EPICARDIAL ECHOCARDIOGRAPHY

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EPICARDIAL ECHOCARDIOGRAPHY

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LEENDERT ALEXANDER VAN HERWERDEN

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Promotor	: Prof. Dr. E. Bos
Overige leden	: Prof. Dr. J.R.T.C. Roelandt Prof. Jhr. Dr. J.W. Wladimiroff Prof. Dr. J. Hess
Co-promotor	: Dr. W. J. Ligtvoet-Gussenhoven

Ter nagedachtenis aan mijn vader
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CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Epicardial echocardiography.

The rapid progress made in cardiac surgery in the past 20 years is attested by the dramatic fall in operative mortality. Nevertheless, the cardiac surgical patient remains at risk from an occasional incorrect or incomplete preoperative diagnosis, and from imperfections in surgical skill. In this era, operative mortality should not be the sole measure of surgical achievement. It is important to achieve an optimal surgical correction since this reduces peri-operative morbidity and enhances the patient's long term prognosis. The progress of the specialty in general is composed of the learning processes of individual cardiac surgeons, and in part this starts again with any new person in the field. Meanwhile, surgeons have to meet new demands such as the need to treat increasingly complex pathology, the preference for reconstruction, and the implantation of homologous material rather than a prosthesis.

One of the ways in which it is possible to improve the surgeon's abilities in all of these aspects of modern cardiac surgery, is to visualize intracardiac anatomy and function before and after correction, using epicardial echocardiography.

The present generation of cardiac ultrasound systems provide good cross-sections of the heart and its chambers. They have profoundly changed methods of preoperative diagnosis. The mobility of the equipment allowed its introduction into the operating room. When the transducer is applied directly to the exposed surface of the heart, the quality of the echocardiographic images is considerably improved, compared with the transthoracic approach.

The potential benefits of this new application of echocardiography raised the curiosity which formed the basis of this thesis.

1.2 Objectives of the study.

From the experiences of Sahn[1] and Spotnitz[2] it was apparent that it is safe to apply an ultrasonic transducer to the exposed surface of the heart. The reported initial

experiences mentioned many potential benefits of the technique, but "the value of intraoperative two-dimensional echocardiography had still to be established".[3]
Considering the likelihood of the intraoperative application of echocardiography in 1983, we formulated 4 objectives:

- Introduction of intraoperative two-dimensional echocardiography with a safe ultrasound system, at any time available to the cardiac surgeon;
- Determine the possible cross-sections necessary for an optimal intraoperative investigation;
- Determine if the technique could confirm, add to or reject the preoperative diagnosis before cardiopulmonary bypass is started, and determine the relevance of this information to the actual clinical situation.
- Determine the value of the technique for the evaluation of the quality of the correction after termination of cardiopulmonary bypass before chest closure.

1.3 Nomenclature.

The technique described in this thesis will be referred to as "epicardial echocardiography". The addition "intraoperative" is unnecessary, since "epicardial" presumes operative access to the heart. If the transducer is applied to the aorta or other great vessels after a median sternotomy, it would be more correctly to refer to the technique as "epivascular echography". However, for simplicity, this term will only be used if the transducer is applied to the descending thoracic and abdominal aorta after lateral thoracotomy or thoraco-abdominal incisions.
The technique where the transducer is introduced into the esophagus during the operation will be referred to as "intraoperative esophageal echocardiography".[4]
The traditional approach of echocardiography, by placing the transducer upon the chest, will be referred to as "precordial" or "transthoracic echocardiography".

1.4 Outline of the thesis.

The questions that follow from the first two objectives will be answered in the methods section (Chapter 2).
Chapter 3 contains mainly papers emphasizing the morphological information that can be obtained with epicardial echocardiography.
The field of intraoperative echocardiography expanded rapidly. We started our studies with epicardial two-dimensional and contrast echocardiography. In the following years, the introduction of color Doppler and esophageal echocardio-

graphy had a profound influence and resulted in the more widespread application of intraoperative ultrasound. Therefore, the results from our studies will be contrasted and compared with other reports in Chapter 4.

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CHAPTER 2

METHODS

2.1 Equipment.

At the end of 1983 both phased array and mechanical sector scanners with frequencies ranging from 2.5 to 5 MHz were tested on open-chested pigs, in the Department of Experimental Cardiology, Thorax Center, Erasmus University Rotterdam (Head;Prof.Dr.P.Verdouw). The only criterion used to select the probes and echocardiographic equipment for subsequent studies, was subjective assessment of the quality of the images which were produced. We preferred the mechanical sector scanner (ATL Mark 300 LX) and accepted the limitations of increased maintenance, and large transducer size compared to phased array systems.[1] Because no thoracic structures intervene when imaging from the epicardium, a 5 MHz transducer was selected. To enhance overall image quality, and in particular that in the near-field, a 50 Ohm resistor was switched in parallel to the transducer.
Since 1988, most intraoperative echo studies have been performed using color Doppler echocardiography (Toshiba SSH-140 or 160A). A 3.75 MHz transducer is used for epicardial color flow mapping and a 5 MHz transducer for two dimensional imaging. Transesophageal imaging is performed with the same echocardiographic machine and a 5 MHz phased array transducer.

2.2 Safety and procedures.

The consequences of exposure of human tissues to diagnostic ultrasound have been the subject of extensive laboratory experiments, and adverse effects have been reviewed by so called "expert watch dog committees".[2] All these efforts arrive at the conclusion, which is probably also applicable to epicardial two-dimensional echocardiography, that while no adverse effects have ever been reported, the possibility of some effects cannot be excluded from the available information.
The use of ultrasound equipment in the special environment of the operating room produces two possible hazards to the patient: electrical safety and sterility.

Electrical safety was tested in the department of Experimental Echocardiography of the Thorax Center, Erasmus University Rotterdam (Head: Prof.Dr.Ir.N.Bom) by K.M. Ligtvoet and J.Honkoop. The equipment was tested in accordance with the I.E.C. 601 regulations for equipment used in the operating room.
Because a mechanical sector scanner was preferred, we faced the problem of potential transducer failure caused by the cold gas sterilization process. As an alternative to sterilizing the transducer, we prepared 2 meter long plastic bags to wrap around the transducer and connecting cable. Tests for bacterial permeability after gas sterilization were negative. Routine and later periodical testing after intraoperative use did reveal an occasional perforation of the plastic bag. The patients in whom the plastic bag showed perforations had an uneventful recovery. Further perforations were prevented by meticulous care during preparation and application of the transducer. Although mediastinal infection remains a potential hazard of the procedure (as for any object entering the sterile area during an operation), we found no relationship between the mediastinal infections that did occur in our clinic, and the performance of intraoperative echocardiographic studies. It is unlikely that superficial wound problems can be ascribed to such a study. The plastic bags are commercially available, sterilized by gamma-radiation (Talas, disposable medical products, art.no. CHI-30011).
The procedure for wrapping the transducer is simple and as follows. The plastic bag is wrinkled like a nylon stocking on the scrub nurse's hand and wrist, up to its end. Sterile gel is applied to the end of the bag in the open hand of the nurse. The transducer is placed in the nurse's hand, and the bag is drawn over the connecting wire by operating room personnel. The sterile gel is prevented from dispersing over the transducer by loosely tying a band around the bag near to the tip of the transducer. It is important to keep sharp instruments aside, and special care should be taken in patients with sharp sternal edges as may occur after a previous sternotomy. After pouring warm saline over the exposed heart in the opened pericardium, the study is performed by the cardiac surgeon in charge.

Most of the studies reported in the articles in Chapter 3 were performed in collaboration with an experienced echocardiographer, who assisted in gain setting and in interpretation. Currently, interpretation of two-dimensional echocardiographic images is performed by the cardiac surgeon. Intraoperative echocardiography using color Doppler echocardiography requires trained personnel to assist in the echocardiographic controls, including the levels of gain. Although electronic phased-array transducers can be gas-sterilized, we have chosen to cover these transducers in the same way as we did with the mechanical transducer, for reasons of simplicity and optimal availability of equipment.

Intraoperative esophageal echocardiography is performed by an experienced echocardiographer. The transducer is introduced under general anesthesia in the induction room. Studies are performed during chest opening and after termination of cardiopulmonary bypass.
All echo studies are stored on video-tape for review in the operating room and for off-line study.

2.3 Cardiac cross-sections and image orientation.

The convention of precordial echocardiography is to identify a two-dimensional image by referring to the location of the transducer, and the imaging plane.[3,4] For epicardial echocardiography with commercially manufactured transducers, the contact area is the anterior surface of the exposed heart and great vessels (Chapter 3.1,[5]) Intraoperative echocardiographic imaging should follow the conventions of precordial echocardiography, because it requires the cooperation of cardiac surgeons, cardiologists and anesthesiologists.
The epicardial approach is not impeded by the bony structures of the thoracic wall and the lungs, and this leads to an increased versatility of transducer locations compared to the transthoracic approach. However, interpretation of the images is facilitated by some form of standardization.
Basically, there are 5 epicardial and epivascular locations for the transducer: on the right ventricular outflow tract, on the right atrium, on the acute margin of the right ventricle, on the ascending aorta, and on the aorto-pulmonary sulcus.

1. The right ventricular outflow tract:
- long-axis plane: left and right ventricular long-axis views (See fig. 5, page 19 and fig. 3 page 17).
- short-axis plane: left ventricular short-axis view, short axis view at aortic level ("Five-chamber view", see fig.2, page 17).

These cross-sections are comparable to those obtained from the parasternal position on precordial echocardiography. Further examples are given in Chapter 3, and any textbook or atlas on transthoracic two-dimensional echocardiography.

2. The acute margin of the right ventricle:
- four-chamber plane; foreshortened four-chamber view (See fig 2, page 77). This cross-section is a more posteriorly angled version of the four-chamber view obtained from a subcostal position on transthoracic imaging.

3. On the right atrium:

- long-axis plane (See fig. 4, page 80).

This view allows assessment of the left atrium and the right atrium, the inferior vena cava, the coronary sinus and the superior vena cava; it is a view that can only be obtained by epicardial imaging.

4. On the aorta:

- long axis plane (See fig.1A, page 16, fig.1B, page 24, fig. 2, page 61)
- short axis plane (See fig.1, page 61, fig.5, page 80.)
- four-chamber plane (See fig. 1 B, page 16).

These cross-sections are unique to epicardial echocardiography and are complementary to those obtained on esophageal echocardiography, especially when studying pathology in the distal ascending aorta and proximal aortic arch. Left ventricular outflow gradients are best measured with a continuous wave Doppler transducer firmly pressed on the lateral side of the distal ascending aorta.

5. Aorto-pulmonary sulcus:

- long-axis plane.

This position facilitates color Doppler assessment of mitral regurgitation.

When performing epicardial echocardiography, the investigator should comply with the conventions used to identify images obtained on transthoracic two-dimensional echocardiography, and with the usual orientation of images on the screen.[3] However, this image orientation is extremely confusing for the cardiac surgeon. Short-axis cross-sections are displayed on the screen as if the observer is standing at the patient's feet and looking towards the patient's head. Almost all cardiac incisions, however, allow visual inspection of the heart from the base towards the apex, or from the patient's right shoulder towards the feet. This means, for instance, that what is displayed on the left of the screen on a short-axis echocardiographic view of the mitral valve, will be seen by the surgeon on the right during visual inspection through a left atrial incision. This may be inconvenient in complex pathology, and can be solved by temporarily rotating the transducer through 180 degrees.
The other confusing convention of displaying images is that the aorta is orientated to the right of the screen. When the surgeon moves the transducer to the left, the structures examined will appear on the right side of the screen. This is confusing, for example, while assessing patients with aortic dissection, but the operator should become accustomed to it.

2.4. Contrast material.

Agitated saline was used as the echocardiographic contrast material. Microbubbles (responsible for the contrast effect) were obtained by rapidly moving saline containing some heparinized blood, to and fro between 2 syringes connected to each other by a three way stopcock. Usually, 1 or 2 cc proved to be sufficient for a good contrast effect.

The contrast material was injected through a needle into the right ventricle, for testing of the tricuspid valve.

Incompetence of the mitral valve was determined after injection of contrast material into the left ventricle by transseptal puncture, or when the contrast material was injected through a left atrial pressure monitoring line after it had been advanced through the mitral valve into the left ventricle. Aortic valve regurgitation was assessed by injection of contrast material into the ascending aorta. Shunts at atrial or ventricular level were determined after injection of contrast material into the left atrium, via the left atrial pressure monitoring line or occasionally by the transseptal route.

A semi-quantitative grading from 0 to 4 for the assessment of the severity of regurgitation was employed, based on the observed density of contrast reflux. The grading is similar to the method used with cineangiography.[6] The left ventricular long-axis image was used for assessment of mitral and aortic regurgitation. The right ventricular inflow view was used for assessment of the tricuspid valve. For the evaluation of ventricular septal defects, we developed a semi-quantitative grading based on the assessment of differences in opacification between the left and right ventricles (See Chapter 3.9). The left ventricular long-axis view (also displaying the right ventricular outflow tract) is used as the imaging plane. The fore-shortened four-chamber view was used for assessment of shunts at atrial level. The contrast effect of agitated saline is caused by the presence of microbubbles.[7] Injections with contrast material have a potential for cerebral embolism, during right ventricular injections in patients with right-to-left shunts, and during left heart injections.[8] Therefore, scrupulous efforts are made to remove all visible air bubbles before injection.

The assumption of safety for the application of echo contrast material follows the same reasoning as for the safety of the application of diagnostic ultrasound. No permanent complications have been reported, while more than 40,000 contrast echocardiograms have been done by peripheral venous injections in patients with and without intracardiac shunts.[9] Microbubbles appear in the aorta after each operation employing extracorporeal circulation, especially after opening the heart or aorta, without an apparent relation to postoperative neurologic deficit.[10] Showers of microemboli of platelet-fibrin microaggregates and gaseous origin are also seen in the microcirculation during cardiopulmonary bypass.[11] The clinical importance of these observations for neuro-psychologic functioning is unclear. Although, in this setting, safety of left sided contrast echocardiography cannot be proven, permanent injury due to the procedure is unlikely.

2.5. Design of the study.

The data described in this thesis relates to patients studied with intraoperative two-dimensional echocardiography between November 1983 and December 1988. Patients referred for surgical correction of intracardiac or aortic pathology with the use of cardiopulmonary bypass were eligible.
The patients were studied before cardiopulmonary bypass was started and, if relevant, the study was repeated after termination of bypass. Some patients were studied when they presented problems after termination of cardiopulmonary bypass, in whom no prebypass studies had been performed. For all patients studied, we recorded whether the echo study confirmed, added to or rejected the preoperative diagnosis. The standard against which the echocardiographic findings were tested was the findings during surgical intracardiac inspection. Any change in the planned surgical approach was documented.
The findings of the echo study performed before the start of cardiopulmonary bypass were interpreted with knowledge of the information obtained by preoperative diagnostic studies.
After cardiopulmonary bypass was terminated, we recorded whether or not the echo data provided relevant information for the surgeon concerning post-bypass management.
The material in this data-base was used for studying consecutive series of patients (Chapter 3.1 and 3.8), and for further detailed studies of particular diseases of interest.

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CHAPTER 3.1

Intraoperative epicardial two-dimensional echocardiography

L. A. van Herwerden, W. J. Gussenhoven, J. Roelandt, E. Bos, C. M. Ligtvoet, M. M. Haalebos, B. Mochtar, F. Leicher and M. Witsenburg

Thoraxcenter, Erasmus University Rotterdam and Interuniversity Cardiology Institute of the Netherlands.

The usefulness of intraoperative epicardial two-dimensional (2D) echocardiography using a commercially available 5 MHz mechanical sector scanner was evaluated in 200 patients. The scanhead was inserted into a gas sterilized plastic bag and placed on the exposed heart. Unsuspected new diagnoses were made in 7 patients. In 68 patients additional morphologic information was obtained. This information influenced surgical management in 32 patients. Intraoperative echocardiographic analysis of the surgical correction revealed the expected results in 184 patients. In 16 patients the investigation provided important information in the decision of immediate reoperation. We conclude that epicardial two-dimensional echocardiography performed by the surgeon familiar with the interpretation of echocardiographic cross-sections yields important information for surgical management. The technique has become an important adjunct in our cardiac surgery department for immediate decision making and leads to optimal results.

Introduction

Two-dimensional intraoperative echocardiography can provide information on cardiac function and morphology. However this technology adds expense and time to surgery[1 – 6]. Previous studies have not documented how frequently intraoperative two-dimensional echocardiography has improved diagnosis and management. Therefore in 200 consecutive patients with congenital or valvular disease we used intraoperative two-dimensional epicardial echocardiography to determine the validity and completeness of the preoperative diagnosis. Furthermore we determined how often this information altered surgical management.

Methods

ECHOCARDIOGRAPHIC INVESTIGATION

A mechanical 5 MHz imaging system was used (ATL-Mark 300 LX). In the first 10 studies the scanhead and cable were gas sterilized and placed directly on the exposed heart. This procedure of sterilization, however, resulted in deterioration of the motor drive in the scanhead occurring during the vacuum procedure. This problem was solved by placing the carefully cleaned transducer and cable (chlorhexidine 0·1%) into a gas sterilized plastic bag. Watertank tests indicated that the spatial resolution was not affected by the plastic bag and serial observations using pigs showed that the ultimate image quality did not deteriorate. To achieve good ultrasound coupling sterile gel was placed within the plastic bag and warm saline was poured over the heart.

Excessive acoustic energy was generated by the transducer (designed for precordial application) even with minimal output because of its proximity to the heart intraoperatively and the absence of damping tissue. As a consequence overloading of the receiving part of the ultrasound instrument occurred which reduced the resolution in the near field. Therefore a damping resistor (50 Ohm) was switched in parallel with the transducer element. This was sufficient to prevent overloading of the receiver thereby considerably improved the image quality. We also noted that diathermy interfered with the ultrasound frequency resulting in asynchroneous dots on the video output screen. Of course, this can be easily avoided

Table 1 Morphologic diagnosis in 200 patients

Aortic valve lesion	36	ASD II	10	DORV	6
Mitral valve lesion	27	ASD I	4	TGA	13
Combined valve lesion	10	VSD	23	Single outlet heart	3
CAD	9	PS	4	UVH	3
CAD + additional lesions	17	VSD + PS	5	Miscellaneous	9
LA tumour	5	Tetralogy of Fallot	16		

ASD I = primum type atrial septal defect; ASD II = secundum type atrial septal defect; CAD = coronary artery disease; DORV = double outlet right ventricle; PS = pulmonary stenosis; TGA = complete transposition of the great arteries; UVH = heart with uni-ventricular connection; VSD = ventricular septal defect.

Initial echocardiograms were obtained after sternotomy and pericardiotomy prior to cardiopulmonary bypass. A second set of echocardiograms was made before closure of the chestwall with the patient in a hemodynamic stable condition. In the very young infant the image quality of the near field in the first 10 mm may be inadequate for detailed information. Accordingly, several acoustic coupling media to increase the distance between the heart and the transducer have been tested; these included a plastic bag filled with saline, mamma prostheses and a commercially available ultrasound conductor (3M-Kitecko). None proved to be successful. A more appropriate procedure is to make the recording with the pericardium unopened. This facilitated filling of the chest with warm saline.

The handling of the probe was carried out by the surgeon while the ultrasound equipment was manipulated by the echocardiographer. Initially the scanhead was placed on the right ventricular surface. The cardiac cross-sections which are systematically visualized include both right and left ventricular long axis and serial short axis views. Due to the large transducer assembly apical views were not obtained. Four chamber views proved possible from the right ventricular surface. When necessary additional cross-sections of the aortic root, ascending and descending aorta and the pulmonary arteries were visualized. Contrast was injected to test for valve competence or residual insufficiency and the presence of shunts after repair. Saline solution was injected directly into the right heart or into the left side of the heart (via the left atrial pressure line). The study was usually completed within a few minutes.

STUDY PATIENTS

The study group consisted of 200 patients undergoing open heart surgery. A large percentage of these patients were referred from community hospitals. They included newborns and patients up to 73 years (yrs) old. With the exception of 4 patients, two with bacterial endocarditis and two with left atrial myxoma, all had undergone preoperative cardiac catheterization and angiography. Cardiac surgery was performed in 127 patients for congenital heart disease (mean age 2 years) and in 73 patients for acquired heart disease (mean age 50 years) (Table 1). Nine patients who underwent coronary artery bypass grafting were included in the study in order for the investigators to become familiar with the epicardial positioning of the transducer and to document normal intracardiac anatomy. Intraoperative data were immediately analyzed by the echocardiographer together with the surgeons. Subsequently the recordings were reviewed and discussed in relation to the traditional external preoperative echocardiographic, catheterization and angiographic data as well as to the surgical findings.

Results

The information which had influence on the surgical decision making in the 200 patients studied intraoperatively is summarized in Table 2. The echographic images obtained in three infants were inadequate and limited precise anatomic evaluation.

Table 2 Intraoperative two-dimensional echocardiography

Patients studied	200	
Unsuspected new diagnosis	7	
Additional information	68	
important for surgical management		32
additional and of interest		36
Assessment of intracardiac repair important for surgical management	16	

Table 3

Preoperative diagnosis	Intraoperative echocardiographic diagnosis
Aortic insufficiency	Aortic dissection
Saccular aneurysm	Aortic root dissection
Mitral valve insufficiency (MI)	MI and ventricular septal defect
Aortic stenosis (AoS)	AoS and atrial septal defect (type II)
Atrial septal defect (ASD) type II	Sinus venosus type ASD
Ventricular septal defect	Atrioventricular septal defect (complete type)
Ruptured aneurysm of aortic sinus	Outlet perimembranous ventricular septal defect

UNSUSPECTED INTRAOPERATIVE NEW DIAGNOSIS

In seven patients the preoperative diagnosis established on the basis of a complete evaluation including cardiac catheterization could not be confirmed by intraoperative two-dimensional echocardiography. The new diagnoses which were revealed resulted in a change in surgical management. In all these patients the intraoperative echocardiographic diagnosis was subsequently substantiated at surgical inspection (Table 3). The change in surgical strategy, for example in the patient with an unsuspected aortic dissection included the introduction of the arterial bypass line into the femoral artery rather than the ascending aorta (Fig. 1). The unsuspected atrial septal defect in a newborn infant referred for severe aortic stenosis required an additional atriotomy to close the defect (see Table 3).

ADDITIONAL INFORMATION

Additional morphologic information obtained in 68 patients.

Examples of pertinent and helpful additional information for surgical management were:

(a) An unsuspected abscess in the aortic annulus was visualized intraoperatively in two patients undergoing surgery for bacterial endocarditis of the aortic valve (Fig. 2).

(b) In one patient an anomalous chord was seen in the left ventricular outflow tract connecting the anterior mitral valve leaflet with the interventricular septum. From preoperative investigation it was thought that the mitral valve abnormality was similar to that seen in atrioventricular septal defect.

(c) Preoperative investigations in the infant with valvular and infundibular pulmonary stenosis were equivocal about the morphology of the infundibular obstruction. Intraoperative two-dimensional echocardiography identified localized hypertrophy of the infundibular septum and a discrete valvular stenosis (Fig. 3). On the basis of these observations it was decided to perform only a commissurotomy; a trans-annular outflow reconstruction was considered unnecessary.

(d) Of the 16 patients undergoing correction of tetralogy of Fallot, the intraoperative echo demonstrated absence of the infundibular septum in three. The diagnosis was thus a doubly committed subarterial ventricular septal defect. In three other patients no overriding was observed with intraoperative echocardiography and this was confirmed during surgery. In another two the overriding was found to be more than 50 percent from the right ventricle, thus a double outlet ventricular connection was present rather than a classic tetralogy of Fallot.

(e) In five patients the intraoperative echo gave detailed information about position and size of the ventricular septal defect.

(f) Detailed morphologic information of the valvular and subvalvular components of the tricuspid and mitral valve apparatus was obtained in six patients which was of importance for valve reconstruction. In valve insufficiency a precise delineation of a partial scallop, prolapse or a chordal rupture was possible.

Examples of additional information and of interest for the surgeon were:

(a) An unsuspected enlarged coronary sinus due to a persistent left caval vein was observed in nine patients.

(b) Intraoperative echocardiography provided the precise attachment of the stalk of a left atrial myxoma to the lowermost portion of the interatrial septum or to the posterior mitral valve leaflet

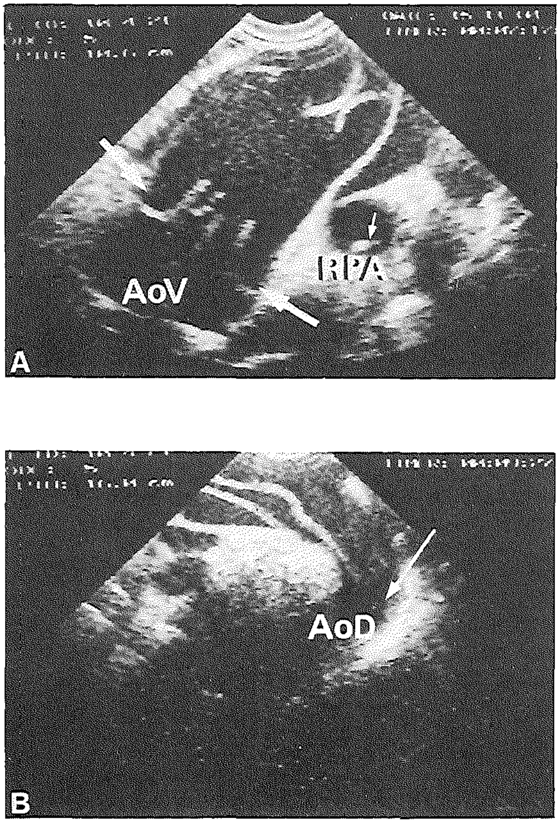

Figure 1 Intraoperative two-dimensional echocardiograms obtained with the aortic arch as the point of entrance for imaging a patient submitted for aortic valve replacement because of valve incompetence. The echocardiographic images clearly demonstrate a dissection in the ascending aorta (panel A) beginning just distal to the aortic sinuses (arrows) and extending towards the descending aorta (AoD) (panel B; arrow). Note the Swann Ganz catheter positioned in the right pulmonary artery (RPA; small arrow). AoV = aortic valve.

