absence of leakage flow and adequate venting can be assessed. As for conventional cardiac surgery IOTEE is used to assess the operative outcome in a postpump study.

CATHLAB

Complications During Coronary Intervention
If complications of intervention occur in the cathlab, echocardiography is helpful in assisting the diagnosis and management. When a patient develops signs of cardiogenic shock and pericardial tamponade after biopsy or coronary intervention, rapid diagnosis is primordial. Furthermore, left ventricular function and regional wall motion can be rapidly assessed. In most instances and particularly under resuscitation, TTE will be performed. However, elective TEE has also been reported to be of use during complex or high-risk coronary interventions [33].

Transcatheter ASD, PFO and VSD Closure
TEE is crucial for the assessment of the atrial septal defect morphology, its diameter, presence of septal aneurysm and presence of multiple shunts. Careful analysis allows proper patient selection for transcatheter defect closure [34]. During the procedure, TEE is used for the measurement of the stretched diameter (balloon sizing) and the selection of the appropriate occluder size [35]. TEE allows precise guiding, positioning and finally release of the septal occluder (Figure 3). As in the setting of atrial septal defect closure, TEE can also be used as a guidance and monitoring tool for the closure of a persistent foramen ovale. Although transcatheter ventricular septal defect closure (VSD) is performed less frequently, TEE is mandatory for safe closure to assess the morphology, the diameter, the relation of the VSD to the valves and guidance of the procedure [36, 37].

In all of the above procedures TEE allows immediate assessment of the interventional result and of a residual shunt.

Recently, successful transcatheter ASD and PFO closure has been reported with intracardiac echocardiography guidance [38]. ICE is thus a promising alternative to TEE as a monitoring tool for ASD and PFO device closure, since it eliminates the need for general anaesthesia.

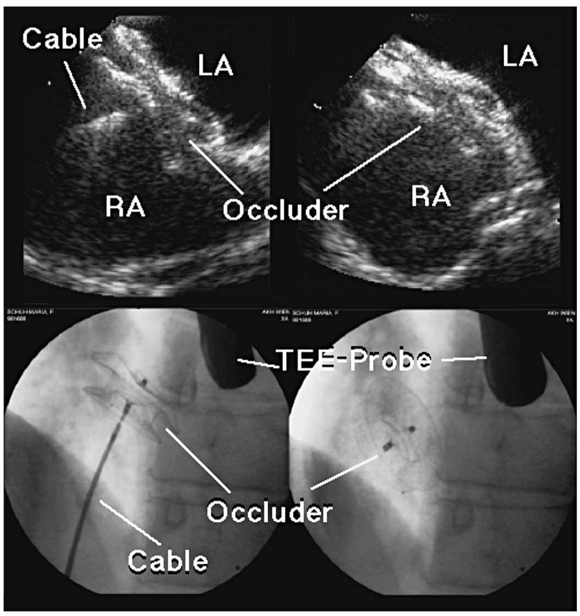

Figure 3. Positioning of an Amplatzer atrial septal defect occluder under TEE guidance (top left panel) and assessment of the result after release of the occluder (top right panel). The lower panels show the corresponding images obtained by fluoroscopy. LA = left atrium, RA = right atrium

Valvuloplasty in Mitral Stenosis
Percutaneous balloon valvuloplasty is an alternative to cardiac surgery in certain cases of mitral stenosis [39]. Echocardiography allows the quantification of mitral stenosis and the assessment of suitability of the valve apparatus for this procedure. TEE is also used to exclude a left atrial thrombus prior to the intervention. TEE for the monitoring of the valvuloplasty procedure is feasible, safe, and well tolerated [40]. TEE facilitates transseptal catheterization, permits proper positioning of the balloon during the dilatation procedure and enables early detection of complications. Valvuloplasty can be monitored and the decision whether or not subsequent dilatations are necessary is facilitated [40]. TEE can be used effectively during balloon mitral valvuloplasty to reduce the rate of complications resulting from transseptal catheterization and balloon valvuloplasty and reduce procedure and fluoroscopy time [41]. Valvuloplasty, when aided by TEE has a tendency to decrease the frequency of significant mitral regurgitation without compromising the final mitral valve area [42]. Echocardiography allows computation of the mitral valve area using the pressure half time method and planimetry and permits the measurements of mean and maximal gradients across the valve. Thus, echocardiography plays an important role, not only in the evaluation of immediate post-procedural results, but also in the long-term follow-up of these patients. Several authors now postulate that TEE should routinely be performed during valvuloplasty.