(Fig. 4). This oriented the surgical approach and facilitated resection of the tumour.

ASSESSMENT OF INTRACARDIAC REPAIR

We learned that direct assessment of the result of valve reconstruction and correction of a congenital malformation was of advantage in several patients. In patients with tetralogy of Fallot and double outlet right ventricle, the dimensions of both right and left ventricular outflow tract can be estimated. In two patients with double outlet right ventricle it was felt that reoperation was necessary. They had an increased right ventricular pressure and systolic obliteration of the right ventricle outflow tract was demonstrated echographically. Evaluation of the Mustard or Senning procedure in patients with complete transposition of the great arteries was shown to be of special interest. Precise three-dimensional assessment of the intra-atrial baffle required multiple four chamber sections. Closure of the ventricular septal defect was analyzed

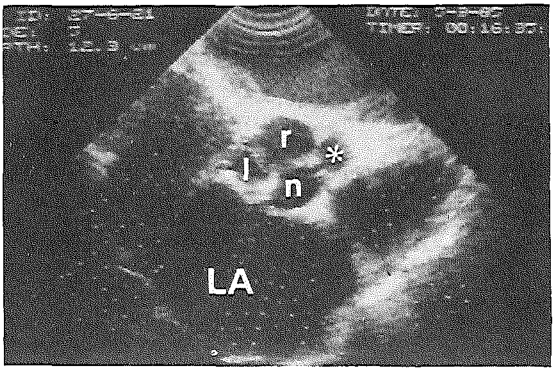

Figure 2 Intraoperative two-dimensional echocardiogram with the right ventricle as point of entrance for imaging a patient with bacterial endocarditis of the aortic valve. The echocardiographic investigation shows an abscess at the commissure between the right (r) and non-coronary (n) aortic valve cusp (asterisk). LA = left atrium; L = left coronary cusp.

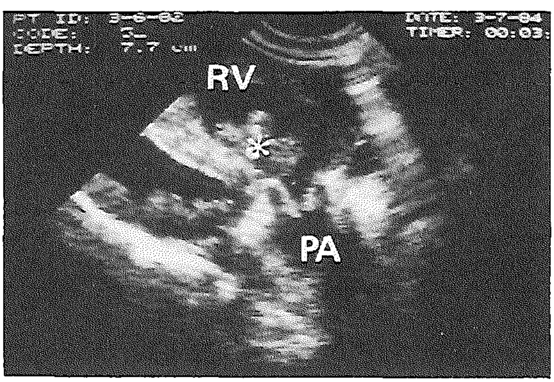

Figure 3 Intraoperatively obtained right ventricular outflow tract view in a patient referred for surgery because of subvalvular and valvular pulmonary stenosis. The pulmonary valve shows a pinhole orifice stenosis which was corrected by a commissurotomy. The outflow tract of the right ventricle is obstructed by localized hypertrophy of the infundibular septum (asterisk). PA = pulmonary artery; RV = right ventricle.

anatomically in all and in 18 patients functionally verified by echo contrast injected into the left atrium. In 2 patients significant residual shunting was demonstrated. Clinical follow-up, however, showed that in neither of the two patients this residual shunting had any haemodynamic consequences.

Contrast echocardiography, used in seven patients to evaluate valve competence after reconstructive mitral valve surgery, demonstrated moderate valve insufficiency in one patient and a competent valve in six patients (Fig. 5).

A patient who underwent coronary artery bypass grafting, presented with increased left atrial

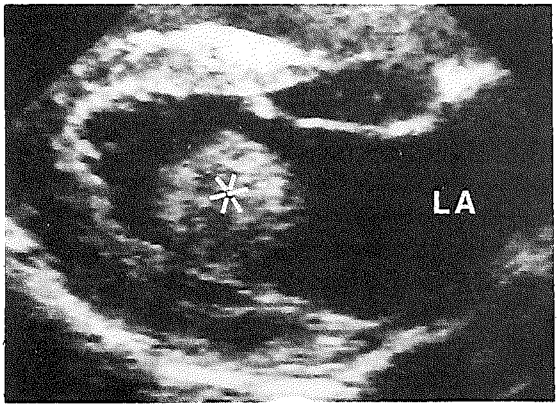

Figure 4 Intraoperative two-dimensional echocardiogram obtained with the transducer directly placed over the right ventricle in a patient submitted to surgery for a left atrial tumour. Intraoperative echocardiography revealed that the tumour (asterisk) was attached to the posterior mitral valve leaflet. LA = left atrium.

pressure and was in an unstable cardiac condition. It was not clear whether the deterioration was the result of mitral incompetence or of left ventricular pump failure. Echocardiography was carried out which revealed normal mitral valve morphology and poor left ventricular contraction. It was decided to insert an intra-aortic balloon pump and the patient survived. Finally, two-dimensional echocardiography was used in one patient to search for a broken intra-atrial pressure line after cardiopulmonary bypass. The line was found in the left atrium and removed safely on cardiopulmonary bypass by a left atrial approach before the chest was closed.

INTRACAVITARY CONTRAST EFFECT

In a majority of patients contrast echoes were seen in both the left and right heart cavities. Three types of contrast echoes could be distinguished. One resulted from the venous infusion systems. These contrast echoes were only seen during a short period of time in the right atrium and right ventricle and were most apparent immediately after the injection of drugs. They were usually seen in the younger patients with a congenital heart defect. A second type of contrast was observed following cardiopulmonary bypass. This contrast effect was seen as highly reflective particles originating from within the left atrium and passing via the left ventricle into the aorta. This type of contrast formation was seen with equal frequency in the younger (4) and older (7) patients and there was no relation to the underlying morphologic disorder. A third type of contrast effect, was seen before and after cardiopulmonary bypass and probably originated from red blood cells (see also Figs. 1, 2 and 5). It was observed either in the left (19 patients) or right (11 patients) heart cavity or in both left and right heart cavities (23 patients). It occurred mainly in elderly patients with mitral and/or aortic valve disease.

Discussion

We experienced that intraoperative two-dimensional echocardiography provided relevant information for surgical decision making. Before extracorporeal circulation it allowed the surgeon to verify the preoperative diagnosis and to detect additional and important information for subsequent surgical management. After the completion of the operation and before closure of the chest, the technique allowed assessment of the surgical results and has been helpful in solving critical problems.

M-mode echocardiography has been used intraoperatively to document outflow tract dimensions[4,10], ventricular septal motion[11] or left ventricular function[2]. Intraoperative monitoring of left ventricular function, however, can best be obtained by transesophageal echocardiography

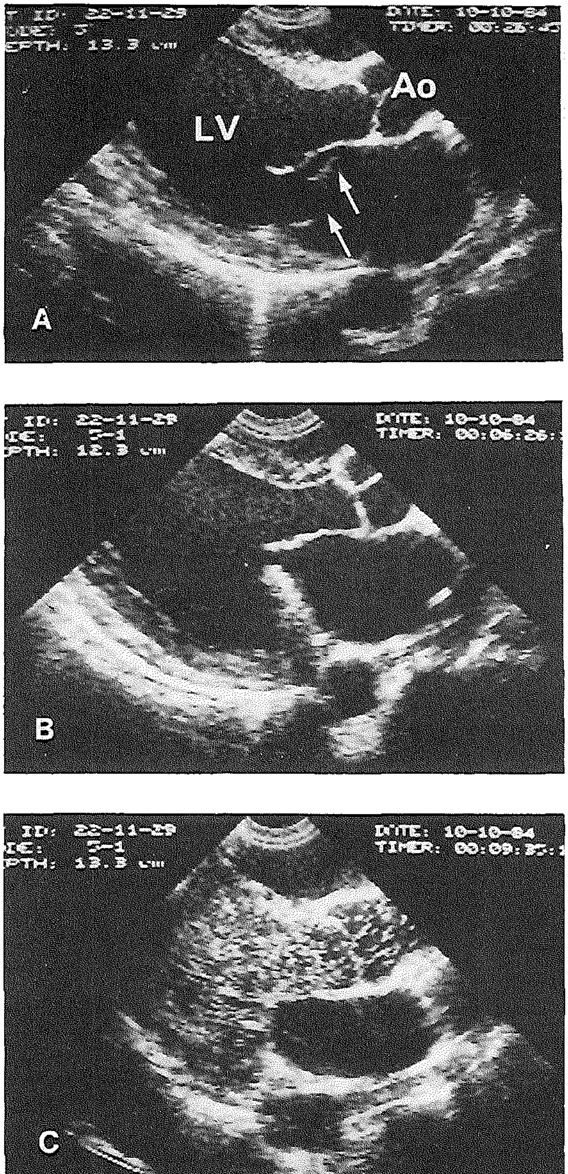

Figure 5 Left ventricular long axis views obtained from a patient with severe mitral valve incompetence. Intraoperative echocardiograms show a partial dehiscence of the posterior mitral valve leaflet from its normal chordal attachments (panel A, arrows). Reconstructive surgery was performed by excising the pathologic part of the posterior mitral valve leaflet. Postoperative epicardial echocardiographic investigation before the chest was closed shows the reconstructed posterior mitral valve leaflet (B). Left ventricular contrast study (panel C) revealed a competent mitral valve. Ao = aorta; LV = left ventricle.

rather than by the epicardial approach, since this technique can be performed independent from the surgeon[1,3].

Epicardial intraoperative echocardiography poses a few practical problems. Gas sterilization of phased array transducers has been promoted[5,6], but this procedure is not possible for a mechanical transducer as it causes failure of the motor drive. Therefore we used a gas sterilized plastic tube bag which has the additional advantage that the same transducer can be used for different patients on the same day. The transducer, not designed for intraoperative work, however, is relatively large particularly for the small infant. A small high frequency finger tip transducer with a phased array design (>5 MHz) would be preferable. Based on our observations we feel that intraoperative two-dimensional echocardiography is extremely useful and it seems appropriate to summarize our experiences as follows:

INDICATIONS

In this series we have studied the use of intraoperative two-dimensional echocardiography in patients undergoing surgery for congenital heart disease, valve disease and bacterial endocarditis. In addition, the echographic investigation was extremely helpful when the surgeon found an abnormal cardiac geometry not corresponding to the preoperative diagnosis or when problems occurred after corrective surgery.

ATRIAL LEVEL

Both the left and right atrium can be studied. Using the modified four chamber view the entrance of the inferior caval vein is readily identified, sometimes bordered by an Eustachian valve. In the same echoplane the entrance of the coronary sinus is visualized, indicating the lowermost portion of both atria. The right auricle can also be used as the point of entrance. With these cross-sections we were able to specify the precise position of an atrial septal defect, the attachment of a left atrium tumour, to demonstrate an enlarged coronary sinus caused by a persistent superior left caval vein or to evaluate the cardiac repair in case of a total anomalous pulmonary venous drainage or complete transposition of the great arteries.

ATRIOVENTRICULAR LEVEL

Connection between atrium and ventricle is identified from four chamber and left ventricular long axis views. With these views a detailed analysis of both the mitral and tricuspid valve morphology is possible.

We were able to identify an anomalous chord of the anterior mitral valve leaflet which inserted on the interventricular septum in the outflow tract, partial prolapse of the mitral or tricuspid valve leaflets and ruptured chordae. The site of ventricular septal defects was readily determined and in this series one ventricular septal defect which was not diagnosed preoperatively was found. We never encountered problems in interpretation as a result of dropout in the perimembraneous ventricular septum[12]. On the other hand dropout may occur after closure of a defect at the junction between patch and septum.

VENTRICULO-ARTERIAL LEVEL

Left ventricular and right ventricular long axis views were used for detailed analysis of the size of both outflow tracts, the level of outflow tract obstruction and the position of the great arteries relative to the ventricular septum. This information is particularly useful in patients with tetralogy of Fallot, double outlet right ventricle, complete transposition of the great arteries, subaortic stenosis and pulmonary valve stenosis.

ARTERIAL LEVEL

Imaging of the ascending aorta allows demonstration of the size of the aortic root and pulmonary arteries. This has been useful to analyse the right pulmonary artery internal diameter in a patient in whom an aorta-pulmonary anastomosis was closed. Imaging of a dilated ascending aorta was found to be extremely informative. In two patients in this series an unsuspected aortic dissection was established and the surgical strategy had to be modified e.g. the femoral artery was used for extracorporeal circulation rather than the ascending aorta containing the dissection.

USE OF ECHOCARDIOGRAPHIC CONTRAST

We have used contrast echocardiography to evaluate shunt repair. We learned that after an injection of saline into the left atrium residual shunting was present in a few patients. Clinical follow-up did not show any significant haemodynamic compromise. Contrast echocardiography was also used to assess reconstructive valve surgery. In one patient out of seven, we demonstrated a moderate leakage of the valve. Although the practical value of intraoperative contrast echocardiography has been suggested[6-9] we feel that much work is necessary before the clinical value of this approach will be established.

INTRACAVITARY CONTRAST EFFECT

We have recognized three types of intraoperative echocardiographic contrast effect. One results from injection via the infusion system and is only seen in the right heart cavity, lasts for a short period of time, and is similar to the contrast effect seen after peripheral venous injection in the echocardiographic laboratory. It most likely results from microbubbles of air present in the injectate.

The second type of contrast effect occurs after cardiopulmonary bypass and appears as bright reflections originating in the left atrium and moving via the left ventricle into the aortic root. This was present in 5 percent of our patients. There was no relation with the underlying pathology, the age of the patient, nor with the duration of bypass. None of these patients had clinical evidence of a neurologic deficit after surgery or during follow-up. This type of contrast effect has also been reported by Spotnitz *et al.*[5] and Rodigas *et al.*[13]. Both authors, however, have found a higher incidence (42%; 49%). The controversy about the incidence may be explained by the fact that Rodigas *et al.*[13] designated the identification of 5 microbubbles as positive. We recognized only the presence of uncountable numbers of microbubbles as positive. A second explanation is the interval between the echographic investigation and the termination of the extracorporeal circulation. The longer this interval the smaller the amount of bubbles. The significance, however, of this phenomenon is not clear. One explanation of their origin is that these bubbles originate from entrapped air which dissolve spontaneously[14].

The third type of echocontrast was seen either in the right, left or both heart cavities. We believe that this type of echocontrast results from red blood cells. Due to the high ultrasound frequency it was noted that the intracardiac cavities could not be imaged as an 'empty' cavity, but maintained with 'echo noise'. The intensity of this type of contrast showed variations with the cardiac cycle. It was seen mainly in the older patients undergoing valve surgery.

The ability of the surgeons to perform echocardiographic studies increased rapidly with their experience and the immediate on line interpretation of the echocardiographic cross-sections prior to surgical correction is straight forward and of importance for intraoperative surgical decision making. Assessment of the results of intracardiac repair of some complex conditions requires a learning process both to obtain adequate images as well as to interpret these images. After 18 months of experience the technique has become a routine procedure in our surgical department, particularly in patients with morphologic cardiac abnormalities.

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KEY WORDS: Intraoperative two-dimensional echocardiography, cardiac surgery, congénital heart disease, acquired heart disease.

CHAPTER 3.2

Intraoperative two-dimensional echocardiography in complicated infective endocarditis of the aortic valve

Six patients with complicated native and prosthetic aortic valve endocarditis were operated on. The data from cineangiocardiography and from precordial and intraoperative two-dimensional echocardiography were compared with the surgical findings. Surgical inspection revealed a mycotic aneurysm in six patients. In addition, a fistulous connection to the right atrium, an abscess in the interventricular septum, and mitral valve endocarditis were found in one of the patients. The pathologic conditions disclosed during the operation were correctly visualized with two-dimensional epicardial echocardiography, done before cardiopulmonary bypass. Cineangiography provided this information in one patient, and precordial two-dimensional echocardiographic analysis was correct in two patients. Thus, intraoperative two-dimensional echocardiography provides detailed information in complicated native and prosthetic aortic valve endocarditis that is of importance in the surgical management.

Lex A. van Herwerden, M.D., Elma J. Gussenhoven, M.D., Jos R. T. C. Roelandt, M.D., Max M. P. Haalebos, M.D., Bas Mochtar, M.D., Kees M. Ligtvoet, M.Sc., and Egbert Bos, M.D., *Rotterdam, The Netherlands*

Complete preoperative diagnosis of the complex pathologic conditions in destructive native and prosthetic aortic valve endocarditis remains difficult,[1-5] and correction is a challenge to the surgeon.[6-8] The potential of intraoperative two-dimensional echocardiography for surgical decision-making has been stressed by Spotnitz[9] but has not been widely implemented.[10-13] We evaluated the findings of intraoperative epicardial two-dimensional echocardiography in relation to the preoperative and surgical findings in six patients with complicated infective endocarditis of the aortic valve and root.

Study patients

Since November 1983 we have performed intraoperative epicardial two-dimensional echocardiography in more than 300 patients, of whom 119 were adults. Six adult male patients had infective endocarditis with complex pathologic conditions of the aortic root. Four patients (Patients 1 through 4) had native valve endocarditis, and two patients (Patients 5 and 6) had prosthetic valve endocarditis. Clinical characteristics of the patients are given in Table I.

One patient underwent an emergency operation because of hemodynamic deterioration and development of a total atrioventricular block. Despite intensive antibiotic treatment the infection of the aortic and mitral valve was uncontrolled.

Five patients had symptoms of severe aortic valve insufficiency, but their hemodynamic condition and response to antibiotic treatment allowed a 6 week course of intravenous antibiotics to be completed before the operation.

Methods

Complete preoperative precordial two-dimensional echocardiographic studies were available in all patients by use of a phased-array system.

Four patients (Patients 3 through 6) were in a stable hemodynamic condition, and information on the coronary arteries was thought important because of their age, precordial complaints, or both. They underwent cardiac catheterization and angiography of the left ventricle and aortic root, for which the standard left and right anterior oblique projections were used. Angiography was considered unnecessary in one patient who was in a critical hemodynamic condition and in another

From the Department of Cardiopulmonary Surgery, Thoraxcenter, Academic Hospital Rotterdam-Dijkzigt and Erasmus University Rotterdam, and the Interuniversity Cardiology Institute of The Netherlands.

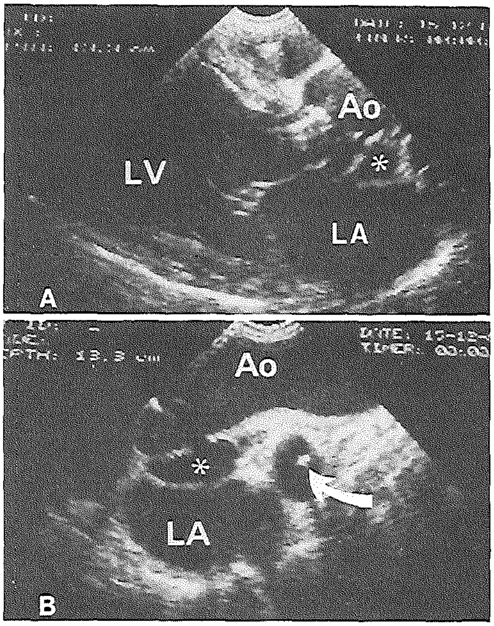

Fig. 1. Intraoperative epicardial two-dimensional echocardiograms obtained in a patient (Table I, Patient 3) with infective endocarditis of aortic valve. *A,* Left ventricular long-axis view, obtained with transducer placed on right ventricular outflow tract, demonstrated unsuspected supra-annular aneurysm in left coronary sinus *(asterisk). B,* Transducer positioned on ascending aorta *(Ao)* revealed size of aneurysm *(asterisk).* Note Swan-Ganz catheter in right pulmonary artery *(arrow). LA,* Left atrium. *LV,* Left ventricle.

patient because sufficient information was believed to be available. Intraoperative epicardial two-dimensional echocardiographic studies were performed with a commercially available 5 MHz mechanical sector scanner (ATL-Mark 300 LX). The transducer was placed in a gas-sterilized plastic bag. For good ultrasound coupling, sterile gel was put in the plastic bag, and warm saline solution was poured over the exposed heart.

The examination was performed by the surgeon in charge. He was assisted by an experienced echocardiographer (E.J.G.) for proper imaging and interpretation. The studies were performed after pericardiotomy and before cannulation of the heart.

The transducer was placed on the right ventricular outflow tract for imaging left ventricular long-axis and short-axis views. From this contact point foreshortened four-chamber views were imaged. For a better visualization of the pathologic conditions posterior to calcified aortic valve cusps or prosthetic valves, the transducer was placed on the ascending aorta.

All intraoperative echocardiographic studies were performed within 5 minutes.

Results

Pertinent angiographic data and preoperative and intraoperative two-dimensional echocardiographic data are listed in Table I. The morphologic abnormalities of interest resulting from the destructive infective endocarditis and visualized by the different imaging techniques are discussed below.

Cineangiocardiographic findings. Cineangiocardiography was performed in four patients. A mycotic aneurysm was demonstrated once (Patient 5). In another patient (Patient 6) an abnormal connection was seen between the aortic root and the left atrium. Moreover, contrast material was noted between the original aortic wall and the valved conduit. The hemodynamic condition of this patient limited the amount of contrast material that could be used. Consequently, further detailed information of the complex pathologic findings from other projections could not be obtained.

In two other patients (Patients 3 and 4), cineangiographic studies did not diagnose the mycotic aneurysm found during the operation. In Patient 3, there was a 5 month interval between angiography and the operation. In Patient 4, the mycotic aneurysm was missed and recognized only at retrospective analysis.

Preoperative echocardiography. A mycotic aneurysm was unequivocally demonstrated in one patient (Patient 2). In a second patient (Patient 5), a posterior aneurysm was noted. However, precise analysis of the aneurysm was hampered by the aortic valve prosthesis. In four other patients, precordial echocardiography failed to diagnose the mycotic aneurysm because of insufficient image quality (Patients 1, 3, and 4) and by interposition of prosthetic valve material (Patient 6).

Intraoperative echocardiography. A complete visualization and correct diagnosis of the anticipated as well as the unexpected pathologic conditions found at the time of operation were made with intraoperative two-dimensional echocardiography in all patients (Fig. 1). Unexpectedly, intraoperative echocardiographic investigation clearly demonstrated a fistula between the aorta and the right atrium in one patient (Fig. 2).

The complex pathologic conditions in Patient 6 were completely appreciated only with intraoperative echocardiography (Fig. 3).

Surgical findings

Surgical inspection in all six patients confirmed the intraoperative echocardiographic features. All patients

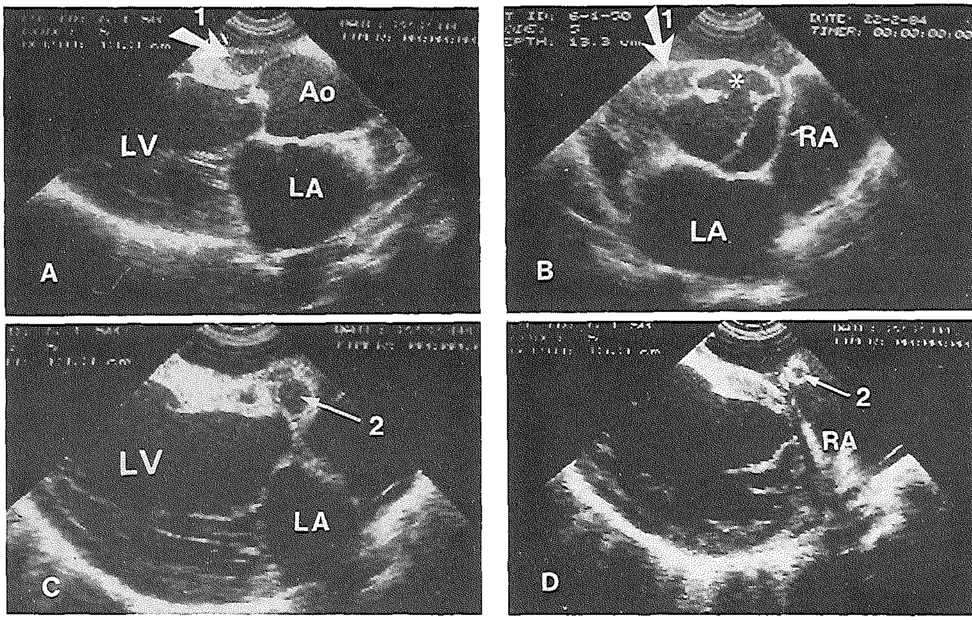

Fig. 2. Intraoperative two-dimensional echocardiograms obtained in a patient (Table I, Patient 1) with infective endocarditis of aortic valve and abscess in interventricular septum. *A*, Abscess *(arrow 1)* is seen close to aorta *(Ao)* by left ventricular long-axis view obtained with transducer placed on right ventricular outflow tract. *B*, Short-axis view disclosed adjacent to this abscess *(arrow 1)* an unsuspected aneurysm in right sinus of Valsalva *(asterisk)*. Four-chamber view with slight anterior *(C)* and posterior tilt *(D)* of transducer revealed circular echo-free communication originating from aortic root, indicative of fistula *(arrow 2)* between aorta and right atrium *(RA)*. *LV*, Left ventricle. *LA*, Left atrium.

Table I. *Pertinent clinical data, preoperative results, and intraoperative epicardial echocardiographic findings*

Patient	*Age (yr)*	*Clinical aspects*	*Cineangiography*	*Precordial 2DE*	*Intraoperative 2DE*
1	34	Urgent, AV block, shock, β-hemolytic streptococcus, native valve	Not performed	Abscess in IVS, flail AoV, vegetations MV	Anterior mycotic aneurysm, abscess in IVS, flail AoV, vegetations MV, fistula Ao-RA (Fig. 2)
2	19	Elective, *Streptococcus viridans*, native valve	Not performed	Anterior mycotic aneurysm, flail right AoV	Anterior mycotic aneurysm, flail right AoV
3	54	Elective, blood culture negative, native valve	—	—	Posterior mycotic aneurysm, flail AoV (Fig. 1)
4	63	Elective, *Streptococcus bovis*, native valve	—	—	Lateral mycotic aneurysm
5	34	Elective, *Staphylococcus epidermidis*, PVE	Posterior mycotic aneurysm, paravalvular leakage	Posterior mycotic aneurysm	Posterior subannular mycotic aneurysm
6	50	Elective, β-hemolytic streptococcus, PVE conduit	Connection Ao-LA? contrast around valved conduit, compression left main coronary artery	Dilated ascending Ao	Posterior subannular mycotic aneurysm, "paraconduit leak" (Fig. 3)

Legend: 2DE, Two-dimensional echocardiography. AV, Atrioventricular. IVS, Interventricular septum. PVE, Prosthetic valve endocarditis. Ao, Aorta. AoV, Aortic valve. MV, Mitral valve. LA, Left atrium. RA, Right atrium. —, No relevant information obtained.

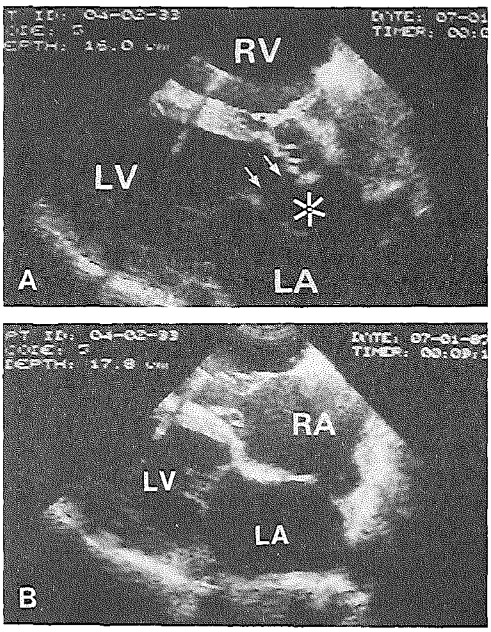

Fig. 3. Intraoperative two-dimensional echocardiograms obtained in a patient (Table I, Patient 6) known to have valved conduit endocarditis. *A,* Left ventricular long-axis view revealed large echo-free area *(asterisk)* interposed between valved conduit and left atrium *(LA).* Discontinuity was noted between anterior mitral valve leaflet and posterior aortic wall *(small arrows). B,* Four-chamber view disclosed continuity between anterior mitral valve leaflet and interatrial septum, indicating extension of aneurysm. *RA,* Right atrium. *RV,* Right ventricle. *LV,* Left ventricle.

with a native valve showed extreme valve destruction. A mycotic aneurysm was found in all patients. In four patients (Patients 1 through 4), the aneurysm was supra-annular, and the cavity was covered by smooth epithelium or granulation tissue. In two of these patients (Patients 1 and 2), the annular destruction caused left ventricular–aortic discontinuity. In the remaining two patients (Patients 5 and 6), the orifice of the mycotic aneurysm was subannular as a result of destruction of the mitral-aortic fibrous continuity. One of these patients (Patient 6; Fig. 3) had dehiscence of a valved conduit with paraconduit leakage to the area between the conduit and the "wrapped" aortic wall.

Finally, in one patient (Patient 1), an abscess was found in the interventricular septum and, in addition, a fistula between the noncoronary sinus of Valsalva and the right atrium together with mitral valve endocarditis.

Discussion

The sequelae of destructive aortic valve endocarditis with surgical relevance are annular erosions with left ventricular discontinuity and abscess formation in the surrounding tissues. The infection may lead to mycotic aneurysm formation in the aortic wall or to destruction of the fibrous aortic–mitral valve continuity with subannular false aneurysm formation. Fistulous connections may develop to all surrounding cardiac chambers, predominantly to the right atrium. The value of echocardiography for the preoperative visualization of these complications and their differential diagnosis has been described.[14-20] There are, however, limitations because of inadequate visualization of the aortic root resulting from "window problems,"[21] patient suitability, and interposition of heavily calcified valves or valve prostheses.[3] Transesophageal echocardiography has the potential to overcome these limitations.[21,22]

The value of cineangiography is limited by the number of views that can be obtained and the inherent superimposition of structures and cavities filled with contrast medium.[19,23] In patients with unstable hemodynamics contrast material may be poorly tolerated. In addition, cardiac catheterization may be hazardous because of embolization.[23] Thus, preoperative echocardiographic and cineangiocardiographic investigation sometimes fail to provide the detailed information needed for an optimal and time-efficient corrective procedure.[1-5,24]

Intraoperative two-dimensional echocardiography reveals this detailed information by providing multiple cardiac views unhampered by the thoracic wall structures. Optimal resolution is obtained because of the proximity of the transducer to the heart and the use of a higher transducer frequency.[9-13]

In all six patients in this study, the pathologic conditions encountered were assessed by direct inspection after opening the heart or the aorta. Intraoperative epicardial two-dimensional echocardiography demonstrated significant pathologic findings undiagnosed by preoperative investigations. In four of six patients, only intraoperative two-dimensional echocardiography allowed complete visualization and correct diagnosis of all pathologic conditions relevant for surgical management.

Intraoperative echocardiography allowed the surgeon to plan the procedure more precisely before cannulation and bypass. When consultation was needed, it was completed before initiation of cardiopulmonary bypass (Patients 3 and 4). Recognition of an unsuspected fistula (Patient 1) made probing in an area with acute inflammation and a ventricular septal abscess unnecessary and indicated the need for double venous cannulation and atriotomy. Patient 6 had a subannular mycotic aneurysm together with a false aneurysm around a valved conduit. This uncommon and complex condition was recognized only with the intraoperative echocardiographic study. With this information less time was required during cross-clamping for exploration of the condition.

Patients (like Patient 1) who require an urgent operation and in whom only echocardiographic studies are performed for the preoperative work-up may benefit from intraoperative echocardiography. Precordial two-dimensional echocardiography and elective cineangiography remain important procedures for a complete preoperative work-up in patients with infective aortic valve endocarditis. However, intraoperative epicardial two-dimensional echocardiography may contribute additional information that proves decisive for surgical management.

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CHAPTER 3.3

Detailed Analysis of Aortic Valve Endocarditis: Comparison of Precordial, Esophageal and Epicardial Two-Dimensional Echocardiography with Surgical Findings

Elma J. Gussenhoven, MD, Lex A. van Herwerden, MD, Jos Roelandt, MD, Egbert Bos, MD, and Nico de Jong, MSc

Transducer miniaturization makes it possible to image the heart from the esophagus. The advantage of this approach is that the sound beam is not hampered by the chest wall and echographic windows created by lungs and ribs.[1] The "window problem" is also solved when the echo system is used intraoperatively with the transducer directly applied to the heart.[2]

The purpose of this report is to compare the two-dimensional echocardiographic (2DE) findings obtained with the conventional precordial, esophageal, and intraoperative epicardial approach with the surgical findings in a male patient with bacterial endocarditis of the aortic valve.

CASE REPORT

A 19-year-old man was known to have a moderate valvular aortic stenosis on clinical grounds. Two months after dental treatment without antibiotic prophylaxis he became sick and complained of nocturnal precordial discomfort, malaise, and fever. On admission to our department, the diagnosis of bacterial endocarditis of the aortic valve was suspected and was subsequently confirmed by blood cultures positive for *Streptococcus viridans*. Intravenous antibiotic therapy was started without delay.

Echocardiographic Studies

Precordial 2DE Investigation (3.5-MHz Phased Array System). Vegetations were seen at the annulus of the anterior aortic wall consistent with the diagnosis of endocarditis. In the anterior part of the aortic wall, an echo-free recess was present and was interpreted as an abscess or as an aneurysm of the right aortic sinus (Fig. 1A,B). After aortic insufficiency developed, the left ventricular cavity increased in size, and its walls became hyperkinetic.

Esophageal 2DE Investigation (3.5-MHz Phased Array System). An aneurysm was seen interposed between the aortic root and the right ventricular outflow tract (Fig. 1C,D). There was open communication between the aortic root and the aneurysm. Only remnants of the left and noncoronary cusp were visible, and a flail right aortic cusp was observed in the left ventricular outflow tract. Vegetations were seen on the left coronary cusp near its commissure with the right coronary cusp. Between the left and noncoronary cusps, a small echo-free space was visible in the posterior aortic wall. The aortic wall above the noncoronary cusp demonstrated peculiar cyclic movements (see Fig. 1C,D).

This information was considered sufficient to proceed to surgery without further angiographic investigation.

Epicardial 2DE Investigation (5 MHz Mechanical Scanner). Intraoperative 2DE performed be-

From the Thoraxcentre, Erasmus University and Academic Hospital Rotterdam-Dijkzigt, and the Interuniversity Cardiology Institute, Rotterdam, The Netherlands.

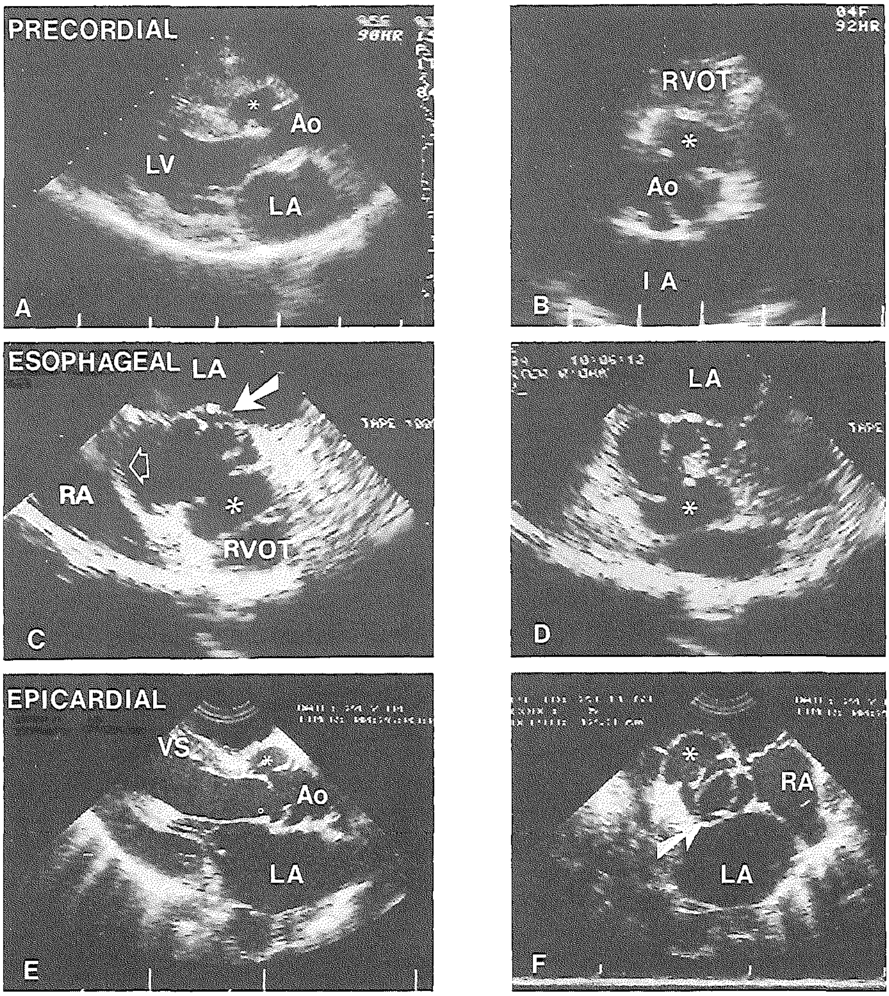

FIGURE 1. Two-dimensional echocardiograms obtained from precordial (A,B), esophageal (C,D), and intraoperative epicardial transducer positions (E,F). The mycotic aneurysm is indicated in all the cross sections by an asterisk, and it is bounded by remnants of the original annulus. It has open communication with the aortic lumen (Ao) and is bordered inferiorly by the interventricular septum (VS) and anteriorly by the right ventricular outflow tract (RVOT). A large vegetation is seen on the right aortic cusp (A,D, and E). The esophageal study revealed that the aortic wall near the noncoronary cusp, adjacent to the right atrium (RA), demonstrated prominent systolic expansions (C; open arrow). A fourth aortic cusp is seen on panels C and F (see arrow).

fore extracorporeal circulation confirmed the presence of a large echo-free area adjacent to the anterior aortic wall bordered by two dense echo structures, leaving an open communication with the aortic lumen (Fig. 1E,F). Two distinct valve cusps, the left and the noncoronary cusps, were seen, with a small echo-free area in between. At the commissure between right and left coronary cusps, extraneous echoes were visible moving up and down during the cardiac cycle.

Surgical Findings

Surgical exploration of the aortic root revealed destruction of the annulus at the right coronary cusp area. Only a small part of this area near the commissures was not affected. In the right aortic sinus, a mycotic aneurysm was seen with a discrete rim of aortic wall tissue. The orifice of the right coronary artery was normal. The right coronary cusp was severely deformed because of the vegetations and was torn from its commissural attachments. The left and noncoronary cusps were both fibrotic, and a small hypoplastic fourth leaflet was interposed between their commissure. Part of the anterior aortic wall was edematous and bulging outwards. This abnormal area extended towards the right and noncoronary sinus. The aortic valve cusps were excised. A Teflon® patch was inserted using the edges of the mycotic aneurysm. A St. Jude prosthesis No. 21 was inserted in aortic position, and the edematous and bulging aortic wall was replaced by a Hemashield prosthesis.

DISCUSSION

Aneurysms of the aortic sinus may be congenital or acquired as a complication of bacterial endocarditis. The right sinus is most commonly involved. The acquired mycotic aneurysm results from an annular abscess and is usually related to the right ventricular outflow tract.[3] The primary lesion in the development of an aortic sinus aneurysm is a separation of the aortic media from the annulus, losing its lower attachment and retracting upwards away from the aortic valve. The patient presented here was known to have aortic valvular stenosis and developed bacterial endocarditis complicated by a mycotic aneurysm of the right aortic sinus. The analysis provided by transesophageal 2DE has been extremely helpful in deciding against cardiac catheterization. New information thus obtained with this device includes the definition of a mycotic aneurysm rather than an abscess in the anterior aortic wall and the unique recognition of cyclic movements in this area, suggesting a deformed and diseased aorta. Moreover, a small echo-free area in the posterior aortic wall was noted, interposed between the left and noncoronary cusp, which turned out to be a fourth hypoplastic aortic cusp.

Intraoperative epicardial echocardiography was performed in order to exclude possible coexistence of additional destructive lesions. Such lesions could have been missed with previous investigations or may have developed during the previous 3 weeks. This intraoperative study confirmed the esophageal findings. Surgical exploration revealed a correct echocardiographic analysis.

The epicardial study illustrated herein is an example from a large clinical series of intraoperative 2DE. Its application has proven of great significance for the surgeon in over 270 patients.

This report indicates that esophageal 2DE is a useful and important adjunct to precordial echocardiography for demonstrating detailed morphologic information about the aortic root relevant to surgical decision making.

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CHAPTER 3.4

ECHOCARDIOGRAPHIC ANALYSIS OF REGURGITANT MITRAL VALVES: INTRAOPERATIVE FUNCTIONAL ANATOMY AND ITS RELATION TO VALVE RECONSTRUCTION.

Lex A. van Herwerden, MD, Alan G. Fraser*, MB MRCP,
Elma J. Gussenhoven, MD, Jos R.T.C. Roelandt, MD,
S. Hong Ki The, MD, Egbert Bos, MD.

The current preference for valve repair in patients with mitral regurgitation requires that more surgeons become familiar with the techniques of reconstructive surgery. Echocardiography has become the principal method for imaging of valvar pathology. Traditionally, echocardiographic analysis of regurgitant mitral valves has concentrated on the description of abnormalities of leaflet motion such as prolapse, while surgical correction aims to restore coaptation of the edges of the leaflets. To reconcile these different approaches, the echocardiographic features of 67 incompetent mitral valves, the findings on direct inspection, and the types of repair performed in 33 patients, were analyzed. The zone of coaptation of the mitral valve was studied in a series of epicardial long-axis views. Four patterns of leaflet closure were found: normal apart from a dilated annulus (12%); normal apposition but absent coaptation (6%); asymmetrical apposition but intact coaptation (43%); and abnormal apposition and absent coaptation (39%). In addition, leaflet motion was described (prolapse, retraction or neither), and the antero-posterior dimension of the mitral annulus was measured. There was a direct relationship between these echo-cardiographic findings and the types of reconstructive techniques which were used. This echocardiographic analysis offers a logical approach to the pre-operative diagnosis of regurgitant mitral valves, and with epicardial imaging, it enhances the surgeon's ability to apply the full spectrum of reconstructive techniques.

Thoraxcenter, Department of Cardiopulmonary Surgery, University Hospital Rotterdam-Dijkzigt, Erasmus University Rotterdam, and the Interuniversity Cardiology Institute, The Netherlands.
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INTRODUCTION.

Reconstructive surgery for mitral regurgitation is preferable to prosthetic valve replacement.[1-9] Traditionally, the repair technique has been determined by the specific type of pathology observed during visual inspection.[10-14]
Two-dimensional echocardiography is now the preferred method of visualizing mitral valvar pathology,[15] but current echocardiographic criteria were not developed to determine the suitability of a valve for reconstruction, or the type of valve repair that should be applied.[16] However, detailed and specific information about the structure of each regurgitant mitral valve is essential to the surgeon. There is a learning curve for performing successful reconstructive surgery, which is influenced by both a proper analysis of the valvar pathology leading to the application of the appropriate repair technique.[12-14]
We reviewed the intraoperative two-dimensional echocardiographic studies of patients who underwent surgical correction of pure mitral regurgitation, in order to provide a framework for the echocardiographic analysis of regurgitant mitral valves. Since the aim of surgical repair is to restore leaflet coaptation to obtain valve competence,[10,11] we specifically observed leaflet closure in the zone of coaptation. Other features of leaflet motion were also assessed, and the size of the mitral annulus was estimated. The relationships between echocardiographic patterns, the findings on subsequent visual inspection, and the type of surgery performed, were studied.

PATIENTS AND METHODS.

Study patients

The intraoperative two-dimensional echocardiograms of 78 patients who underwent operation for correction of pure mitral regurgitation between 1984 and 1989, were analyzed retrospectively. Other patients with signs of valve stenosis or a congenital etiology were excluded. In 11 patients the echocardiographic studies were incomplete, leaving 67 patients for analysis. Their mean age was 58 years (range 29-76), and there were 44 men and 23 women. Two patients had grade II, 21 patients grade III and 41 patients grade IV mitral regurgitation, as determined by biplane cineangiography using Seller's criteria.[17] In 3 patients cineangiography was not performed.
The etiology was classified according to Carpentier[10,11] as degenerative in 39 patients and ischemic in 19 patients. The others had infective endocarditis(4), rheumatic heart disease (2) or a non-ischemic cardiomyopathy (3 patients).

Surgery

Cardiac surgery was performed during cardiopulmonary bypass with moderate hypothermia. Visual analysis of the mitral valve was performed during cardioplegic arrest, using the criteria of Carpentier,[10,11] and the findings were recorded in the operation report. Mitral valve reconstruction was performed in 33 patients (49%) and the valve was replaced by a prosthesis in 34 patients.
Concomitant procedures included coronary artery bypass grafting in 23 patients, aortic valve replacement in 6 patients, tricuspid valve repair in 6 patients, and tricuspid valve replacement in 1 patient. In 1 patient a left ventricular aneurysm was resected, in 1 patient a secundum atrial septal defect was closed, and in 1 patient partial anomalous pulmonary venous drainage was corrected.

Intraoperative echocardiography.

The intraoperative two-dimensional echocardiographic studies were performed with a 5 MHz mechanical sector scanner (ATL 300LX) or a 5 MHz phased array system (Toshiba SSH-160A). The transducer was wrapped in a gas sterilized plastic bag, and placed on the right ventricular outflow tract.[18,19] Two-dimensional echocardiograms were obtained by the cardiac surgeon just before cardiopulmonary bypass was started. The studies were stored on videotape.

Echocardiographic analysis of the mitral valve.

The transducer was placed on the right ventricular outflow tract, to image the left ventricle and mitral valve in long axis. This transducer position was maintained, with minor modifications to its angle and site, while several slow echocardiographic sweeps were made through the mitral valve, producing a series of images between the postero-medial and antero-lateral commissures. Thus, closure of the leaflets during systole was observed carefully along the whole of the zone of coaptation of the mitral valve. These sequential scans[20,21] in the left ventricular long axis view were the major source of information on leaflet closure, leaflet motion and mitral annular size. The echocardiographic study was considered complete, if the leaflets were seen along the entire closure line of the mitral valve, and if the antero-posterior dimension of the mitral annulus could be measured.

1. Leaflet closure was described in terms of apposition and coaptation. The term **apposition** was used to describe the relative positions of the leaflet edges to each other in the zone of coaptation during systole. The **leaflet edge** in any plane was defined as the point of angulation between the lines formed by the chordae and the body of the valve leaflet. Apposition was judged to be **normal** if the leaflet edges met along the entire closure line,

or if they were symmetrically aligned opposite each other (Figures 1 and 2). Apposition was considered to be **abnormal** whenever the edges were not symmetrically aligned (Figures 3-7). The leaflets were considered to **coapt** if any parts of the tissues of the anterior and posterior leaflets met during systole (Figures 1 and 3).

2. After description of leaflet closure, **motion of the bodies of the leaflets** was observed. For this analysis during surgery, a leaflet was considered to **prolapse** if its body or any other leaflet tissue, reached or passed the mitral annulus during systole, in a long axis plane (Figures 3 and 4). For this definition, the limits of the annulus were considered to be a notional line drawn between the hinge points at the bases of both leaflets. The leaflets were considered to show **retraction** if the body of the leaflet was arrested in the left ventricular cavity during systole, at an unusual distance from the plane of the mitral valve annulus, or if the body of the anterior mitral leaflet was angulated towards the left ventricle during systole (Figures 5 and 6).
3. Finally, **the size of the annulus of the mitral valve** was estimated from a caliper measurement superimposed on the left ventricular long-axis image. The longest distance between the base of the aortic cusp at the posterior aortic root, and the hinge point of the posterior mitral leaflet, was considered to reflect the antero-posterior dimension of the mitral orifice. The mitral annulus was considered to be unequivocally dilated if this antero-posterior dimension was 35 mm or more. In patients with an unusually small body surface area (2 patients) a dimension of 30 mm or more was judged to be enlarged.

   When present, description of other valvar pathology was added. The posterior mitral leaflet was considered to be **"frozen"** if the leaflet did not move during the cardiac cycle and if it was not retracted during systole (Figure 7). Chordal rupture was characterized by a free-floating movement of the chordae within the left atrium during systole.

Classification

In order to relate the echocardiographic observations to the specific repair techniques which we used to restore closure of the valve leaflets, the patterns of leaflet apposition and coaptation were classified. There were 4 main categories (Table 1): normal apposition and intact coaptation (Pattern I, Figure 1), normal apposition, but absent coaptation (Pattern II, Figure 2), abnormal apposition but intact coaptation (Pattern III, Figure 3), and no apposition and absent coaptation with one or both leaflet edges undefined (Pattern IV, Figures 4 and 5).

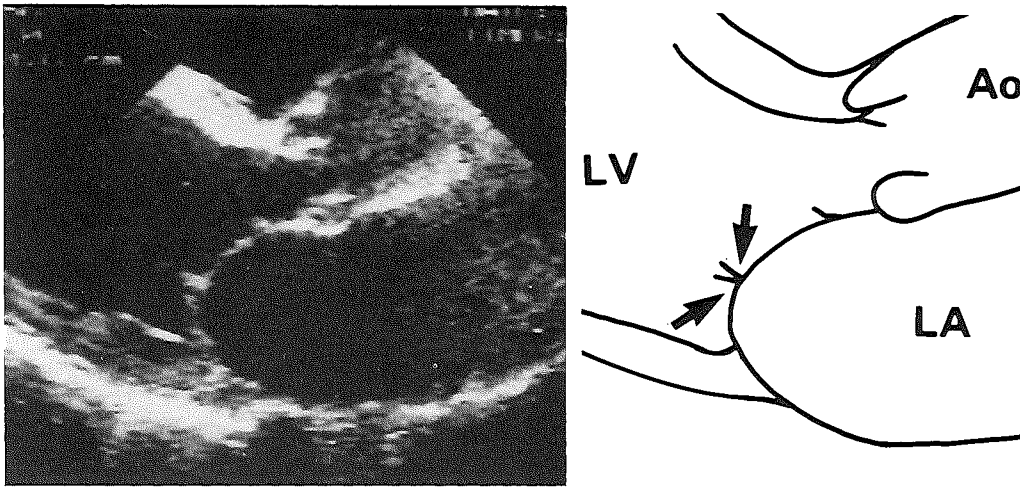


Figure 1: This and the following figures are left ventricular long axis views obtained by placing the transducer directly upon the exposed right ventricular outflow tract.
Pattern I (normal apposition and intact coaptation).
Echo analysis: The leaflet edges (arrows) are apposed and there is normal coaptation. Leaflet motion: no prolapse or retraction. The antero-posterior diameter of the annulus is 42 mm (enlarged). **Suggested surgery**: Ring annuloplasty.
Legend to this and following figures: Ao = aorta, LA = left atrium, LV = left ventricle.