Septal Ablation in Hypertrophic Obstructive Cardiomyopathy
Left ventricular outflow tract obstruction may be responsible for symptoms in hypertrophic obstructive cardiomyopathy. In patients refractory to medical therapy, percutaneous septal ablation is an effective alternative to surgery. It reduces both, symptoms and outflow gradients in hypertrophic obstructive cardiomyopathy [43]. Echocardiographic guidance adds substantially to safety and efficacy of the procedure and should therefore be considered routinely [44]. Myocardial contrast selectively injected into the septal perforator arteries can delineate the perfusion bed of the septal perforators and can predict the infarct size that follows ethanol injection. The estimation of the size of the septal vascular territory with myocardial contrast echocardiography is accurate, safe and feasible [45] (Figure 4). It helps avoiding potentially fatal complications caused by necrosis of myocardium distant from the septal target area [46]. In addition TTE allows immediate assessment of outflow tract gradients and regional wall motion abnormalities after ablation. Thus, echocardiography is able to detect the immediate effects of therapy seen in some patients.

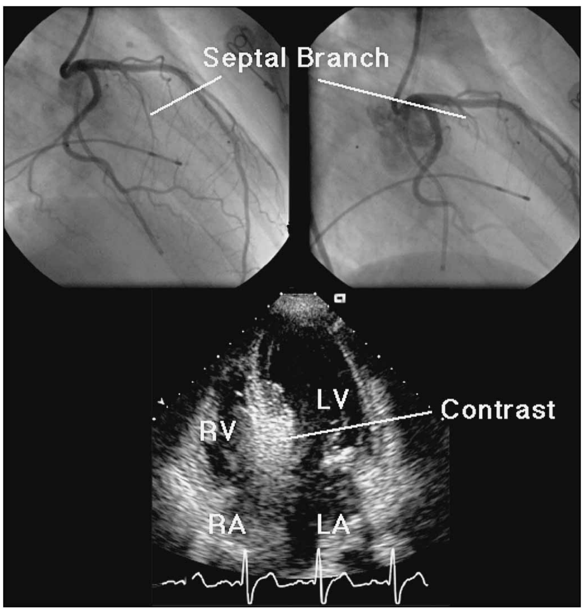

Figure 4. The septal branch of the left anterior descending coronary artery in a patient with hypertrophic obstructive cardiomyopathy (top panels). Estimation of the size of the septal vascular territory with myocardial contrast echocardiography (lower panel). LA = left atrium, RA = right atrium, LV = left ventricle, RV = right ventricle

Ablation and Placement of Biventricular Pacemaker
Patients undergoing radiofrequency ablation of left-sided accessory pathways require transseptal puncture. TEE facilitates puncture and may reduce the risk of cardiac perforation especially in patients with a normally sized left atrium [47]. TEE may be valuable for identifying an atrial thrombus during transseptal puncture and in positioning the ablation catheter at the pulmonary vein ostium. Measurement of pulmonary vein size allows sizing of the ablation catheter (lasso catheter). TEE is also used to detect procedure-related complications such as the detection of thrombi in the pulmonary veins and pulmonary venous stenosis.

ICE has also been shown to be feasible to guide ablation procedures [48]. ICE helps to delineate the anatomy of intra- and extracardiac structures and simplifies correct positioning of the transseptal dilator, puncture of the fossa ovalis, and cannulation of the left atrium in a timely and uncomplicated fashion [49].

Similarly, ICE is used for positioning of the lasso catheter at the pulmonary vein ostium.

Limitations

The benefit that can be achieved with periprocedural echocardiography is also operator dependant. Extensive expertise in performing and interpreting the studies is mandatory. In addition, a thorough background in cardiology and/or anaesthesiology as well as an understanding of the procedures, which are to be performed, is mandatory. The assessment of valvular lesions, paravalvular leaks, and other complications of surgery is even more challenging in the operating room, where the haemodynamic status is altered and the consequence of misinterpretation or failure to detect a relevant finding can lead to a catastrophic outcome. In the cathlab, anaesthesia is needed in most instances for performing TEE.

Conclusion

Echocardiography is now routinely used in numerous periprocedural settings both in the operating room and the cathlab. Its ability to aid in formulating the plan, monitor the procedure and immediately assess the surgical result has significantly improved management and outcome of patients. Intraoperative TEE is now routinely used in most centers for cardiac surgery and is of particular value in valve operations. Intraoperative TEE allows early detection and quantification of residual regurgitation in mitral valve repair and detection of paravalvular leaks or outflow tract obstruction. In addition, TEE allows monitoring of cardiac function and volume status during surgery. Echocardiography also plays an increasing role in the cathlab where it can guide procedures such ASD and PFO closure, septal ablation in hypertrophic cardiomyopathy, valvuloplasty of mitral stenosis and ablation of atrial arrhythmias. Developments in echocardiography such as intracardiac ultrasound, but also the advent of new procedures and techniques both in the cathlab and operating theatre will further expand the use of echocardiography in the future.

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