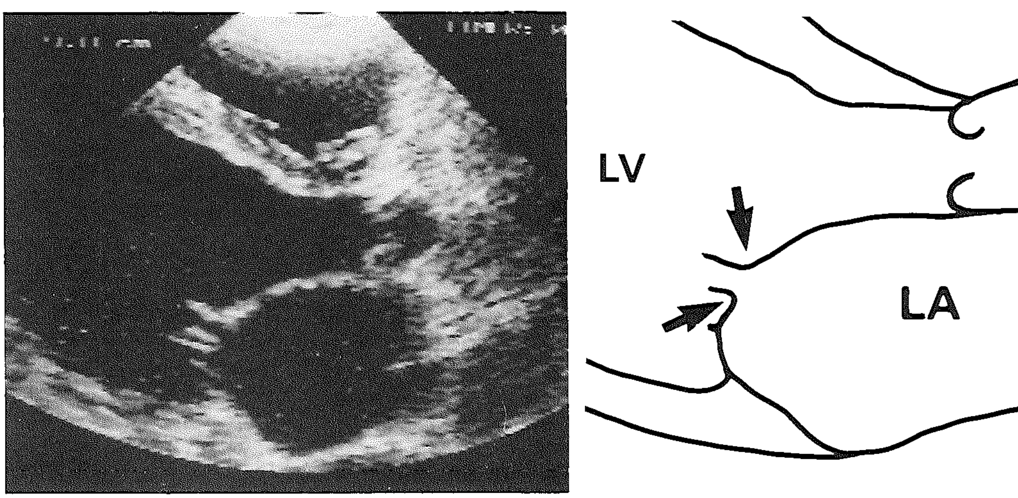


Figure 2:
Pattern II (normal apposition, absent coaptation).
Echo analysis: The leaflet edges (arrows) are symmetrically aligned opposite each other but the leaflets do not coapt. Leaflet motion: no prolapse or retraction. The antero-posterior dimension of the annulus is 40 mm (enlarged). **Suggested surgery**: Ring annuloplasty.

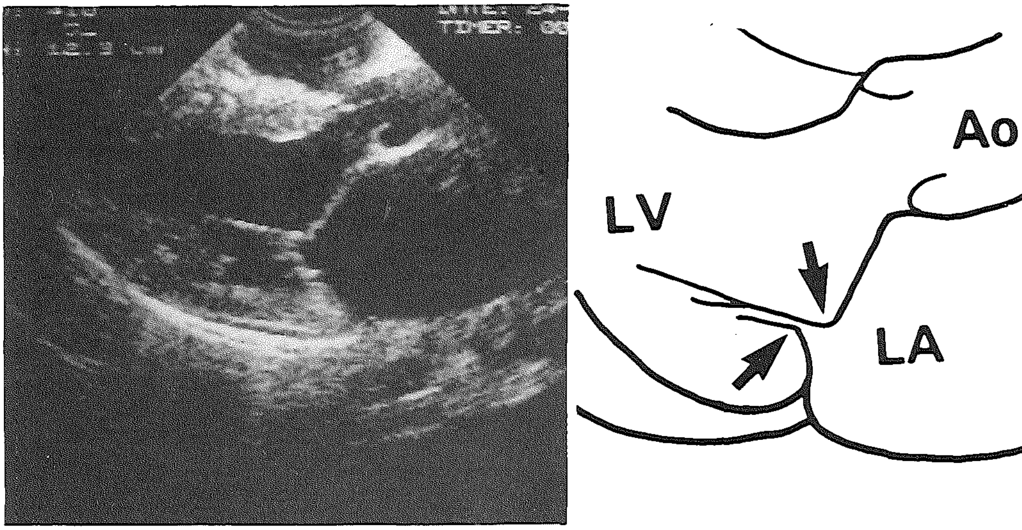
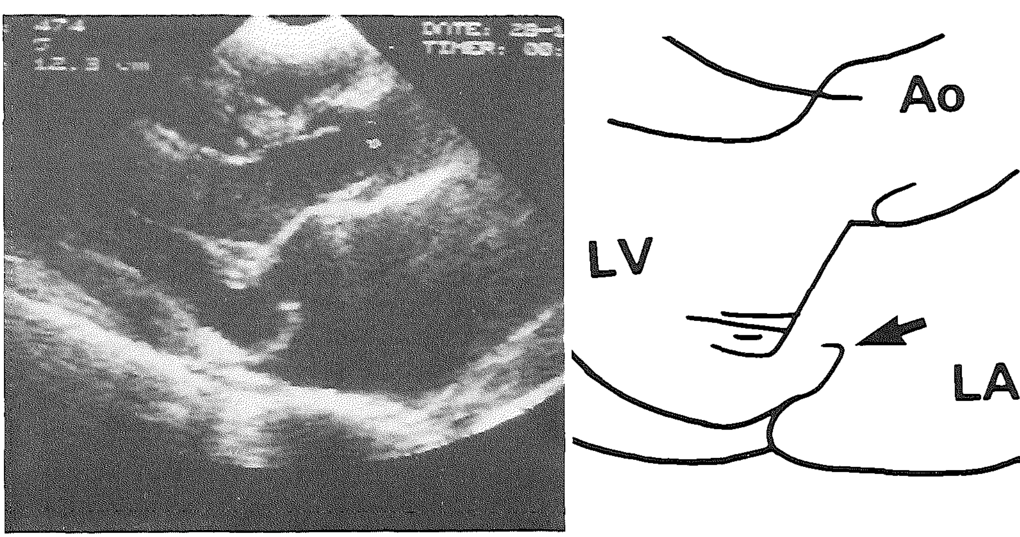


Figure 3:
Pattern III (abnormal apposition and intact coaptation) with anterior leaflet prolapse.
Echo analysis: The leaflet edges (arrows) appose abnormally, but the leaflets do coapt. The anterior leaflet shows central prolapse. Note that the body of the anterior leaflet does not pass the mitral annulus in this patient. The aortic-mitral fibrous continuity is seen as dense reflections below the attachment of the coronary cusp of the aortic valve, demonstrating the distance between the base of the aortic valve cusp and the hinge point of the anterior mitral leaflet.
Antero-posterior dimension of the annulus is 38 mm (enlarged).
Suggested surgery: shortening of anterior leaflet chordae, and ring annuloplasty according to the surgeon's preference.



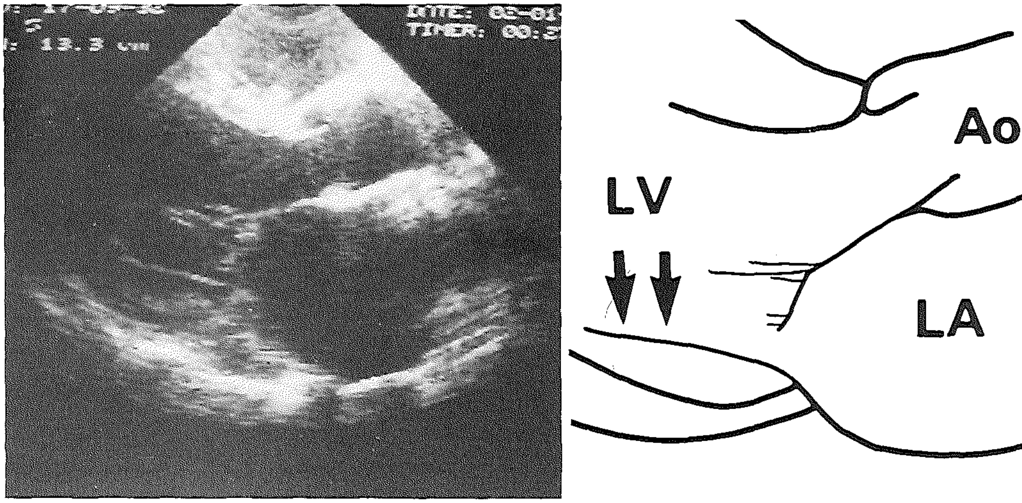


Figure 5:
Pattern IV (abnormal apposition and absent coaptation) with anterior and posterior leaflet retraction
Echo analysis: The leaflet edges do not appose and the leaflets do not coapt. The posterior leaflet is retracted (arrows). The anterior leaflet shows an angle towards the left ventricular cavity and it is displaced away from the mitral annulus. The antero-posterior dimension of the annulus is 40 mm (enlarged).
Suggested surgery: beyond basic reconstructive techniques. A low-profile prosthesis can be inserted without leaflet resection.

Figure 4:
Pattern IV (abnormal apposition and absent coaptation) with posterior leaflet prolapse.
Echo analysis: One of the leaflet edges (arrow) is undefined and the leaflets do not coapt. Leaflet motion: the posterior leaflet shows central prolapse. The antero-posterior dimension of the annulus is 48 mm (enlarged).
Suggested surgery: quadrangular resection of the posterior mitral leaflet and annuloplasty.

Table 1. Intraoperative echocardiographic findings in 67 patients with mitral valve regurgitation requiring surgical correction

Pattern	Leaflet closure		Leaflet motion		Annulus	No.	
	Apposition	Coaptation	Prolapse	Retraction			Etiology
I	normal	intact	-	-	normal	1	isc 1
8 (12%)					enlarged	7	deg 4, isc 1, cm 2
II	normal	absent	-	-	enlarged	4	isc 4
4 (6%)							
III	abnormal	intact	aml	-	normal	2	isc 2
29 (43%)			aml	-	enlarged	12	deg 6, isc 3, rhe 2, cm 1
			pml	-	enlarged	13	deg 8, isc 3, end 2
			aml+ pml	-	enlarged	2	isc 2
IV	abnormal	absent	-	pml	normal	1	isc 1
26 (39%)			-	pml	enlarged	1	isc 1
			aml	-	enlarged	6	deg 4, end 2
			pml	-	enlarged	15	deg 15
			aml+pml	-	enlarged	2	deg 2
			-	aml+pml	enlarged	1	isc 1

Legend to Table 1.
aml: anterior mitral leaflet; cm: cardiomyopathy; deg: degenerative; end: active endocarditis; isc: ischemic; pml: posterior mitral leaflet; rhe: rheumatic.

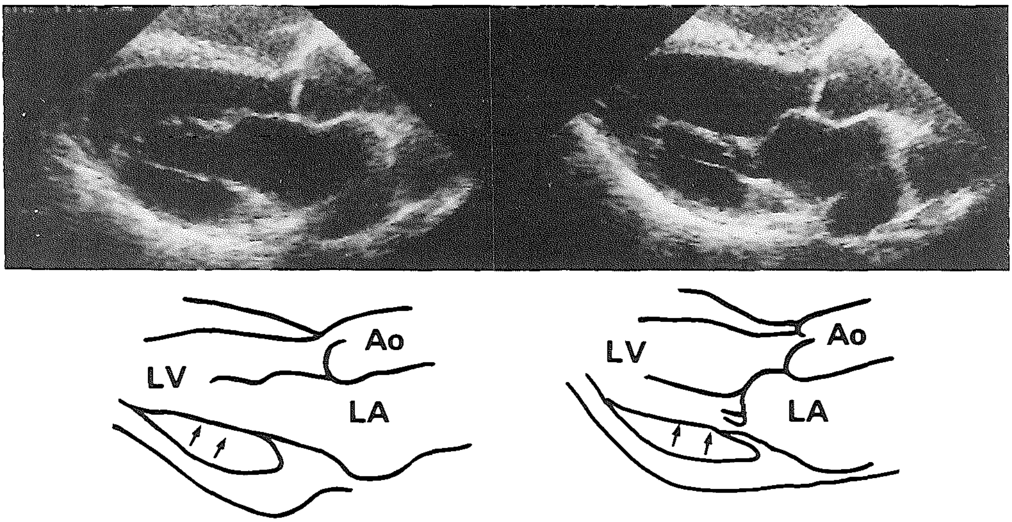


Figure 6:
Pattern IV. Diastolic (A) and systolic (B) still-frames. The posterior leaflet (arrows) is **retracted** into the left ventricle throughout the cardiac cycle.

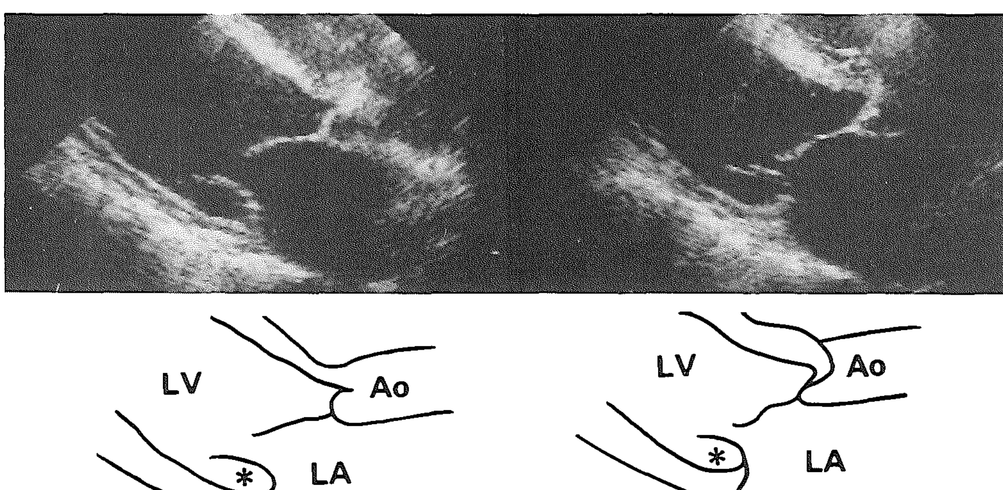


Figure 7:
Pattern II. Diastolic (A) and systolic (B) still-frames. The posterior leaflet (asterix) hardly moves during the cardiac cycle; **"frozen leaflet"**. The posterior leaflet demonstrated normal pliability during surgical inspection.

Within these patterns, valvar pathology was further subdivided according to motion of the leaflets and the dimension of the annulus (Table 1). Theoretically, in each category there may be associated mitral valve prolapse or retraction and, or annular dilatation.

RESULTS

Intraoperative echo findings and surgical observations.

The findings of the epicardial echocardiographic studies and their relation to the etiology of mitral valve disease in the 67 patients who were studied, are summarized in Table 1.

Pattern I (Figure 1) was seen in 8 patients. In this group, neither leaflet prolapse nor retraction was observed. Seven patients had a dilated annulus. In 1 patient a ruptured chord of the posterior leaflet was seen on echocardiography, but the related prolapse demonstrated on surgical inspection was not visualized. Another patient, who had no abnormality on echocardiography apart from an enlarged annulus, had stiffening of the leaflet edges and rough zone on surgical inspection. In the other 6 patients the visual observations confirmed the echocardiographic findings and revealed no other pathology apart from the dilated annulus, which was relevant for valve repair.

Pattern II (Figure 2) was encountered in 4 patients, all of whom had ischemic heart disease. The leaflets showed no prolapse or retraction. The annular dimension was enlarged in all 4 patients. On surgical inspection the leaflets appeared normal and there was moderate dilatation of the annulus. The "gap" seen between the leaflets with echocardiography could of course not be demonstrated in the flaccid and arrested heart after cardioplegia.

Pattern III (Figure 3) was seen in 29 patients. In 2 patients, prolapse of the anterior mitral leaflet was encountered and the dimension of the mitral annulus was normal. The other patients all had an enlarged mitral annulus. In them, abnormal apposition of the leaflet edges was due to prolapse of the anterior leaflet in 12 patients (Figure 3) and to prolapse of the posterior leaflet in 13. In 2 patients both leaflet bodies prolapsed, but there was override of one of the leaflet edges over the other. Surgical inspection revealed posterior leaflet prolapse in 1 patient whose cross-sectional echocardiograms had been interpreted to show anterior leaflet prolapse.

Pattern IV was seen in 26 patients (Figures 4 and 5). The mitral annulus was enlarged in all patients except one, who had severe retraction of the posterior mitral leaflet. Of the remaining 25 patients, 6 had prolapse of the anterior leaflet and 15 prolapse of the posterior leaflet (Figure 4). In 2 patients both leaflets showed gross prolapse into the left atrium. One patient had retraction of both mitral leaflets (Figure 5) and another patient had retraction of the posterior leaflet (Figure 6). Surgical observations revealed no other data with relevance to valve repair.

Other findings.

In 6 patients the posterior mitral leaflet was immobile throughout the cardiac cycle ("frozen leaflet", Figure 7). Surgical inspection revealed that the leaflet showed inflammatory stiffening in only 1 patient, who had rheumatic disease. The posterior leaflet was pliable in the other 5 patients, all of whom had ischemic heart disease and had had a posterior myocardial infarction.
Chordal rupture was observed with echocardiography in 26 patients. On surgical inspection 2 other patients were found to have chordal rupture, but the chordal remnants were found to be attached to the papillary muscle rather than to the leaflet.
In the 67 patients studied, the antero-posterior dimension of the mitral annulus ranged from 26 to 60 mm. The mean was 47 mm.

Surgical procedures

The mitral valve was replaced by a prosthesis in 34 patients. Reasons to replace, rather than to reconstruct, the valve were related to the preference of the attending surgeon, the clinical circumstances and leaflet characteristics. In 4 patients an attempt was made to reconstruct the valve, but immediately followed by valve replacement. Patients with active endocarditis were not considered for valve repair.
The details of the reconstructive techniques which we employed in 33 patients and the relation to the echocardiographic valve analysis, are given in Table 2. In 1 patient with normal apposition and coaptation (Pattern I), no leaflet prolapse or retraction and a normal annulus size, a posterior leaflet prolapse in the commissural area was found and treated with a small quadrangular resection. Enlargement of the annulus was treated by the insertion of a Carpentier annular ring in 4 patients with normal apposition of the leaflets (Pattern I and II) and no other procedure was required. Quadrangular resection was performed in 18 patients with prolapse of the posterior leaflet, irrespective of whether abnormal apposition was associated with normal coaptation (5 patients, Pattern III) or absent coaptation (13 patients, Pattern IV).
In 3 patients with abnormal apposition but intact coaptation (Pattern III), the posterior leaflet prolapse could be treated with chordal shortening. In 3 patients with abnormal apposition and intact coaptation (Pattern III), the anterior leaflet

Table 2. Echocardiographic classification in 33 patients with mitral valve regurgitation and type of mitral valve reconstruction performed.

Pattern	Leaflet closure		Leaflet motion		Annulus	
	Apposition	Coaptation	Prolapse	Retraction		Surgery
I	normal	intact	-	-	normal	local repair (1)
					enlarged	annuloplasty (1)
II	normal	absent	-	-	enlarged	annuloplasty (3)
III	abnormal	intact	aml	-	normal	chordal/papillary muscle shortening (2)
			aml	-	enlarged	pap. muscle shortening* (1)
			pml	-	enlarged	q-resection pml* (5) chordal shortening* (3)
			aml+pml	-	enlarged	pap. muscle shortening* (2)
IV	abnormal	absent	-	pml	normal	ring annuloplasty (1)
			pml	-	enlarged	q-resection pml* (13)
			aml+pml	-	enlarged	q-resection pml, chordal shortening/reinsertion* (1)

Legend to Table 2.
aml: anterior mitral leaflet; pap. muscle shortening: papillary muscle shortening; pml: posterior mitral leaflet; q-resection: quadrangular resection; *: implantation of annuloplasty ring upon surgeon's preference.
Between brackets the number of procedures performed.

prolapse was treated with chordal or papillary muscle shortening. In 1 patient with abnormal apposition and no coaptation (Pattern IV) and posterior leaflet retraction, a ring was used to reduce the normal sized annulus to the surface area of the anterior leaflet. One patient with absent apposition and absent coaptation (Pattern IV) had posterior leaflet prolapse treated with quadrangular resection and anterior leaflet prolapse treated with chordal shortening and reinsertion.

In 5 patients insertion of a ring was the only procedure performed. In 20 patients out of 25 patients with an enlarged annulus, a ring was added to the repair.

DISCUSSION

Interest in valve reconstruction rather than valve replacement for the treatment of mitral regurgitation has increased, because it is associated in non-randomized studies with better survival and a reduction in valve related morbidity,[1,4,5] and because valve repairs are durable.[1,3,6,10] Moreover, evidence is accumulating that left ventricular function is preserved better after valve reconstruction than after replacement.[7-9] These factors justify an aggressive approach to the application of reconstructive techniques.

Valve repair is technically more demanding than valve replacement, and it is associated with a definite learning curve.[12-14] Such operations require a longer ischemic cross-clamp time than is necessary for prosthetic valve replacement.[5,12,13] This includes the time required for visual analysis of the valve, and for intraoperative decision making. Proper visual inspection has to be learned, but is often impaired by the flaccidity of a cardioplegic arrested heart or by a small left atrium, particularly in patients with mitral regurgitation of ischemic etiology. These problems, and the relatively high operative mortality associated with many operations involving the mitral valve,[22,23] may be good reasons to avoid the risks of a failed reconstruction, by inserting a prosthesis. These obstacles to performing reconstructive valve surgery may be overcome if accurate and reliable information about mitral valvar morphology is available to the surgeon, which indicates the type of repair likely to be required. It was the purpose of this retrospective study to document the ability of intraoperative epicardial echocardiography to provide such data. We have used the data to describe a logical frame-work for the echocardiographic analysis of the morphology of the regurgitant mitral valve.

Echocardiographic valve analysis.

The main cross-section which was used for intraoperative imaging of the mitral valve was the left ventricular long axis view. This is comparable to the standard parasternal long-axis view obtained on precordial echocardiography. The parasternal long-axis plane is preferred over other cross-sections to describe displacement of the bodies of the mitral leaflets.[24,25]

Unlike precordial echocardiography,[16] the high resolution of epicardial echocardiography allows exact determination of the edges of the leaflets. Since a reconstructive operation for mitral regurgitation aims to restore symmetrical coaptation of the leaflets,[10,11] clear visualization of their edges is necessary. Focussing on leaflet closure when analyzing regurgitant mitral valves, circumvents the problems of defining normal and abnormal leaflet motion.

Sequential scanning[20,21] is required to describe the extent and distribution of normal or abnormal closure of the leaflets fully, along the entire zone of coaptation. The commissural areas in particular must be studied in detail, because insufficient interrogation will lead to wrong conclusions being made about the cause of valvar insufficiency. Angulation of the transducer so that it can be directed towards the leaflets near the postero-medial and antero-lateral commissures, is much easier during epicardial echocardiography than during a normal precordial study.

In the present series, intraoperative epicardial echocardiography was very helpful for defining mitral valvar pathology and identifying the cause of regurgitation. The majority of patients were studied by two-dimensional echocardiography alone, but more recently color flow mapping has been a valuable adjunct to the analysis of these problems. It is used now routinely, and when doubt arises as to which leaflet is abnormal and giving rise to regurgitation, the direction of the jet is very informative.

In patients with normal closure of the mitral leaflets (Pattern I), or with normal apposition but loss of coaptation (Pattern II), valve insufficiency is usually due to annular dilatation alone. If the annulus size is normal, then perforation of a leaflet or other unusual pathology should be suspected. Patients with other patterns of closure (Patterns III and IV) have abnormal motion of the leaflets - either prolapse or retraction. These abnormalities and their location should be described separately for each leaflet. We deliberately avoided the term normal leaflet motion, since no criteria are available to define this concept.[26]

Some patients with Pattern III leaflet closure were determined in this study to have prolapse of a leaflet even though the body of the leaflet did not appear on the echocardiographic images above the annulus (Figure 3).[20] These patients had abnormal apposition of the edges of the leaflets. On visual inspection all of them had prolapse, as defined surgically by the overlap of one leaflet over the other when gentle traction was applied to nerve hooks placed under the opposing leaflet. Although there was no obvious abnormality of the bodies of the leaflets in these patients, there was significant regurgitation due to the abnormal relationship of the edges of the leaflets. Echocardiographers should be aware that inspection of such valves consistently reveals prolapse as defined surgically.

In this series, a prolapse of the **body** of the leaflet was not treated specifically, unless it was associated with another abnormality affecting the apposition or coaptation of the edges of the leaflets. For this reason, also, undue concentration on leaflet prolapse during precordial or transesophageal echocardiographic studies of regurgitant mitral valves, rather than on pattern of leaflet closure, is unhelpful. In 3 patients we used the term "retracted leaflet" to describe the situation in which the posterior leaflet is pulled into the left ventricle, or the anterior leaflet shows angulation towards the left ventricular cavity, during systole (Figures 5 and 6). The associated pathology has probably been described previously, as "incomplete mitral leaflet closure", but this term is defined with precordial echocardiography in the apical four-chamber view.[27,28]
We have also introduced the term "frozen leaflet". This was observed in 5 patients, and always involved the posterior leaflet (Figure 7). This pattern of motion was caused by loss of pliability of the leaflet as a consequence of rheumatic valve disease in 1 patient, and by expansion of the akinetic basal myocardium after myocardial infarction in the other patients. This abnormality of mitral leaflet motion does not appear to have been recognized previously and would be very difficult to recognize on visual inspection of a flaccid heart.

Measurement of the annulus is another major step in the echocardiographic analysis of the mitral valve. The dimension of the annulus as defined in this study does not coincide with the annulus as seen on inspection at surgery, but it is practical for use during intraoperative echocardiography. In patients with mitral regurgitation, it is often difficult to identify the hinge point of the anterior leaflet. The measurement which we employed overestimates the size of the annulus by approximately 5 mm., because it includes the region of fibrous continuity between the aortic and mitral valves (Figure 3).[29]

Valve analysis by direct inspection.

The classification of regurgitant mitral valves which we have described, is based entirely on the echocardiographic analysis of functional anatomy. In contrast, the widely used anatomic classification of Carpentier is derived from visual inspection of the valve and an assessment of leaflet motion and pliability,[10,11] which are obtained in the fibrillating or cardioplegic arrested heart. The Carpentier classification describes leaflet motion as normal, prolapsed or restricted. "Normal" motion is assumed if a leaflet appears freely mobile and capable of normal excursion,

but without prolapse. "Prolapse" is identified by applying traction to the edges of leaflets. The leaflet motion is called "restricted" if the leaflet does not open normally. These definitions, especially of "normal" and "restricted" motion, are difficult to apply reliably, and so the Carpentier classification cannot be transferred directly to echocardiographic images. Probably what we call "retracted" motion will be referred to as "restricted" leaflet motion during visual inspection.
One disadvantage of epicardial echocardiography compared with direct inspection, is that it may be impossible to distinguish between different causes of reduced leaflet motion. These include hemodynamic factors such as a low cardiac output or severe aortic regurgitation, but also valvar disease resulting in a stiff leaflet, which all my cause a "frozen " leaflet.

Relevance of echocardiographic findings to reconstructive surgery

In the present series, reconstructions were performed according to the techniques of Carpentier [10-14] and as summarized in Table 2. This represents our initial experience, and the majority of repairs only included the application of basic techniques. Occasionally, there may be an indication to apply other reconstructive techniques.[3,4,6,7]
In most patients with Pattern I and in all with Pattern II leaflet closure, the only surgical procedure which is required is correction of the annular dilatation, by the insertion of a ring or by another procedure. The regular adult-sized Carpentier rings (size 32-36) reduce the mitral annulus as measured in this study to 25-30 mm.
In patients with pattern III leaflet closure, coaptation is preserved. Correction of anterior leaflet prolapse as defined in this study, is possible using chordal or papillary muscle shortening procedures. Correction of central posterior leaflet prolapse is most safely performed by quadrangular resection. Posterior leaflet prolapse in the commissural area may be treated by shortening of the supporting tissues or by small quadrangular resection.
In patients with pattern IV leaflet closure, coaptation is lost due to major deficiencies in the support mechanism of the leaflet. Treatment of prolapse of the anterior leaflet requires transposition of a secondary chorda or transfer of the chordae of the opposing posterior leaflet.[30] The treatment of patients with central prolapse of the posterior leaflet is mainly quadrangular leaflet resection, because up to 50 % of the posterior leaflet can be excised. If the prolapse involves more than 50% of the leaflet, then more extensive repair techniques are required.
In patients with abnormal leaflet closure due to retraction of one or both leaflets, experienced surgeons can perform more complex repairs or choose to replace the valve.

Conclusions

Intraoperative epicardial echocardiography is useful in patients with mitral regurgitation, for assessing valvar pathology and for determining the type of repair which should be applied. With this information, the surgeon can consider risks in patients with complex valvar disease, associated pathology such as ischemic heart disease and his personal experience with the required repair technique, before the aorta is cross-clamped. Echocardiographic valve analysis is particular valuable when visual analysis is impaired due to a small left atrium or the flaccidity of a cardioplegic arrested heart. It reveals valvar pathology that is extremely difficult to repair, and supports the surgeon's learning process.
Echocardiographic analysis of the mitral valve as used in this series, is possible because of the high quality of epicardial images. It may, however, also be helpful in the preoperative evaluation of patients by transthoracic echocardiography, especially when they have good ultrasound windows. High quality imaging of the mitral valve is also possible with transesophageal echocardiography, but the value of this approach for the preoperative analysis of the mitral valve will depend on full visualization of the entire zone of coaptation including the posteromedial commissure, and on correct interpretation of the tangential cross-sections through the zone of coaptation.

ACKNOWLEDGMENTS

We appreciate the contribution of the nursing staff of the operating rooms for assistance in obtaining the intraoperative echocardiographic images and the surgeons Max Haalebos, Bas Mochtar, Frans Leicher and Gert Kootstra for performing intraoperative echocardiographic studies.

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CHAPTER 3.5

LEFT VENTRICULAR OUTFLOW TRACT OBSTRUCTION AFTER MITRAL VALVE REPAIR ASSESSED WITH INTRAOPERATIVE ECHOCARDIOGRAPHY.

L.A. van Herwerden MD., A.G. Fraser MRCP., E. Bos MD.
Thorax Center Dykzigt Hospital, Erasmus University
Rotterdam, The Netherlands.

To the Editor:

Persistent left ventricular outflow tract obstruction (LVOTO) due to systolic anterior motion (SAM) is an infrequent but disturbing complication of mitral valve repair.[1-3] In a recent report, SAM and LVOTO was detected by intraoperative echocardiography in 5 patients, and then immediate reintervention including valve replacement was performed in 4.[3] However, we have found that immediate reintervention may be not required. We report 2 patients who developed SAM and transient, severe LVOTO immediately after termination of cardiopulmonary bypass. Without further intervention, neither patient had persistent LVOTO at follow-up, either at rest or during exercise.

Case 1. A 61 year old man with severe mitral regurgitation was operated using cardiopulmonary bypass, moderate hypothermia and cardioplegic arrest. On inspection the posterior leaflet showed central prolapse due to chordal rupture, and the anterior leaflet showed prolapse centrally and towards the posteromedial commissure due to chordal elongation and rupture. The mitral anulus was distended and the anterior and posterior leaflets were both enlarged. The valve was repaired by posterior leaflet quadrangular resection, fixation of a ruptured chord and shortening of elongated chords to the anterior leaflet. The repair was completed by insertion of a Carpentier ring No. 34. The remaining part of the posterior leaflet measured 22 mm. centrally. After termination of cardiopulmonary bypass, epicardial echocardiography and color Doppler flow mapping showed systolic anterior motion of the anterior mitral leaflet (Fig.1), turbulent flow in the left ventricular outflow tract, and a competent mitral valve. Ten minutes after termination of

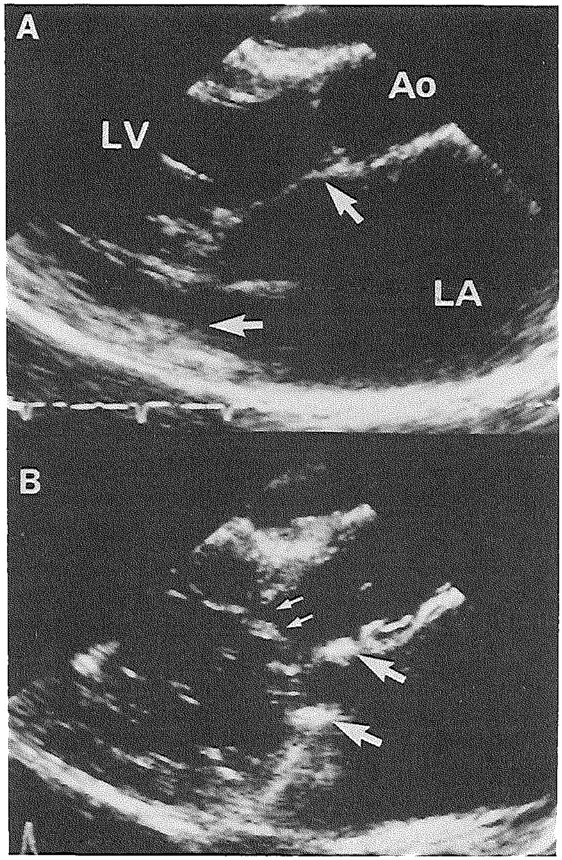

Figure 1.
Postoperative epicardial two-dimensional echocardiogram in the left ventricular long-axis view in Case 1. The small arrows point at systolic anterior motion of the anterior mitral leaflet. The heavy arrows point at the Carpentier ring. Legend: Ao = aorta, LA = left atrium, LV = left ventricle.

bypass a peak velocity across the LVOT of 4.2 m/sec (estimated gradient 70 mmHg) was measured using continuous-wave Doppler (CW-Doppler) with the transducer on the distal right lateral aspect of the ascending aorta (Fig 2A). Thirty minutes after termination of bypass the gradient had fallen to 16 mmHg without additional treatment (Fig.2B). Subsequently, the thorax was closed. Precordial echocardiography was performed 3 weeks after surgery. Mild systolic anterior movement of the anterior leaflet of the mitral valve persisted but the peak velocity of flow across the LVOT was only 1.6 m/sec, representing a resting gradient of 10 mmHg. During exercise this did not change, and after amyl nitrate inhalation, the peak velocity across the LVOT increased to 2.2 m/sec, equivalent to a peak gradient of 19 mmHg. There was no significant residual mitral regurgitation

Case 2. A 66 year old man with severe mitral regurgitation of degenerative etiology and associated coronary artery disease underwent mitral valve repair and bypass grafting of the right coronary artery. On inspection the posterior leaflet showed central prolapse and chordal ruptures. The anterior mitral leaflet was large and the anulus was distended. The valve was reconstructed by quadrangular resection of 50 % of the posterior leaflet. The remaining part of the posterior leaflet measured 20 mm centrally. A Carpentier ring size 34 was inserted and was not considered to be too small. During termination of bypass, the circulation was supported with 4 mcg/kg/min dobutamine. On echocardiographic inspection, there was moderately severe SAM, insignificant residual regurgitation, and a velocity across the LVOT of 4.2 m/sec (estimated gradient 70 mmHg). During continued inotropic support, the circulation further recovered. The estimated peak gradients measured 30 minutes after termination of bypass and just before chest closure were 50 mmHg and 30 mmHg respectively. The patient was restudied 6 months after operation. There was no SAM and no residual regurgitation. The resting gradient measured 1.1 m/sec (estimated gradient 5 mmHg), and after both exercise or amyl nitrate inhalation it was 1.35 m/sec (estimated gradient 7 mmHg).

Discussion

Persistent LVOTO after reconstruction for degenerative mitral valve regurgitation which has included a rigid ring seems to occur in 6-10% of patients.[1-3] Knowledge of the late follow-up of these patients is limited, but reports suggest that there are no serious clinical consequences, although there may be a tendency to recurrence of mitral valve incompetence.[3]

The mechanism leading to SAM in patients with mitral regurgitation of a degenerative etiology after Carpentier repair, is thought to be an association of excess leaflet tissue in a narrowed mitral valve anulus, with a reduced angle between the aortic and mitral valve planes and a change of in- and outflow patterns.[1] Specific criteria predicting SAM with persisting LVOTO after mitral valve repair are not established. Excess leaflet tissue, a high posterior mitral leaflet and remodelling of the ring seem to be elements of the repair that are amenable to modification, and may therefore prevent LVOTO due to SAM.[1]

Intraoperative echocardiography can alert the surgeon to the occurrence of SAM, and allows an estimate to be made of the severity of the LVOTO.[3] However, there are no data on the intraoperative incidence of SAM after valve repair. Five patients with SAM and LVOTO were recently reported, who underwent immediate reinter-

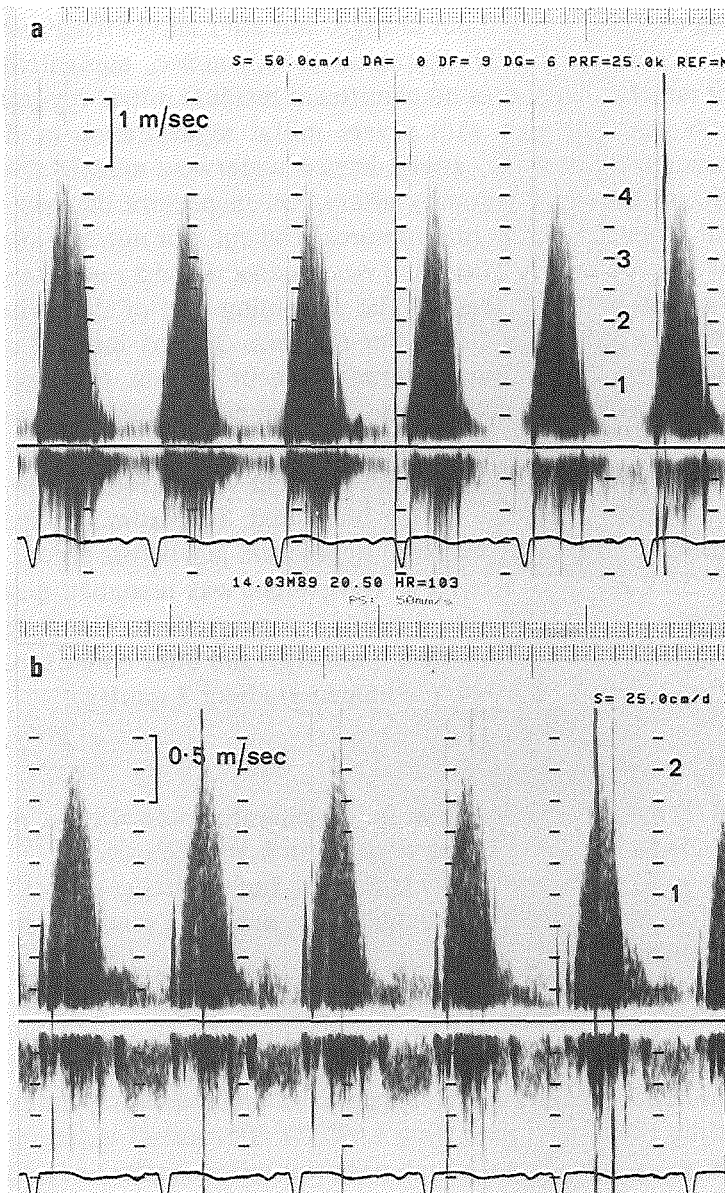

Figure 2.
Intraoperative continuous wave Doppler with the transducer on the distal ascending aorta.
A. Ten minutes after termination of cardiopulmonary bypass, the systolic peak velocity is 4.2 m/sec (estimated gradient 70 mmHg).
B. Thirty minutes after termination of cardiopulmonary bypass, the systolic peak velocity is reduced to 2 m/sec (estimated gradient 16 mmHg). Note the reduced scale of panel B.

vention after gradients between 40 and 90 mmHg were measured with continuous-wave Doppler. We found 5 patients with part of the anterior leaflet showing SAM after Carpentier valve repair, in a limited group of 20 patients with valve regurgitation of a degenerative etiology. Only the 2 patients reported in this letter had LVOTO, which did not persist. The decrease of the left ventricular gradient during recovery after bypass was considered as an indication of a temporary, dynamic obstruction not requiring further intervention. In addition, one of these patients received inotropes during this period. In the short term follow up of our patients, there were no significant outflow gradients. This suggests that our intraoperative decisions were justified.

If SAM and LVOTO occurs after termination of cardiopulmonary bypass, sufficient time should be taken before a decision for reintervention is made. Left ventricular outflow gradients shortly after termination of bypass may be dynamic and are not necessarily indicative of persistent LVOTO after Carpentier mitral valve repair.

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CHAPTER 3.6

The Role of Intraoperative Two-Dimensional Echocardiography in the Assessment of Thoracic Aorta Pathology

O. A. Schippers[1], *W. J. Gussenhoven*[2], *L. A. van Herwerden*[1], *M. A. Taams*[1], *J. Roelandt*[1], *N. Bom*[1], *and E. Bos*[1]

[1] Thorax Centre, Academic Hospital, Rotterdam-Dijkzigt
[2] Interuniversity Cardiology Institute, Netherlands

The role of intraoperative two-dimensional echocardiography is discussed in 15 consecutive patients with thoracic aorta pathology undergoing cardiac surgery. A 5 MHz mechanical scanner was used before and immediately after cardiopulmonary bypass. In 5 patients intraoperative two-dimensional studies revealed crucial morphologic information which, consequently, had a marked influence on their planned surgical procedure. In 3 patients the findings provided additional information whereas in the remaining patients the intraoperative echocardiographic findings confirmed the preoperative diagnosis. Following surgery the adequacy of cardiac repair was assessed and, in one patient, epicardial echocardiography indicated the necessity for reoperation. The application of intraoperative two-dimensional echocardiography leads to a better understanding of the pathology involved and facilitates a more appropriate decision concerning the surgical procedure.

Introduction

Conventional non-invasive and invasive methods may fail to provide an accurate diagnosis in patients suspected of thoracic aorta pathology. False negative echocardiographic (11, 16, 23), angiographic (4, 5, 12, 20) and computed tomographic (7, 13) studies of aortic dissection are not uncommon. Hence, cardiac surgeons may face an unexpected aortic dissection necessitating an alternative surgical procedure. External inspection of a malformed thoracic aorta does not always provide evidence of the exact nature of the dissection which, consequently, might hamper the planning of the surgical procedure. The potential role of intraoperative echocardiography in patients with aortic dissection has recently been documented (2, 6, 9). We report our experience with intraoperative echocardiography in 15 consecutive patients operated for pathology of the thoracic aorta.

Patients and Methods

Fifteen patients in whom thoracic aorta pathology was diagnosed, or suspected, were intraoperatively studied by two-dimensional echocardiography. These patients represent 5 percent of the intraoperative examinations that were made over a two-year period. The group comprised 8 male and 7 female patients, age range 10–74 years (mean age 50 years). The preoperative diagnosis was based on physical examination, chest radiograph, electrocardiography, precordial two-dimensional echocardiography, computed tomography and/or cardiac catheterisation.

The preoperative diagnoses were: aortic aneurysm (5 patients); aortic dissection (3 patients); aortic insufficiency (1 patient) and coronary artery disease (2 patients).

Reoperation was involved in the case of 4 patients. Two of these patients had previously undergone replacement of the ascending aorta with a valved conduit and both presented with an aneurysm of the ascending aorta caused by a false aneurysm between the conduit and wrapped aorta. A third patient previously underwent aortic valve replacement because of infective endocarditis and now presented with an aortic aneurysm and paravalvular leak. The fourth reoperated patient presented with a saccular aneurysm of the ascending aorta and coarctation of the aorta. This patient underwent a two-stage surgical procedure in which the coarctation was corrected first.

Intraoperative echocardiographic studies were performed with a mechanical 5 MHz imaging system (Mark 300LX). The carefully cleaned transducer and cable were wrapped in a gas-sterilised plastic bag containing sterile gel to facilitate good ultrasonic contact while saline was poured over the heart. Fourteen patients underwent a medial sternotomy and one patient a lateral thoracotomy. Epicardial echocardiography was performed before cardiopulmonary bypass was instituted. Postoperative epicardial echocardiograms were obtained before chest closure.

Initially, left ventricular long- and short axis views were obtained by placing the transducer on the right ventricular outflow tract (9). Subsequently, the ascending aorta and aortic arch were imaged by moving the transducer from proximal to distal over the thoracic aorta. When considered necessary, contrast studies were performed following repair using a manually agitated saline solution. Contrast was injected either via the left atrial monitoring line or directly into the ascending thoracic aorta.

Fourteen patients were investigated pre- and post-operatively, whilst one patient was investigated only after repair. In general, the echocardiographic study took less than 3 minutes.

Results

Diagnostic and intraoperative two-dimensional studies were carried out in all patients. In all cases, the intraoperative echocardiographic findings were subsequently confirmed by surgical examination. The intraoperative echocardiographic diagnoses and preoperative findings are listed in Table 1.

Prior to repair

In 5 of the 14 patients studied, intraoperative echocardiography revealed crucial morphologic information which subsequently guided the course of the surgical procedure (Table 2). Unexpectedly, in 2 of these patients a dilated ascending aorta was noted at visual inspection. The first of these patients (no. 1) was referred for aortic valve replacement because of severe aortic insufficiency. Intraoperative echocardiography revealed a DeBakey type I aortic dissection (Fig. 1). The planned procedure was altered, arterial cannulation was performed via the femoral artery and the ascending aorta was replaced by a valved conduit.

In the second patient (no. 2), scheduled for coronary artery bypass grafting, a similar condition was expected after sternotomy. A dilated ascending aorta was noted on inspection; intraoperative echocardiography, however, excluded a dissection and regular arterial cannulation could be performed.

In a third patient (no. 3), a repeat procedure for saccular aneurysm of the ascending aorta was performed one month after correction of a coarctation of the aorta. Unexpectedly, an aortic dissection DeBakey type II was demonstrated by intraoperative echocardiography. The distal extension of the dissection ended just before the origin of the brachiocephalic artery (Fig. 2). It was decided to place the aortic cross clamping just before the take-off of the cerebral arteries and to perform arterial cannulation in the aortic arch.

Finally, 2 patients (nos. 4 and 5) with an aortic valved

Table 1 Results of preoperative diagnoses and intraoperative findings

Patient no.	Intraoperative findings	precordial 2DE	Angiography	Computed Tomography
1 (Fig. 1)	Dissection *DeBakey* type I	AR	Ao ↑; AR	NP
2	Dilated ascending aorta	LV ↑	CAD	NP
3* (Fig. 2)	Dissection *DeBakey* type II	Ao ↑ AR	Ao ↑ (Fig. 2) AR; coarctation Ao	NP
4*	Valved aorta conduit; dilatation of wrapped aorta; disrupted RCA	Ao ↑	Ao ↑ disrupted RCA	NP
5* (Fig. 3)	Valved aorta conduit; dilatation of wrapped aorta	Ao ↑ (Fig. 3)	Ao ↑	NP
6	Dissection *DeBakey* type I	NP	Dissection *DeBakey* type I	NP
7	Dissection *DeBakey* type I	Dissection *DeBakey* type I	Dissection *DeBakey* type I	NP
8	Aortic aneurysm (ascendens)	Ao ↑	Ao ↑	NP
9	Aortic aneurysm (ascendens)	Ao ↑	Ao ↑	NP
10	Aortic aneurysm (ascendens)	Ao ↑ AR	Ao ↑ AR	NP
11	Aortic aneurysm (descendens)	No pathology seen	Ao ↑	Ao ↑
12	Dissection *DeBakey* type III	NP	Dissection *DeBakey* type III	Possible dissection
13 (Fig. 4)	Aortic arch aneurysm (saccular)	No pathology seen	Ao ↑	Pulmonary artery aneurysm
14*	AR; Ao valve prosthesis; infective endocarditis	AR	AR	NP
15	Iatrogene aortic dissection following bypass	NP	CAD	NP

* = patient had previous cardiac surgery; NP = not performed; AR = aortic regurgitation; Ao = aorta; LV = left ventricle; ↑ = dilated; CAD = coronary artery disease; RCA = right coronary artery; 2DE = two-dimensional echocardiography

Table 2 Intraoperative echocardiographic findings and surgical consequences

Patient no.	Preoperative diagnosis	Intraoperative findings	Surgical consequences
1	aortic regurgitation	aortic dissection *DeBakey* type I (Fig. 1)	arterial cannulation via the femoral artery; valved aorta conduit necessary
2	coronary artery disease	dissection excluded	regular cannulation performed
3	saccular aneurysm ascending aorta; corrected coarctation	aortic dissection *DeBakey* type II (Fig. 2)	arterial cannulation via the aortic arch; aorta conduit necessary
4, 5	valved aorta conduit; dilatation of wrapped aorta	position of conduit localized inside the aneurysmatic ascending aorta (Fig. 3)	findings guided position of arterial cross-clamp

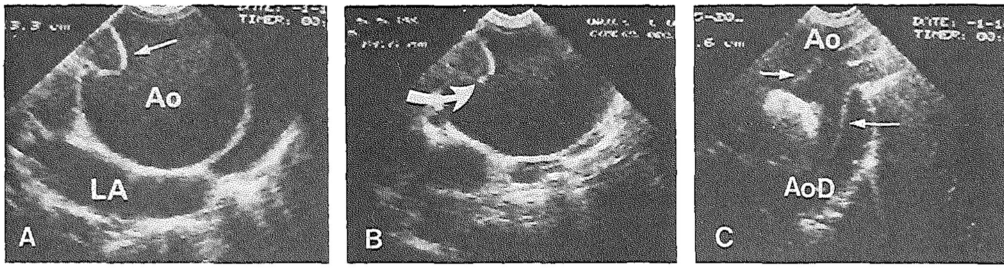
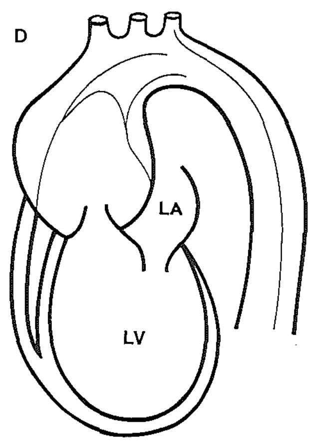


Fig. 1 Intraoperative two-dimensional echocardiograms (A–C) and corresponding diagram (D) obtained in a patient with aortic insufficiency. At external inspection the ascending aorta was found to be unexpectedly dilated. A: short axis view with the transducer positioned on the ascending aorta (Ao) revealed a circumferential tear through the intima adjacent to the aortic valves (⇐). Note the dilated ascending aorta relative to the left atrium (LA) dimension. B: the entry tear was seen at a level slightly higher in the ascending aorta (⇐). C: the transducer directed to the aortic arch reveals that the dissection extended into the descending aorta (AoD; ⇐). The caliber of the descending aorta was normal. LV = left ventricle



conduit were referred for surgery because of progressive dilatation of the wrapped aorta containing the conduit. In both patients extensive interstitial adhesions limited the inspection. Intraoperative two-dimensional echocardiography was helpful in both cases in locating both the conduit within the dilated aorta and the site of the leak, thus enabling the surgeon to accurately determine the aortic cross-clamp position (Fig. 3).

In 9 of the 14 patients intraoperative echocardiographic findings confirmed the preoperative diagnosis. The proximal origin and distal extension of a DeBakey type I dissection, as well as the entry tear, were accurately identified in 2 patients (nos. 6 and 7). Intraoperative echocardiography in 4 patients confirmed the diagnosis of fusiform or saccular aneurysm (nos. 8–11). In the remaining 3 patients the preoperative data had been either conflicting or indecisive (nos. 12–14); consequently the intraoperative echocardiographic data were of help in guiding the course of the surgical approach. Computed tomography indicated a possible dissection originating from the aortic arch in one patient (no. 12). With intraoperative echocardiography, however, a DeBakey type III dissection just distal to the left

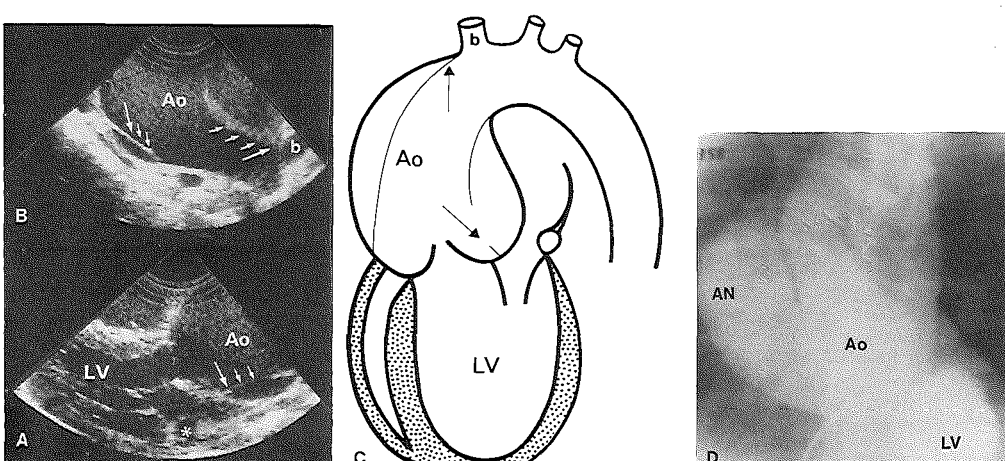


Fig. 2 Intraoperative two-dimensional echocardiograms (A–B) and corresponding diagram (C) obtained in a patient submitted for repair of a saccular aneurysm (AN) of the aorta, proven angiographically (D). A: the dissection was seen in the ascending aorta (Ao) beginning distal to the aortic valves (⇐). The entry tear was seen in this region. The coronary sinus (*) proved to be enlarged due to a persistent left superior caval vein. B: the dissection was shown to end just before the origin of the brachiocephalic artery (b). LV = left ventricle

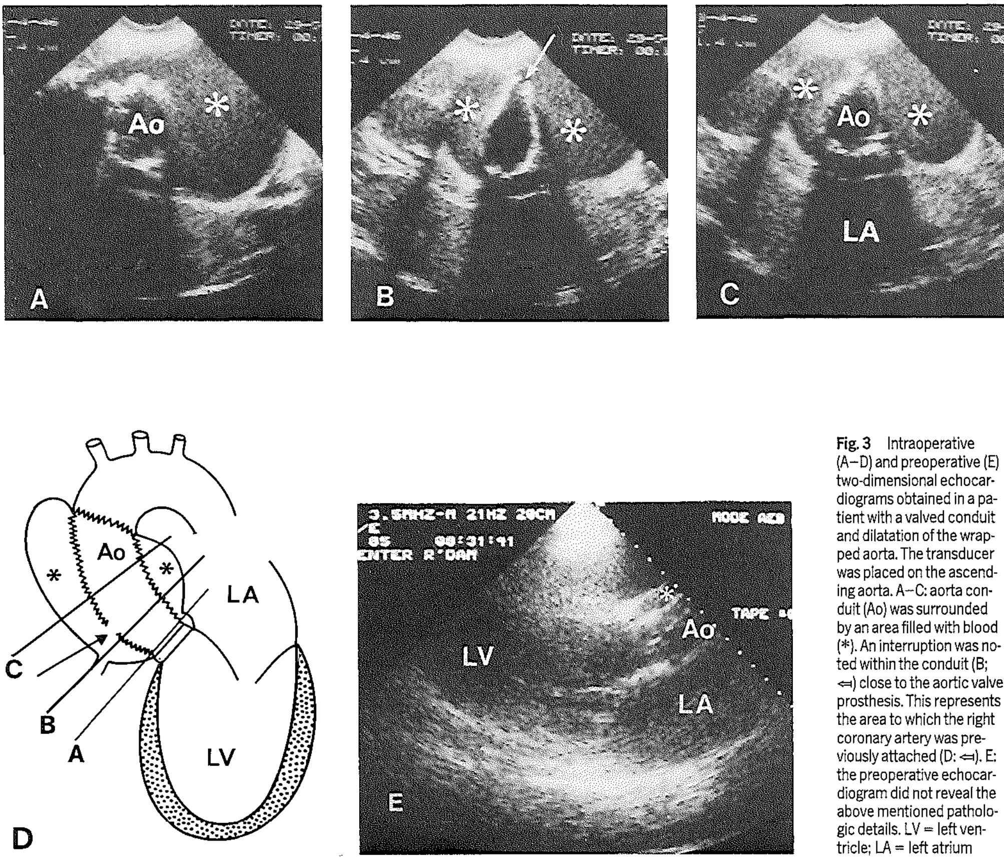


Fig. 3 Intraoperative (A–D) and preoperative (E) two-dimensional echocardiograms obtained in a patient with a valved conduit and dilatation of the wrapped aorta. The transducer was placed on the ascending aorta. A–C: aorta conduit (Ao) was surrounded by an area filled with blood (*). An interruption was noted within the conduit (B; ⇐) close to the aortic valve prosthesis. This represents the area to which the right coronary artery was previously attached (D: ⇐). E: the preoperative echocardiogram did not reveal the above mentioned pathologic details. LV = left ventricle; LA = left atrium

subclavian artery was visualised. Computed tomography and angiography presented conflicting results in the second patient (no. 13). Intraoperative echocardiography revealed a saccular aneurysm in the aortic arch (Fig. 4) which was in accord with angiography. The third patient (no. 14), with a Hancock valve in aorta position and recent infective endocarditis, was preoperatively diagnosed as having the unusual combination of a mycotic aneurysm of the left coronary sinus, resulting in a paravalvular leak associated with a fusiform aneurysm of the ascending aorta. Intraoperative echocardiography demonstrated the pathology in detail and excluded the presence of additional abnormalities frequently associated with this complex pathology (10).

Following repair

Intraoperative echocardiography demonstrated adequate repair in 14 of the 15 patients. In one patient (no. 15), following elective coronary artery bypass grafting, a hematoma was noted at the aorta cannulation site. Intraoperative two-dimensional echocardiography revealed an iatrogenic aortic dissection, indicating the need for reoperation. In 2 patients contrast studies were performed. In one patient complete closure of a saccular aneurysm within the aortic arch was proven as no trace of contrast bubbles passed the suture line (Fig. 4). In the second patient contrast was injected into the ascending aorta to exclude significant insufficiency following repair of aortic dissection by graft replacement of the ascending aorta. The amount of regurgitation was minimal and the native valve remained untouched.

Discussion

Aortic aneurysm and aortic dissection are the most common pathology of the thoracic aorta in adults. In spite of updated diagnostic and surgical techniques, surgical mortality remains relatively high (3, 14). Major limitations include: inadequate imaging due to limited approaches with precordial echocardiography (1, 16, 23), limited views and limited contrast injections with angiography (4, 5, 12, 20), and pericardial or pleural thickening, overlapping structures and rapid movement of the

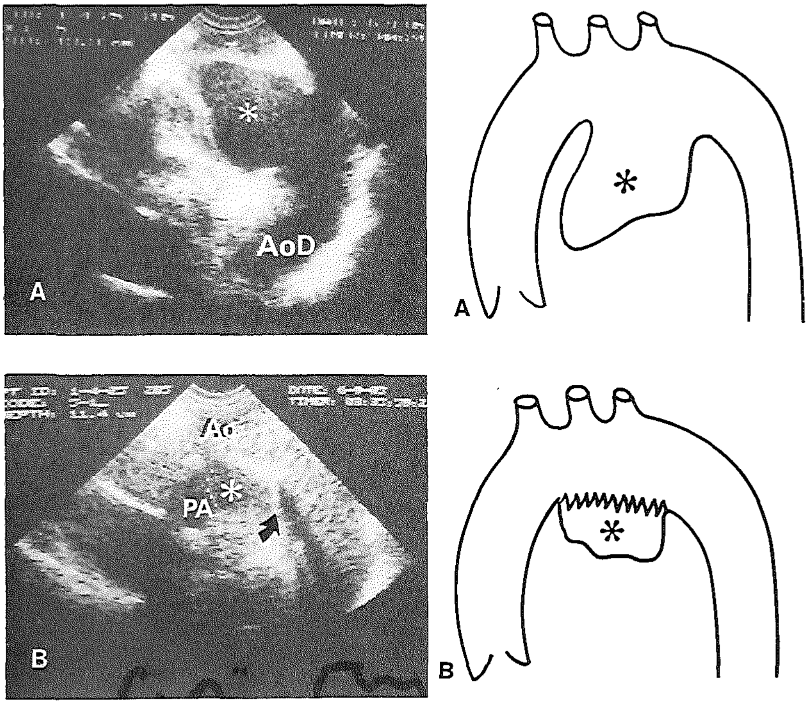


Fig. 4 Intraoperative two-dimensional echocardiograms (A, B) and corresponding diagrams obtained in a patient with a saccular aortic arch aneurysm. A: before correction a large aneurysm inside the aortic arch was visualized (*). B: after correction the size of the aneurysm reduced significantly (*). To test the adequacy of the closure, contrast was injected via the left atrial monitoring line. Contrast opacified the thoracic aorta (Ao), whereas no trace of bubbles was seen within the aneurysm. The arrow indicates the suture line. AoD = descending aorta; PA = pulmonary artery

intimal flap in computed tomography (2, 22). Our experience in this study confirms these limitations. Although all our patients underwent a comprehensive preoperative investigation, these standard techniques did not necessarily provide a sufficiently accurate and detailed diagnosis. For this purpose, intraoperative two-dimensional echocardiography has proven to be a unique and invaluable technique to confirm the preoperative diagnosis, and to determine the type of surgical procedure necessary, prior to aorta cross-clamping (2, 9, 10).

This study confirms the potential role of echocardiography in the assessment of thoracic aorta pathology. Although angiography is still accepted as the universal standard in the diagnosis of aortic dissection, false negative studies are not uncommon, and an incidence from 7 up to 18 percent has been reported (5, 20). This situation occurred in 2 patients in this study; only with intraoperative two-dimensional echocardiography was dissection adequately demonstrated. Re-analysis of the angiogram of the patient referred for operation of a saccular aortic aneurysm showed no dissection; probably due to the fact that the dissection occurred in a dilated ascending aorta. In the more common form of dissection, the false lumen is more readily demarcated (12).

The failure of angiography to diagnose a dissection in the second patient may be explained by the simultaneous and equal opacification of the true and false lumens, and by the fact that the intimal flap was not in a plane tangential to the beam directions used (Fig. 2) (2). In addition, we consider that the false negative outcome might be due to the absence of clinical suspicion for this entity (1). Conversely, intraoperative echocardiography can exclude dissection when suspicion is raised on external inspection, but not diagnosed preoperatively.

Moreover, by identifying the precise pathology in 3 patients, intraoperative echocardiography proved to be particularly helpful in planning the surgical procedure, especially as the preoperative data were indecisive in one patient and conflicting in the two others.

With reoperation, multiple adhesions hampered external inspection in 2 patients with aneurysmatic wrapped aorta containing conduit. The internal morphology visualised with intraoperative two-dimensional echocardiography appeared to be a reliable guide for positioning the aorta cross-clamp.

Intraoperative echocardiography is an ideal technique for evaluation of surgical repair; it is readily performed and can be combined with contrast studies (6, 8, 15). The use of contrast echocardiography excluded significant aortic insufficiency in one patient and, in a second patient, a saccular aneurysm of the aortic arch was shown to be adequately closed. In another patient, intraoperative echocardiography facilitated identification of an intimal tear adjacent to the site of aortic cannulation, due to an iatrogene aortic dissection, which required immediate reoperation (17–19).

The experience obtained with intraoperative echocardiography in this study led to a better understanding of the pathology involved and enabled more appropriate and effective methods of surgical repair.

In our opinion it is the examination of choice for eliminating doubts concerning clinical diagnosis, particularly in emergency conditions. Moreover, intraoperative two-dimensional echocardiography is a rapid and effective adjunct for immediate assessment of surgical outcome prior to chest closure.

Acknowledgement

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Key words

Aortic dissection – Aortic aneurysm – Intraoperative echocardiography – Replacement of ascending aorta – Reoperation

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CHAPTER 3.7

INTRAOPERATIVE TWO-DIMENSIONAL ECHOCARDIOGRAPHY FOR GUIDING SURGICAL CORRECTION IN SUBVALVULAR AORTIC OBSTRUCTION.

L.A. van Herwerden, W.J. Gussenhoven, O.A. Schippers,
E. Bos & F.J. Ten Cate.

Introduction

Congenital obstructive lesions of the left ventricular outflow tract vary in nature and often are complex.[1,2] Although the hemodynamic features resemble, the anatomy between the different types varies and so does the prognosis after surgical intervention.

The best known type of fixed subaortic stenosis is the membranous type. The membrane closely adjacent to the right coronary cusp extends from the surface of the ventricular septum onto the base of the anterior mitral leaflet as a U-shaped diaphragm. The second type is an obstruction caused by a fibromuscular ridge, usually more inferior from the aortic valve. The third type of fixed subaortic stenosis is the so-called diffuse tunnel stenosis. The obstruction forms a narrow channel. Usually the interventricular septum in the outflow tract is grossly hypertrophied and covered by a thick layer of fibrous tissue. Subaortic obstruction caused by hypertrophic cardiomyopathy is mainly characterized by a distinct thickening of the septal myocardium causing a subaortic gradient due to abnormal mitral valve motion. This gradient is not fixed but functional in nature.

Precordial M-mode, two-dimensional and Doppler echocardio-graphy, cardiac catheterization and angiography are established methods to confirm the diagnosis and to define the nature, level and severity of the obstruction.[3] The main indications for surgery in fixed subaortic stenosis are congestive heart failure, cardiomegaly, a systolic gradient across the obstruction of more than 50 mmHg or the development of a strain pattern on the electrocardiogram in childhood. However, due to the complexity of the surgical correction, the indications for treatment of diffuse tunnel stenosis are less well-defined. In cases of hypertrophic obstructive cardiomyopathy surgical intervention must be considered when disabling symp-

toms persist despite medical treatment. Relief of obstruction can be achieved by excision of the membrane or by ventricular septal myotomy/myectomy.
Precise knowledge of the anatomy of the left ventricular outflow tract is crucial for the surgeon as the aortotomy in itself is restrictive in that it prevents the surgeon from inspecting all sites of obstruction.
Recently, we introduced the application of two-dimensional echocardiography in the operating room.[4] Initially, the main purpose was to study patients with congenital heart disease. Subsequently, patients with an acquired heart disease were included in the study. Unsuspected additional morphologic lesions were found not uncommonly which in some patients had major significance for the surgical intervention.[4-6] The magnitude of inaccurate preoperative diagnoses in the setting of left ventricular outflow tract obstruction is not known. Maron and coworkers[7] were the first to document that preoperative echocardiography may not provide an accurate assessment of the interventricular septal thickness. Application of intraoperative two-dimensional echocardiography on the other hand proved to be a more sophisticated method.
We have studied 20 consecutive patients known to have a subvalvular obstructive lesion. The role of intraoperative two-dimensional echocardiography before and immediately after surgical relief of the obstruction is described in this chapter.

Procedure

The intraoperative two-dimensional study was performed with a 5 MHz mechanical sector scanner (ATL Mark 300LX). The transducer was wrapped in a gas sterilized plastic bag. After sternotomy and pericardiotomy, warm saline was poured over the heart to optimize contact between transducer and heart. The surgeon in charge performed the echocardiographic investigation. The right ventricular surface was most commonly used for the study of the left ventricular outflow tract. Left ventricular long axis view as well as short axis view were obtained in the same way as the precordial images. Immediately after termination of cardiopulmonary bypass, and as soon as the patient's condition was stable, a second set of echocardiograms -including a contrast echocardiogram- were made to test the outcome of the surgical repair.

Patients

The study applies to 20 patients in whom the diagnosis of a subvalvular aortic obstruction and gradients had preoperatively been established. All patients had preoperative investigations including precordial echocardiography as well as hemodynamic evaluation and cineangiocardiography. Fifteen patients had fixed sub-

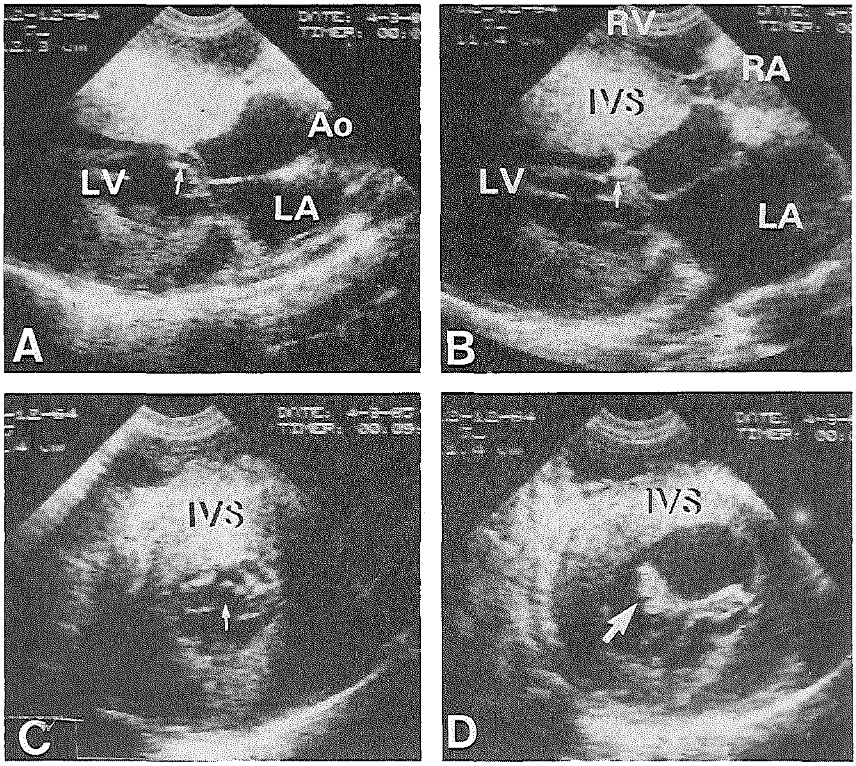

Fig.1. Intraoperative two-dimensional echocardiograms obtained in a patient with hypertrophic obstructive cardiomyopathy. The transducer was placed onto the right ventricular (RV) surface. The left ventricular long-axis view (A) and the modified four-chamber view (B) both revealed the hypertrophied interventricular septum (IVS) of approximately 30 mm thickness. The systolic anterior motion of both the anterior and posterior mitral valve leaflet is recognized in these images as well as in the short-axis view (C; small arrow). The left ventricular short-axis view obtained at a somewhat lower level (D) shows that the ventricular septal thickness was reduced (± 18 mm). In addition, in this cross-section a second obstruction was noted that was represented by an anomalous chord connecting the interventricular septum with the anterior mitral valve leaflet (solid arrow). RA = right atrium; LA = left atrium; LV = left ventricle

aortic stenosis. This was due to a membrane in 14 patients and in one patient a fibromuscular tunnel obstruction together with a ventricular septal defect was involved. Five patients had hypertrophic obstructive cardiomyopathy. There was an equal sex distribution. The age of the patients ranged from 2 months up to 66 years.

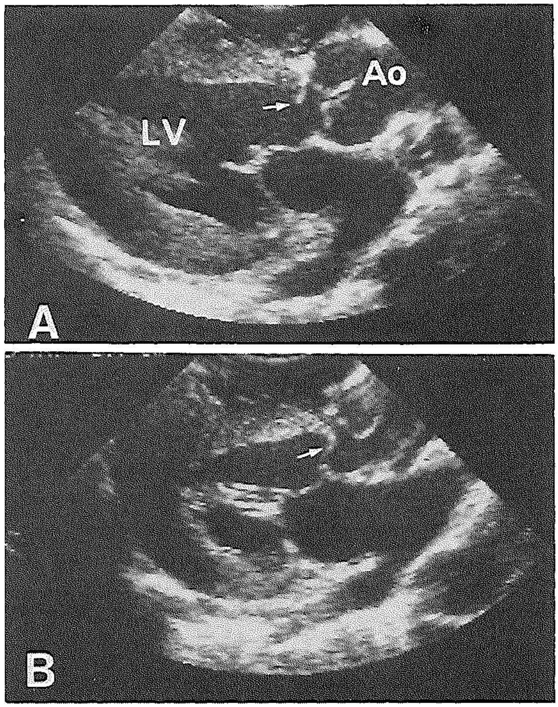

Fig.2. Left ventricular long-axis view (A, B) obtained intraoperatively with the transducer placed onto the right ventricular surface, The patient was known to have a subaortic membrane. Preoperative echocardiographic investigation, however, had left doubt whether the interventricular septum showed characteristics of a hypertrophic obstructive cardiomyopathy. The echocardiographic images revealed left ventricular hypertrophy and a discrete subaortic membrane closely to the right aortic valve (arrow). No evidence was found of hypertrophic cardiomyopathy. Ao = aorta; LV = left ventricle.

Results before repair

In 13 patients intraoperative echocardiography and surgical inspection were consistent with the preoperative diagnosis. In 7 patients the intraoperative study revealed additional morphologic abnormalities. The surgical procedure was influenced by these findings in 3 patients. In one patient with hypertrophic obstructive cardiomyopathy, a second level of obstruction was identified, situated 4 cm proximal from the aortic valve (Fig.1). Excision of this obstruction was performed. In the 2 other patients, the precise underlying pathology remained uncertain after preoperative evaluation. Both had a subaortic membrane with secondary muscular hypertrophy. The likelihood of a co-existing hypertrophic obstructive cardiomyopathy had been suggested by the preoperative echocardiographic findings. With intraoperative echocardiography only a subvalvular aortic membrane was seen which was subsequently excised (Fig.2). In 4 of the 7 patients the additional morphologic information, albeit without surgical consequences, was judged as valuable. In one patient, a subvalvular aortic membrane actually was of fibromuscular nature. Although direct intracardiac inspection by an experienced surgeon would have been sufficient to establish the type of obstruction, intraoperative echocardiography helped to define the way in which to perform the myectomy. In the other patients intraoperative echocardiography did provide more detailed information on the mitral valve apparatus without influencing the surgical procedure. This information included a redundant mitral valve chorda in one patient and a papillar structure in the left ventricle seen in 2 patients, which on the precordial echocardiograms mimicked a false tendon.

Results after repair

All patients were studied intraoperatively immediately after termination of cardiopulmonary bypass. In 9 of the 14 patients with a subaortic membrane the remnants of the membrane were still visible near its attachment to the interventricular septum and/or to the anterior mitral valve. The systolic anterior motion of the mitral valve if present before repair, persisted in all patients after relief of the obstruction, but its magnitude decreased (Fig.3).
In patients with hypertrophic obstructive cardiomyopathy, intraoperative echocardiography assessed the extent of the septal myectomy (Fig.4). Finally, when necessary, left-sided echo contrast studies were used in order to exclude significant aortic or mitral valve regurgitation (Fig.5).

Conclusion

The value of the intraoperative echocardiographic findings in relation to their surgical consequences, is a matter of debate. Nonetheless, an intraoperative echocardiographic study that confirms the preoperatively assessed morphologic diagnosis, is important. Moreover, the technique is the examination of choice in eliminatingdoubts, if any, after the preoperative clinical diagnosis. If the surgeon finds additional unsuspected morphology, his experience enables him to judge whether this finding is of importance. This is best illustrated in 4 patients not known to have left ventricular outflow tract abnormalities. In one patient referred with mitral and aortic valve incompetence, an unsuspected fixed subvalvular aortic obstruction of fibromuscular nature was noted on the intraoperative echocardio-

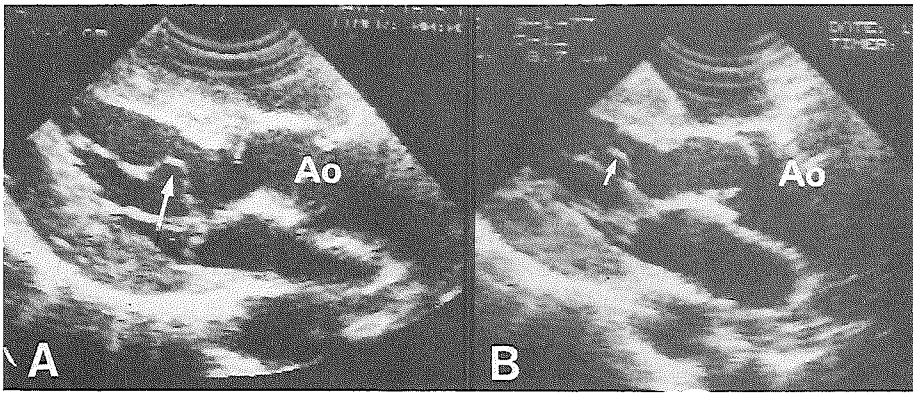

Fig.3. Intraoperative two-dimensional left ventricular long-axis views obtained in a patient with subaortic stenosis due to a membrane, The systolic anterior motion of the mitral valve (arrow) was present before (A) and after (B) surgical repair. Ao = aorta.

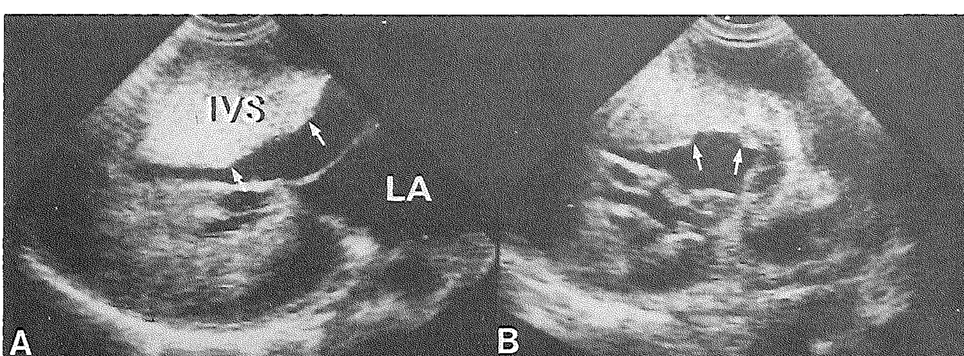

Fig.4. Intraoperative two-dimensional echocardiograms showing the results of left ventricular outflow tract myectomy in a patient with hypertrophic obstructive cardiomyopathy. The short-axis view (B) indicates its width and depth within the interventricular septum (IVS) (arrows). LA = left atrium.

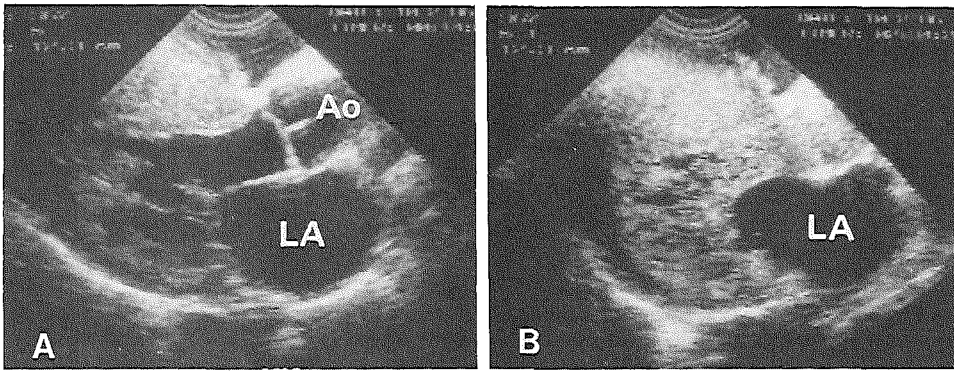

Fig.5. Intraoperative two-dimensional left ventricular long-axis views (A, B) in a patient with hypertrophic obstructive cardiomyopathy and mitral valve incompetence. Following myectomy the contrast study with saline injected in the left ventricle (B) did not reveal a trace of bubbles entering the left atrium (LA). Ao = aorta.

gram (Fig.6). This obstruction could otherwise have been missed but was now resected via an aortotomy, Thus a second operation could be prevented.

In 3 other patients with mitral valve and/or aortic valve disease a highly reflective bar of echoes was seen in the left ventricular outflow tract 2 cm beneath the aortic vale (Fig.7). This phenomenon was due to a local concentration of calcium on the posterior surface of the left ventricular outflow tract which, however, needed no surgical intervention. It is noteworthy that 2 of the 14 patients with subvalvular aortic membrane discussed in this chapter had surgical correction for a ventricular septal defect in childhood. This underlines the importance of intraoperative echocardiography. One should realize that patients referred for surgery may have a preoperatively undiagnosed abnormality (vide supra). Intraoperative echocardiographic detection of such abnormality renders the facility to perform the repair in the same session and thus a reoperation can be prevented.

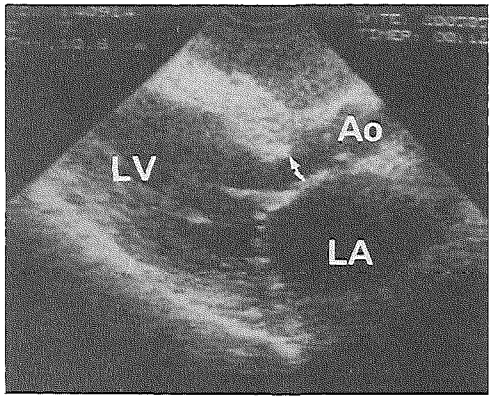

Fig.6. Intraoperative two-dimensional echocardiogram of the left ventricular outflow tract obtained in a patient referred for correction of mitral and aortic valve insufficiency. Unexpectedly discrete subvalvular aortic stenosis of fibromuscular nature was seen (arrow). Note the enlarged left atrium (LA) and left ventricle (LV). Ao = aorta.

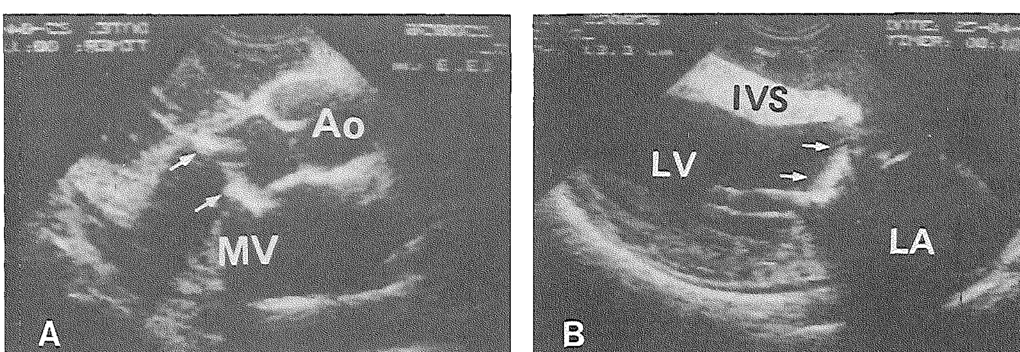

Fig.7. A modified left ventricular longs-axis (A) and four-chamber (B) view obtained in a patient referred for aortic valve replacement because of insufficiency. Unexpectedly the images showed highly reflective echoes upstream (arrows) in the left ventricular outflow tract, apparently connecting the anterior mitral valve leaflet (MV) to the interventricular septum (IVS). Intracardiac inspection revealed a significant bar of calcium in the posterior wall of the left ventricular outflow tract which did not give obstruction. LA = left atrium; Ao = aorta; LV = left ventricle.

Thus, intraoperative two-dimensional echocardiography is a safe, accurate and easy technique. The procedure is not time-consuming. Based on a large population of patients studied the cardiac surgeons have gained experience both in obtaining diagnostic images and in the interpretation thereof. It is this experience that enabled them to use the intraoperative echocardiographic information in an optimal way.

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CHAPTER 3.8

Intraoperative Two-Dimensional Echocardiography in Congenital Heart Disease

ELMA J. GUSSENHOVEN, MD,*,§, LEX A. VAN HERWERDEN, MD,† JOS ROELANDT, MD, FACC,† KEES M. LIGTVOET, MSc,* EGBERT BOS, MD,* MAARTEN WITSENBURG, MD‡

Intraoperative epicardial two-dimensional echocardiography was used in 195 patients undergoing surgery for congenital heart disease to evaluate its potential to identify new diagnostic information immediately before and after surgical correction. In 168 patients the preoperative diagnosis was confirmed by intraoperative echocardiography. In four patients, unsuspected findings were revealed, which resulted in modification of the surgical approach. In 18 patients additional morphologic information was obtained which contributed to alteration or refinement of surgical management. The adequacy of cardiac repair was assessed before closure of the chest in all patients. In six patients this information led to immediate reoperation and in four other patients to inotropic drug therapy.

During congenital heart surgery, epicardial two-dimensional echocardiography may yield important information for surgical management. The technique is an essential adjunct when preoperative diagnostic studies are not conclusive or when the initial response to repair is unsatisfactory.

Despite the joint, preoperative review of all available cardiovascular data by cardiologists and cardiac surgeons, incomplete or incorrect diagnosis, or both, may occasionally occur (1–4). However, there is little published information about the magnitude of this problem. Successful cardiac repair is facilitated by a correct and complete preoperative diagnosis. Because previous studies (2–10) have indicated that intraoperative two-dimensional echocardiography can provide information on cardiac function and morphology, we performed this study to determine how frequently the use of this method provided information vital for surgical management before and after surgical correction of congenital heart disease.

Methods

Patients (Table 1). We studied all patients referred to the Thoraxcenter for correction of congenital heart disease between January 1, 1984 and October 30, 1985. Pediatric cardiologists and cardiac surgeons jointly established the preoperative diagnosis in the customary fashion by reviewing the medical history and examination, the chest X-ray films, electrocardiograms, M-mode and two-dimensional echocardiograms, Doppler echocardiographic studies and cardiac catheterization data.

During the 22 months of this investigation we studied 190 consecutive patients with congenital heart defects. Five patients were excluded from the study, two because of malfunction of the transducer due to the sterilization procedure and three because the echocardiographic images were inadequate for evaluation. The age of the 190 patients included in this study ranged from newborn to 67 years. Ninety percent of the patients were under the age of 16 years; 64 of them were infants less than 1 year of age. Complete intracardiac repair was performed in 88% of the patients. Twelve percent of the operations were palliative, providing physiologic correction.

Intraoperative echocardiography. Initial intraoperative echocardiograms were obtained after sternotomy and pericardiotomy just before cardiopulmonary bypass. A second set of echocardiograms was made after cardiac repair before closure of the chest (10). The intraoperative two-dimensional echocardiograms were obtained by the surgeon in charge, while the ultrasonograph was adjusted by the echocardiographer. Cardiac cross sections were interpreted jointly. A systematic examination included both right and left ventricular long-axis and serial short-axis views using

From the *Thoraxcenter, Erasmus University Rotterdam, †University Hospital Dijkzigt, ‡Sophia Children's Hospital and the §Interuniversity Cardiology Institute, Rotterdam, The Netherlands.

Table 1. Preoperative Morphologic Diagnosis in 190 Patients With Congenital Heart Disease Studied With Intraoperative Two-Dimensional Echocardiography

	No. of Patients
Aortic valve lesion	37
Mitral valve lesion	6
Combined valve lesion	2
Secundum-type atrial septal defect	18
Primum-type atrial septal defect	10
Ventricular septal defect	31
Pulmonary stenosis	4
Ventricular septal defect and pulmonary stenosis	7
Tetralogy of Fallot	23 (2)
Double outlet right ventricle	7
Complete transposition of the great arteries	4 (19)
Single outlet heart	5
Heart with univentricular connection	2 (2)
Miscellaneous	11

Numbers in parentheses are the number of patients who underwent a palliative physiologic correction or shunt procedure. All other patients had complete cardiac repair.

Table 2. Results of Intraoperative Two-Dimensional Echocardiography in 190 Patients Studied

	Total No. of Patients	No. of Patients <1 Year of Age
Preoperative		
No new information	168 (88%)	62
Altered surgical approach (Group 1)	4 (2%)	0
Refined surgical approach (Group 2)	18 (10%)	2
Postoperative		
No new information	173 (91%)	60
Contributed to surgical management (Group 3)	17 (9%)	4

the right ventricular surface as the contact point. Because of the relatively large transducer assembly of this system, apical views could not be obtained but foreshortened four chamber views were possible from the right ventricular surface. When disease of the aorta or pulmonary artery was suspected, additional cross sections using the ascending aorta as contact point were obtained. When necessary, contrast studies were performed to ascertain whether residual shunting occurred after repair. Saline solution was injected into the right or left heart cavity by means of a venous catheter or left atrial monitoring line.

The echocardiographic study itself never took more than 3 minutes. During and within 5 minutes after the intraoperative studies, the surgeon and the echocardiographer determined the intraoperative echocardiographic diagnosis to decide if these results would alter the surgical technique.

Analysis of data. For the purpose of analysis, we grouped the significant intraoperative findings as assessed on-line in the operating suite, as follows:

Group 1. Intraoperative echocardiographic studies before repair added essential information that altered the surgical approach.

Group 2. Intraoperative echocardiographic studies before repair added information that contributed to refinement of surgical management.

Group 3. Intraoperative echocardiographic studies after repair added essential information that contributed to subsequent management.

Technical information. A mechanical 5 MHz imaging system was used (ATL-Mark 300 LX). In the first 10 studies the scanhead and cable were gas-sterilized and placed directly on the exposed heart. This procedure of sterilization resulted in deterioration of the scanhead. Therefore, in subsequent studies, we wrapped the cleaned transducer and cable in a gas-sterilized plastic bag. To achieve good ultrasound coupling, sterile gel was placed within the plastic bag and warm saline was poured over the heart.

Even with minimal acoustic output from this transducer designed for precordial application, excessive energy was generated because of its proximity to the heart. As a result, resolution in the near field was reduced. Therefore, a damping resistor (50 Ω) was placed in parallel with the transducer element.

None of the patients had complications related to the intraoperative echocardiographic procedure. The results of the intraoperative echocardiographic findings are summarized in Table 2.

Before repair: Group 1. In four patients the intraoperative two-dimensional echocardiographic study revealed new information that altered the surgical approach in three. In the fourth patient vital information was available from the echocardiographic examination, but not effectively communicated to the surgeon. The importance of the intraoperative echocardiographic data is best illustrated by describing each case individually.

Patient A. This 9 year old child was referred for repair of a saccular aneurysm of the ascending aorta. At surgical inspection a fusiform dilated ascending aorta was found. The suspicion of an unusual infantile aortic root dissection was confirmed by intraoperative echocardiography. The intimal flap could be visualized ending just before the origin of the brachiocephalic artery (Fig. 1). This information allowed safe aortic cross-clamping just before the brachiocephalic artery.

Patient B. A 9 year old child referred for treatment of a ruptured sinus of Valsalva aneurysm was found to have an unsuspected outlet perimembranous ventricular septal defect. Consequently, the surgeon decided to close the defect through an aortotomy rather than by an atriotomy and used a single venous canula.

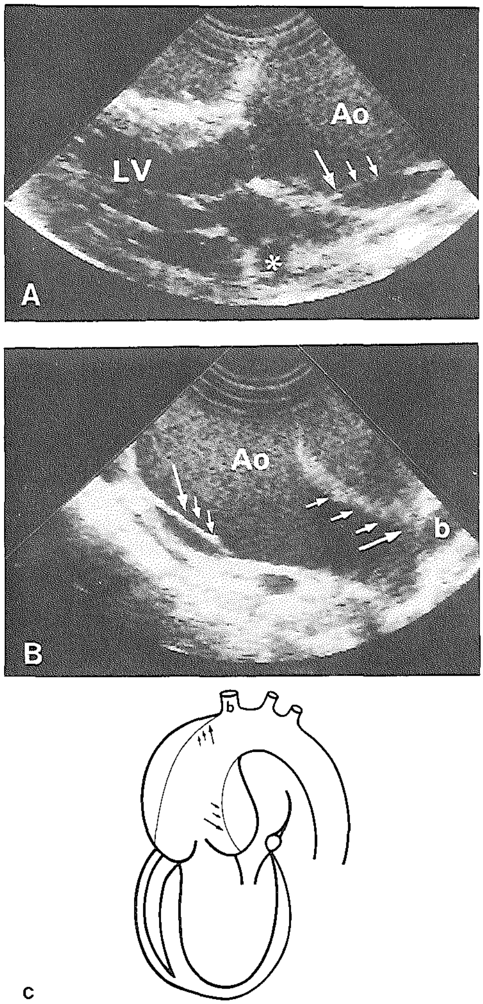

Figure 1. Intraoperative two-dimensional echocardiograms (**A** and **B**) and corresponding diagram (**C**) obtained in a patient submitted for repair of a saccular aneurysm of the aorta (Ao). **A,** The left ventricular long-axis view revealed a dissection in the ascending aorta beginning distal to the aortic sinuses (**arrows**). **B,** With the transducer positioned on the ascending aorta, the dissection (**right arrows**) was shown to end just before the origin of the brachiocephalic artery (b). Note the enlarged coronary sinus due to a persistent left superior caval vein (**asterisk**). LV = left ventricle.

Patient C. Immediately after pericardiotomy, an unsuspected transposition of the great arteries with the aorta anterior to the pulmonary artery was noted in a 3 year old child referred for repair of tetralogy of Fallot and situs inversus. Intraoperative echocardiography revealed a double outlet right ventricle and a subpulmonary ventricular septal defect. The planned surgical procedure was canceled and a Waterston shunt was performed.

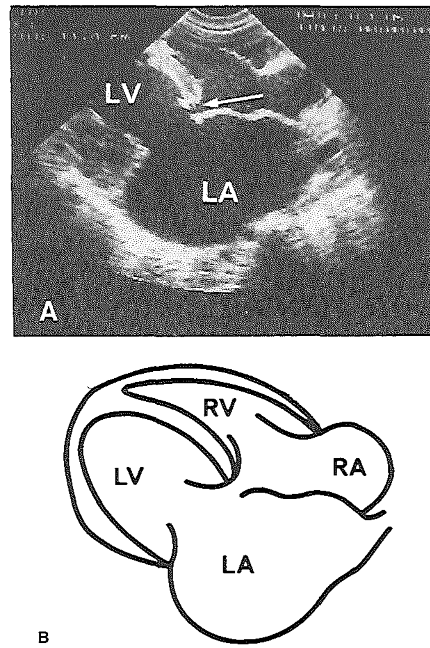

Figure 2. Modified four chamber view (**A**) and corresponding diagram (**B**) obtained intraoperatively in a patient operated on for severe mitral valve insufficiency. **A,** Both the left atrium (LA) and left ventricle (LV) are dilated. A small preoperatively undiagnosed left ventricular-right atrial communication (**arrow**) is visible. The position of this defect is above the level of the entrance of the coronary sinus which was identified in a slightly lower orientated cross section. RA = right atrium; RV = right ventricle.

Patient D. In a 2 year old child with severe mitral valve insufficiency, intraoperative two-dimensional echocardiography revealed an unsuspected shunt between the right atrium and left ventricle (Fig. 2). Although the echocardiographer was thought to have informed the surgeon correctly, the latter remained unaware of this finding and the child had mitral valve replacement only. Two months later a reoperation was necessary because of symptoms due to the shunt at the level of the ventricular septum.

Before repair: Group 2. In 18 patients the intraoperative echocardiographic study revealed additional morphologic information that contributed to refinement of the surgical approach (Tables 3 and 4). In these patients the

Table 3. Four Patients of Group 2 in Whom Surgical Inspection Revealed an Unexpected Cardiac Geometry

Patient No.	Preoperative Diagnosis	Intraoperative Findings	Surgical Consequences
1	Ventricular septal defect; secundum-type atrial septal defect	**Deep AV sulcus;** primum-type atrial septal defect	Regular atriotomy
2	Tetralogy of Fallot	**Deep AV sulcus;** TV underdeveloped (TV diameter 50% smaller than MV diameter)	Central shunt
3	Complete transposition of the great arteries; inf PS	**Juxtaposition atrial appendages;** no additional intracardiac disease visualized	Planned Fontan procedure canceled. No contraindication for Rastelli procedure
4	Double outlet right ventricle	**Juxtaposition atrial appendages;** no additional intracardiac disease visualized	No contraindication for planned procedure

Phrases in boldface indicate unexpected cardiac geometry. Intraoperative two-dimensional echocardiography was performed to reassess the intracardiac geometry. AV = atrioventricular; inf PS = infundibular pulmonary stenosis; MV = mitral valve; TV = tricuspid valve.

preoperative diagnosis was not completely accurate or definitive. Among them were four patients in whom the surgeon noted an unexpected cardiac geometry (Table 3). With intraoperative echocardiography the possibility of additional intracardiac pathology was assessed.

After repair: Group 3. In 17 patients the intraoperative two-dimensional echocardiographic investigation revealed important information after repair. In four newborns, the information on ventricular function after a switch procedure for complete transposition of the great vessels was significant. Despite apparently normal arterial pressures, intraoperative echocardiography after cardiopulmonary bypass revealed a diffuse hypocontractile left ventricle. Inotropic drug therapy was immediately initiated to improve left ventricular function.

Immediate reoperation was believed to be necessary in 6 of the other thirteen patients. In a 9 year old child with pulmonary atresia and ventricular septal defect, surgical correction was performed, including closure of the defect and valved conduit placement between right ventricle and pulmonary artery. Intraoperative two-dimensional echocardiography revealed exaggerated patch movement. Contrast injection through the left atrial monitoring line showed opacification of both ventricles indicating a left to right shunt (Fig. 3). It was decided to reinstitute bypass and to reoperate and a partially disrupted patch was secured.

Immediate reoperation was performed in one patient with tetralogy of Fallot and in two patients with a double outlet right ventricle because increased right ventricular pressure was caused not by residual shunting but by systolic obliteration of the right ventricular outflow tract. As the cause of unstable hemodynamics in another patient with double outlet right ventricle, an obstructive patch in the left ventricular outflow tract was demonstrated and reoperation was necessary.

Finally, in a 1 month old infant who underwent commissurotomy for severe aortic stenosis, the cause of a hypotensive episode after cardiopulmonary bypass was diagnosed by an intraoperative contrast echocardiographic study when an unsuspected secundum-type atrial septal defect was visualized. After closure of the defect, the postoperative course was uneventful.

Table 4. Fourteen Patients of Group 2 in Whom Intraoperative Two-Dimensional Echocardiography Revealed an Incomplete Preoperative Diagnosis and Refined the Course of Surgical Treatment

Preoperative Diagnosis	No. of Patients	Intraoperative Findings	Surgical Consequences
VSD; inf and valv PS	3	Precise nature of RVOTO defined	Transverse ventriculotomy
Inf and valv PS	1	No fixed RVOTO	No ventriculotomy
TGA; inf PS	1	No inf PS	No LVOTO myotomy
SubAoS; IHSS?	1	No IHSS	No LVOTO myotomy
SubAoS	1	Multilevel subaortic obstruction	Resection of additional obstruction
Supravalv AoS	1	Valv AoS; no supravalv AoS	Regular hockeystick incision
Tetralogy of Fallot	4	Absent infundibular septum	Consultation with senior surgeon
Tetralogy of Fallot	2	DORV	Consultation with senior surgeon

DORV = double outlet right ventricle; IHSS = idiopathic hypertrophic subaortic stenosis; inf and valv PS = infundibular and valvular pulmonary stenosis; LVOTO = left ventricular outflow tract obstruction; RVOTO = right ventricular outflow tract obstruction; SubAoS = subvalvular aortic stenosis; Supravalv AoS = supravalvular aortic stenosis; TGA = complete transposition of the great arteries; Valv AoS = valvular aortic stenosis; VSD = ventricular septal defect.

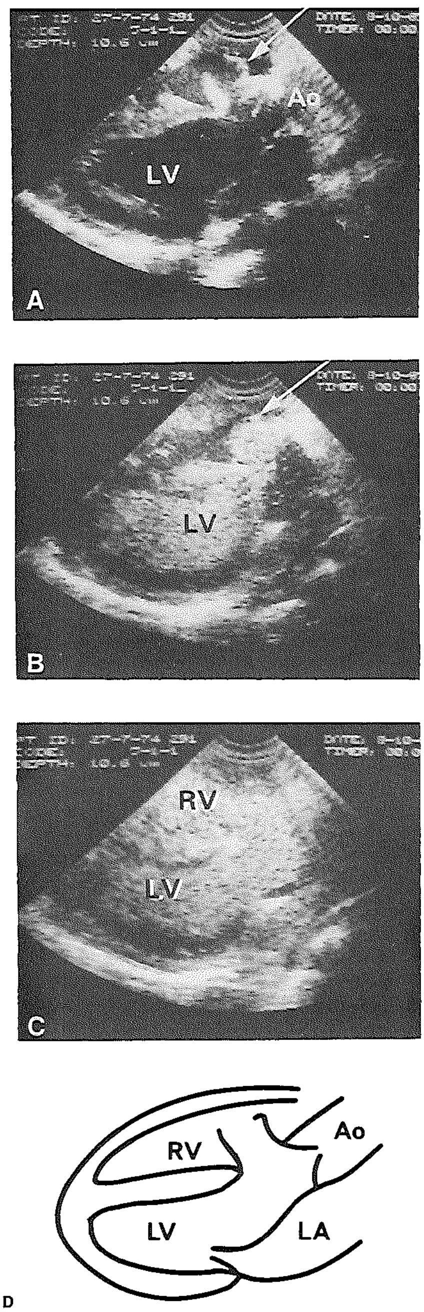

Figure 3. Two-dimensional echocardiograms (**A, B** and **C**) and corresponding diagram (**D**) obtained intraoperatively in a child with pulmonary atresia and ventricular septal defect after repair. **A,** The ventricular septum patch movement was exaggerated and in several images part of the patch was no longer visible (**arrow**). **B** and **C,** After contrast injection through the left atrium monitoring line, opacification of both left (LV) and right (RV) ventricle was noted. Ao = aorta; LA = left atrium.

Discussion

Only few institutions are currently using echocardiography for intraoperative assessment of cardiac anatomy and function. Both the transesophageal and the epicardial two-dimensional echocardiographic approaches are available. The transesophageal approach is used for monitoring cardiac function during surgery (11,12); epicardial echocardiography is applied for detection of air embolism (13,14), left ventricular function studies (15,16), evaluation of valvular and congenital heart disease (2–10,17–19) and for analysis of ventricular septal motion (20) and aortic arch disease (21).

For the cardiac surgeon who must perform corrective surgery, a definitive and complete preoperative diagnosis would be ideal. However, in a certain percentage of patients, a complete preoperative analysis does not always provide an accurate diagnosis, particularly in complicated cases (1–4,10,22–26). Intracardiac malformations may be inadequately assessed by noninvasive and invasive studies (2). To establish the value of intraoperative two-dimensional echocardiography in congenital heart disease we investigated 195 consecutive patients before and after cardiopulmonary bypass. The success rate of obtaining detailed morphologic and functional information was high (97%; 190 of 195 cases).

Advantages. The advantage of epicardial echocardiography is that it allows unique and high quality visualization of cross sections; this visualization is not always obtainable with precordial investigations. The immediate application of the transducer on the right atrial wall and appendage is advantageous for detecting sinus venosus-type atrial septal defects (Fig. 4). Cross sections using the ascending aorta as point of contact proved to be essential in both identifying the extent of aortic root dissection (Fig. 1) and establishing the patency of the pulmonary artery after closure of a Waterston anastomosis (Fig. 5).

The intraoperative echocardiographic observations would have been diagnosed by direct surgical inspection. However, the advantage of the technique is intimately related to the fact that these refinements in diagnosis were made before the start of cardiopulmonary bypass. Consequently, echocardiography allowed redirection of the procedure without increasing the time of ischemia or mechanical perfusion. It was our experience that intraoperative echocardiography did not provide additional or new anatomic information in the

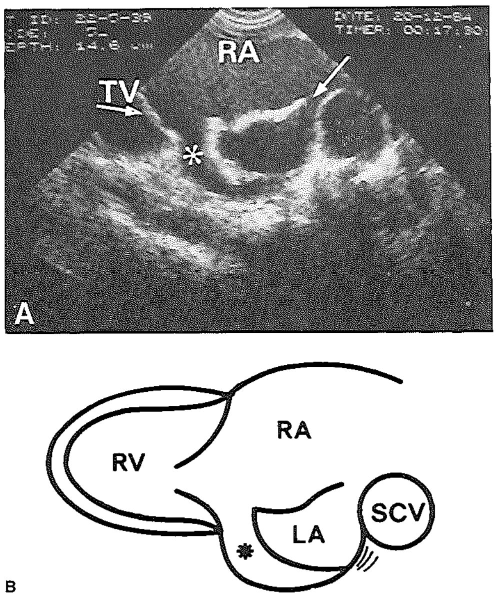

Figure 4. Intraoperative two-dimensional echocardiogram (**A**) and corresponding diagram (**B**) obtained with the transducer directly placed on the right atrium (RA) in a patient submitted for closure of a secundum-type atrial septal defect. Intraoperative echocardiography revealed a sinus venosus-type atrial septal defect (**arrow**). Note the coronary sinus (**asterisk**) and its entrance into the right atrium (RA) close to the tricuspid valve (TV; **arrow**). LA = left atrium; SCV = superior caval vein; RV = right ventricle.

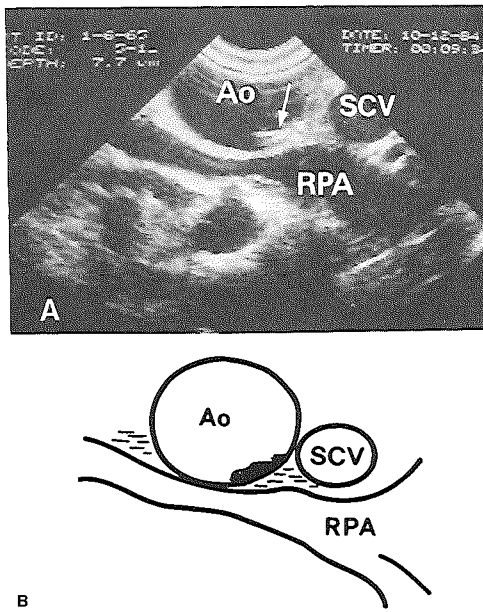

Figure 5. Two-dimensional echocardiogram (**A**) and corresponding diagram (**B**) obtained intraoperatively in a child with tetralogy of Fallot in whom the Waterston anastomosis between aorta and right pulmonary artery (RPA) was closed. The ascending aorta (Ao) is used as the point of contact. The image shows a stitch within the aortic wall (**arrow**) and a right pulmonary artery lumen without obstruction. SCV = superior caval vein.

great majority of patients under 1 year of age (Table 2). This may be explained by the transducer assembly being too large. In three infants referred with right ventricular outflow tract disease, the echocardiographic images were inadequate for evaluation because of near field problems in the first 10 mm. Thus, this technique is less sensitive in this category of patients. Miniaturized higher frequency transducers may help to solve this problem. Accordingly, we tested a hand-held 5.6 MHz miniaturized phased array transducer. Preliminary experience indicates that when it is positioned on the right atrial lateral wall the right ventricular outflow tract can be visualized with high definition.

Before repair: Group 1. The change in diagnosis before bypass allowed the surgeon to select a safe site for arterial cannulation (Patient A), avoid unnecessary atriotomy (Patient B) and in one instance (Patient C) cancel corrective surgery and cardiopulmonary bypass; a palliative shunt was created instead. We think that the incomplete preoperative diagnosis in these patients was related to limitations of conventional diagnostic methods in combination with unusual and complex cardiac pathologic findings. The latter are illustrated in the patient in whom an unsuspected aortic dissection was demonstrated by intraoperative two-dimensional echocardiography (Patient A). This is an unusual lesion and the patient presented with atypical signs and symptoms. Angiographic findings were negative. Previous reports (23,24) have described false negative angiographic studies in this clinical setting.

Before repair: Group 2. When unexpected or unusual cardiac geometry is encountered after sternotomy, epicardial echocardiography allows prompt investigation of potentially associated anomalies. For instance, a deep atrioventricular sulcus suggests an atrioventricular septal defect or tricuspid valve hypoplasia which epicardial echocardiography can easily distinguish (Table 3, Patients 1 and 2). The unexpected finding of a primum-type atrial septal defect had no significant consequences for surgical management because atriotomy had already been planned for the presumed secundum-type atrial septal defect. On the other hand, underdevelopment of the tricuspid valve was considered to be a contraindication for complete repair of tetralogy of Fallot (Table 3, Patient 2). In this patient, intraoperative echocardiography demonstrated a diameter of the tricuspid valve 50% smaller than the mitral valve diameter, which was not diagnosed preoperatively by echocardiography or angiocardiography. Similarly, the shortcomings of the preoperative diagnosis in the patients with unexpected juxtaposition of the atrial appendages (Table 3, Patients 3 and 4) were undoubtedly related to the complexity of the underlying disease. It is not exceptional that juxtaposition of the atrial appendages is missed angiographically and diagnosed only at autopsy (25). It should be emphasized that this condition is regarded as an ominous sign of other severe intracardiac abnormalities (26). Thus, the instantaneous morphologic information is a major benefit of intraoperative two-dimensional echocardiography when dealing with unusual and unexpected cardiac geometry.

The importance of the intraoperative echocardiographic information obtained in the 14 other patients of Group 2 varied (Table 4). Appreciation of the dynamic component of right ventricular outflow tract obstruction in a flaccid heart is virtually impossible. It can be assessed immediately after sternotomy with intraoperative two-dimensional echocardiography. Transverse ventriculotomy is least traumatic to right ventricular function and is therefore the preferable approach. This incision was decided on the basis of the echocardiographic findings in three patients.

As described by Maron and coworkers (3), precordial echocardiography may not allow an accurate assessment of left ventricular outflow tract obstruction. The epicardial approach may be a more sensitive method. Indeed, in one patient referred for resection of a subvalvular aortic membrane, a second level of obstruction was visualized, which might otherwise have been missed, even at surgical inspection (Table 4). Direct intracardiac inspection also allows an experienced surgeon to distinguish double outlet right ventricular connection from tetralogy of Fallot or to recognize the absence of the infundibular septum (Table 4). We believe, however, that two-dimensional echocardiography offers advantages in a clinic with a resident program, particularly in complex congenital heart disease.

Causes of incomplete echocardiographic and angiocardiographic diagnosis. We carefully reviewed the preoperative echocardiographic and angiocardiographic studies of the 22 patients in whom intraoperative echocardiography revealed new or additional morphologic information (Groups 1 and 2). In seven patients, the incompleteness of the preoperative diagnosis was most likely the result of the unusual and complex disease involved. In 15 patients, the additional information could not be obtained preoperatively because of inherent methodologic limitations and the quality of the diagnostic data.

After repair: Group 3. A most important aspect of intraoperative two-dimensional echocardiography is its use immediately after cardiac repair, especially when the hemodynamic status is unsatisfactory. Current hemodynamic methods in the surgical theatre may be inadequate for quantifying a residual intracardiac shunt (27). As suggested previously by Goldman and Mindich (2), intraoperative use of two-dimensional contrast echocardiography may identify significant residual shunting. Indeed, we found that flow characteristics at and around sites of repair can be assessed by means of contrast echocardiography. In the majority of patients contrast echocardiography indicated an adequate cardiac repair. A small amount of contrast medium passing the intracardiac patch was often seen and considered to be without surgical consequences. This probably results from normal patch and interstitch permeability during the first 24 hours (28).

In two instances reoperation was considered necessary. In one patient, dehiscence of a ventricular septal defect patch was found, and in the other, an infant, a coexisting secundum-type atrial septal defect after aortic commissurotomy was demonstrated by contrast study; in both patients, surgical correction was undertaken immediately. The major advantage of contrast echocardiography is that it instantaneously reveals the underlying disorder. The patient with dehiscence of the ventricular septal defect patch had a satisfactory hemodynamic status. Because of the echocardiographic contrast study subsequent oxygen saturation and pressure measurements were performed. Both were indicative of a shunt. In the infant with an unsuspected atrial septal defect, however, cardiopulmonary bypass was reinstituted without delay because of the unstable hemodynamics. It must be noted that the philosophy of our center is not to perform oxygen saturation studies routinely. Furthermore, we would recommend the use of contrast echocardiography to discriminate between residual elevated right ventricular pressure due to a residual ventricular shunt or to partial relief of obstruction.

Analysis of ventricular function. Finally, intraoperative echocardiographic analysis of ventricular function after cardioplegia and complex repair is a sensitive method. This technique proved to be most sensitive in distinguishing between regional hypocontractility due to coronary perfusion defects or to diffuse hypocontractility. Visual judgment of left ventricular contractility is impossible while the electrocardiogram shortly after cardiopulmonary bypass most often does not allow definitive conclusions. In a newborn who underwent an arterial switch correction for total transposition, both the electrocardiogram and the left atrial and aortic pressures were normal whereas intraoperative echocardiography revealed marked global depression of the left ventricle.

Conclusions. In our study, intraoperative two-dimensional echocardiography was safe, accurate and easy to perform, and both the senior and the resident surgeons succeeded in obtaining the intraoperative echocardiographic images. The procedure did not prolong the surgical intervention. Inappropriate incisions could be avoided and the repair optimized. The results of surgical correction were verified. Therefore, we conclude that when preoperative studies leave some doubts or the intraoperative findings at inspection are unexpected, intraoperative two-dimensional echocardiography may add vital information for the surgical care of patients with congenital heart disease.

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CHAPTER 3.9

Recognition of residual ventricular septal defect by intraoperative contrast echocardiography

E. J. GUSSENHOVEN*†, L. A. VAN HERWERDEN*, R. J. VAN SUYLEN*, T. ANSING*, M. WITSENBURG§, N. ELZENGA§, J. QUAEGEBEUR* AND E. BOS*

*Thoraxcenter Erasmus University, Rotterdam, §Sophia Children's Hospital, Rotterdam, and the †Interuniversity Cardiology Institute of The Netherlands

Intraoperative two-dimensional contrast echocardiography was used to detect a residual shunt in 50 patients after surgical repair of ventricular septal defect. Contrast injections were performed following termination of the extracorporeal circulation. In the presence of a shunt the intensity of opacification of both left and right ventricular cavities was compared. In 40 patients no ventricular shunting was observed; insignificant shunting was noted in five patients. Follow-up of these 45 patients proved uneventful.

Significant opacification of the right ventricle was noted in five patients. This finding, however, does not necessarily indicate a residual shunt of significant volume. In two patients the residual shunt was confirmed postoperatively by pulsed Doppler echocardiography but clinically there was no need for surgery. Three other patients subsequently required reoperation and partial patch dehiscence was confirmed in all. Thus, intraoperative two-dimensional contrast echocardiography is a sensitive technique to detect a residual ventricular septal defect, an observation which may warrant reoperation before chest closure.

Introduction

Intraoperative two-dimensional echocardiography offers advantages for surgical decision-making in complex pathology such as congenital heart disease, as it can provide essential and detailed morphologic information before aortic cross-clamping[1–4]. Following correction, it allows inspection of pertinent morphologic aspects of complex congenital heart disease before chest closure[3,4]. Complemented by contrast echocardiography, it facilitates testing of residual shunting or valve function after replacement or reconstruction[4,5]. Accordingly, we evaluated this technique in a series of patients undergoing surgery for ventricular septal defect to determine residual shunting before chest closure and the relationship of these findings to intraoperative pressure measurements and/or postoperative Doppler or cardiac catheterization data.

Study of patients

Intraoperative contrast echocardiographic studies were performed in 50 consecutive patients who underwent closure of a ventricular septal defect. The group comprised 30 males and 20 females ranging in age from 1 month to 12 years (mean age 2 years). Eighteen patients had an isolated perimembranous ventricular septal defect; 26 patients a tetralogy of Fallot, and six a double-outlet right ventricle. Surgical closure of the defect was performed on cardiopulmonary bypass and with cold potassium cardioplegia. In 33 patients, woven Dacron was used for patch material, in 12 patients a Goretex patch, in two patients a pericardial patch and in three patients the defect was closed primarily.

Methods

Two-dimensional echocardiographic examination with a contrast injection was performed, after termination of the extracorporeal circulation, using a mechanical 5 MHz imaging system (ATL-Mark 300 LX). Both transducer and cable were wrapped in a gas-sterilized plastic bag containing sterile gel. To achieve good ultrasound coupling, warm saline was poured over the heart. Both ventricular cavities were visualized using the left and right ventricular long-axis view. Agitated heparinized saline (2–4 cm^3) was used as contrast agent. Contrast was

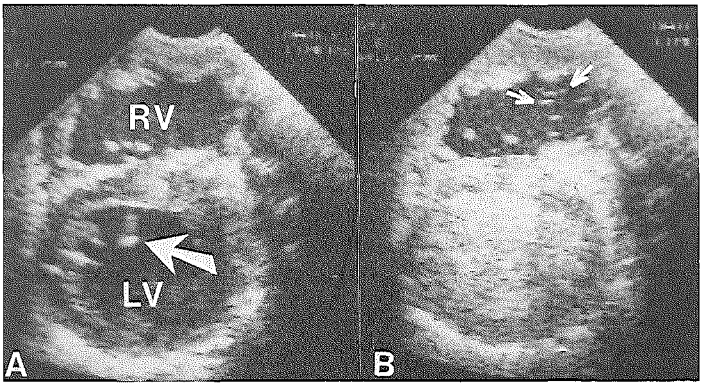

Figure 1 Intraoperative two-dimensional echocardiograms obtained in a patient after correction of a tetralogy of Fallot. Right ventricular long axis view before (A) and after (B) transseptal contrast injection. The left ventricle (LV) is fully opacified. An insignificant amount of bubbles (B; small arrows) is identified in the right ventricle (RV) indicating a successful closure of the defect. Note the tip of the needle in the left ventricle (A; arrow).

hand injected in the majority of patients (43 patients) via the left atrium monitoring catheter or incidentally by the transseptal route using a needle puncture (7 patients). Shunting at atrial level appeared highly improbable as the atrial septum was observed to be intact at the time of surgery or by a left atrium contrast injection showing absence of contrast in the right atrium. Thus, the appearance of contrast echoes in the right ventricle was considered evidence of a shunt at the ventricular level. The amount of bubbles appearing in the right ventricle was expressed by optical assessment as a percentage of the bubbles observed in the left ventricle. An insignificant amount of shunting was characterized by minimal opacification of the right ventricle ($<10\%$, Fig. 1); whereas significant shunting resulted in an opacification of the right ventricle $\geqslant 50\%$ compared with the left ventricle opacification (Fig. 2). A senior paediatric cardiologist examined each patient shortly after operation and also at long-term follow-up ($\geqslant 12$ months). Routine investigations included auscultation and pulsed Doppler echo studies. When necessary, cardiac catheterization and subsequent resurgery were performed.

Results

Echocardiographic contrast studies were completed without complication in all patients. In 40 patients no residual shunting was observed. The short- and long-term follow-up of all these patients was uneventful. In 10 patients a residual shunt was noted. The degree of opacification of the right ventricle was insignificant in five patients (Fig. 1). The postoperative course of these patients was uneventful. Neither auscultation, nor Doppler studies were indicative of a residual ventricular septal defect.

Five patients presented with a significant opacification of the right ventricle (Table 1). Four patients had been operated upon for tetralogy of Fallot and one patient for a double-outlet right ventricle. A total of 10 intraoperative contrast studies were performed in these patients (three studies in two patients; two studies in one patient; one study in two patients). Significant opacification of the right ventricle was noted in 9 of the 10 studies (Fig. 2). Although follow-up studies with pulsed Doppler echocardiography revealed a persistent residual ventricular septal defect, to date there has been no need for reoperation in three of the nine studies (Table 1). Conversely, the six studies also showing significant opacification of the right ventricle were subsequently followed by reoperation for residual ventricular septal defect (Table 1). The reason governing the decision for reoperation will be discussed for each patient individually.

The first patient underwent two reoperations: the first was performed immediately based on equal pressures and the second was performed following cardiac catheterization. The second patient also

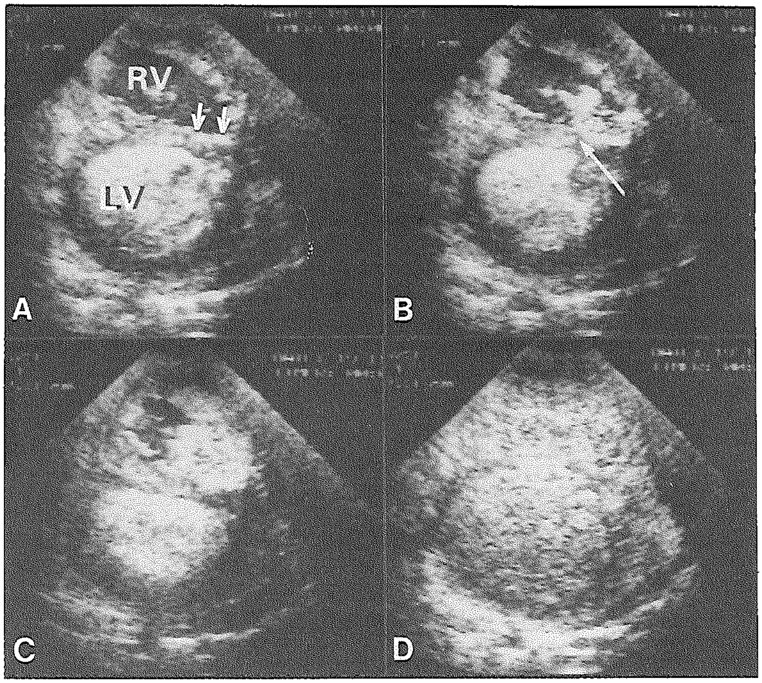

Figure 2 Intraoperative two-dimensional echocardiograms obtained in a patient after correction of a tetralogy of Fallot (A–D). A, the right ventricular long axis view reveals the ventricular septal defect patch in situ (arrows). B, after contrast injection the left ventricle (LV) opacified, subsequently followed by contrast entering the right ventricle (RV; arrow). C–D, both left and right ventricles show identical echodensity of contrast.

Table 1 Pertinent intraoperative echocardiographic findings, pressure measurements, surgical and clinical consequences

Patient	Opacification (RV)	SRVP:SAP (mmHg)	Procedure	Postoperative findings	Results
1/TOF	significant	equal	Immediate reoperation	—	—
	significant	30:75	Closure chest	Qp:Qs=2:1	Reoperation
	significant	40:85	Closure chest	Doppler: VSD+	Clinically well
2/TOF	significant	N.P.	Closure chest	Qp:Qs=1·7:1	Reoperation
	significant	equal	Immediate reoperation	—	—
	significant	N.P.	Closure chest	Qp:Qs=1·8:1	Reoperation planned but patient died
3/TOF	significant	30:100	Closure chest	Qp:Qs=2:1	Reoperation
	no shunt	45:90	Closure chest	—	Uneventful recovery
4/TOF	significant	30:75	Closure chest	Doppler: VSD+	Clinically well
5/DORV	significant	75:100	Closure chest	Doppler: VSD+	Clinically well

DORV=double-outlet right ventricle, N.P.=not performed, Qp:Qs=pulmonary to systemic flow, RV=right ventricle, SRVP:SAP=systolic right ventricular pressure vs systolic arterial pressure, TOF=tetralogy of Fallot, VSD+ =positive for ventricular septal defect.

underwent two reoperations: the first following cardiac catheterization, whereas the second reoperation was carried out immediately based on equal pressures measured intraoperatively. A third reoperation was scheduled based on cardiac catheterization but the child died whilst awaiting surgery. The third patient was reoperated on the basis of cardiac catheterization findings. The fourth and the fifth patients have not, to date, required reoperation in spite of the observation that the right ventricle opacified significantly following a left-sided contrast injection.

Discussion

The ultimate aim of the cardiac surgeon is to perform an adequate repair. In some instances, when dealing with intracardiac shunts, reoperation may be necessary due to a residual shunt.

In most institutes, cardiac catheterization is employed to prove a significant shunt following repair. The application of a complete postoperative echocardiographic investigation combined with contrast and/or Doppler echocardiography is a realistic alternative[6–8]. Santoso and coworkers established residual shunting at atrial level in 6 of 18 patients using venous contrast echocardiography. Because of the absence of clinical evidence for significant residual shunting none of these patients was reoperated upon[6]. Conversely, in another report where the immediate postoperative period was complicated by desaturation, persistent heart failure and/or significant murmurs, residual shunt detected by contrast echocardiography necessitated additional surgical intervention in 8 of 13 children[7].

For the patients' benefit, however, early detection of a residual shunt is highly recommended. Pressure measurements are frequently used to detect elevated right ventricular pressure, particularly in patients with tetralogy of Fallot or double-outlet right ventricle. This method, however, is not able to distinguish between an elevated right-ventricular pressure due to obstruction or due to a significant shunt at ventricular level. In the present study we chose the optical assessment of the amount of bubbles appearing in the right ventricle as this method is the only on-line method available for surgeons faced with the decision of whether or not to reoperate. We found that using contrast echocardiography, residual shunts at ventricular level were absent in 40 patients and insignificant in five patients: the clinical follow-up of these 45 patients was uneventful. These findings are not in accordance with the results of Stevenson and coworkers[9] who found a 93% incidence of residual shunts in patients studied with pulsed Doppler in the immediate postoperative period; a percentage that decreased progressively over the following days. In our opinion it seems unlikely that intraoperative contrast echocardiography is a less sensitive technique than Doppler studies performed postoperatively. In the five patients who showed insignificant opacification of the right ventricle, the overflow of contrast bubbles probably resulted from interstitch permeability before epithelialization[7]. Among the 45 patients with an uneventful clinical follow-up we found that the type of injection did not influence the appearance of bubbles in the right ventricle: a transseptal puncture was performed in six patients whereas in 39 patients the injection occurred via the left atrium line.

Significant opacification of the right ventricle noted in five other patients was consistently associated with a documental residual ventricular septal defect. This observation in itself is regarded as an ominous sign but it does not necessarily indicate a residual shunt of significant volume. Indeed, only six of the nine contrast studies (three patients) with significant opacification of the right ventricle required reoperation. It is fair to say that the decision for immediate reoperation cannot be based solely on the results of intraoperative contrast studies. Intraoperative pressure measurements were not found to be of major value in this study. Additional application of intraoperative continuous wave Doppler might be of further help in discriminating pathologic from non-pathologic shunting.

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KEY WORDS: Intraoperative echocardiography, contrast echo, residual ventricular septal defect.

CHAPTER 4

DISCUSSION

4.1 Historical perspective.

The application of intraoperative ultrasound in cardiac surgical patients has been reported since 1972[1] (Table 1). At that time, individual reports appeared concerning the use of M-mode echocardiography, which was the only ultrasound equipment available.[2,3] The limited additional information obtained with this equipment precluded its clinical application. After the introduction of high resolution two-dimensional echocardiography, progress was made with intraoperative ultrasound in cardiac surgery ([4-8], Chapter 3.1). The current availability of intraoperative color Doppler echocardiography,[9] coinciding with the introduction of single plane esophageal echocardiography as an alternative window to the heart,[10-13] has popularized intraoperative ultrasound to a level where the echocardiographic study is nowadays a routine procedure in many cardiac operations.

TABLE 1. Intraoperative application of echocardiography.

1972	M-mode echocardiography
1982	Two-dimensional echocardiography
1985	Color Doppler echocardiography
1985	Esophageal echocardiography
1990	Biplane echocardiography[14]

Our publications are part of the progress in defining the role of the intraoperative application of ultrasound in cardiac surgery. The publications in this thesis are based on studies using epicardial two-dimensional and contrast echocardiography. They emphasize the information about intracardiac morphology and some aspects of cardiac function that can be obtained with these techniques, which were not

obtained using conventional preoperative investigations. The preoperative echocardiographic diagnosis in many patients has recently been improved by the introduction of esophageal and color Doppler echocardiography, and these have affected the indications for epicardial echocardiography.
The introduction of these new techniques in the operating room has also extended the scope of intraoperative echocardiography. In this chapter the value of these new modalities will be highlighted, and contrasted with conventional intraoperative two-dimensional contrast echocardiography as described in this thesis.

4.2.1 Preoperative esophageal versus epicardial echocardiography.

During the initial phase of our investigations of epicardial echocardiography, (trans)esophageal echocardiography was transformed from a research procedure and implemented fully in the practice of clinical cardiology in adults.[11] This alternative ultrasound "window to the heart" shares with epicardial echocardiography the ability to display images of intracardiac structures which are of higher quality than those obtained on transthoracic echocardiography, since intervening thoracic structures are avoided.[15] Therefore, some of the advantages of prebypass epicardial echocardiography compared to transthoracic echocardiography, are now achieved by preoperative esophageal echocardiography in the awake patient. For example, in patients with complicated infective endocarditis of the aortic valve, we showed that intraoperative two-dimensional echocardiography provided information undetected by other diagnostic methods. This information was highly relevant for the surgical procedure in this condition (Chapter 3.2). Nowadays, esophageal echocardiography has superceded this indication for a prebypass study to a great extent (Chapter 3.3, [16, 17]). The same situation exists for other conditions such as subaortic left ventricular outflow tract obstruction and intracardiac tumor. Compared to epicardial echocardiography, however, single plane esophageal echocardiography has major limitations with regard to cross-sections, image quality, and patient tolerance in the awake patient. The technique cannot be used in small children (Table 2). Therefore, epicardial echocardiography is still complementary in patients with acquired heart disease, by providing relevant additional data to the surgeon. Recently, the value of esophageal echocardiography in congenital heart disease has been explored further.[18] The complex relationship between epicardial and esophageal echocardiography in these patients is discussed in Chapter 4.5.3.

The following discussion will assume a complete preoperative diagnostic echocardiographic examination, and if indicated, single plane esophageal echocardiography in the awake patient.

TABLE 2. Advantages of epicardial and esophageal echocardiography.

Epicardial echocardiography	
	More cross-sections
	Higher image quality
	Surgeon handles transducer
	No limitations in size of patients who can be studied
	Continuous-wave Doppler assessment of left ventricular outflow
	Less intervening intrathoracic structures (airways)
	No anterior flow masking
	No limitations in availability of transducers
Esophageal echocardiography	
	Less interruption of the surgical procedure
	No posterior flow masking
	More skilled handling of the equipment

4.2.2 Intraoperative esophageal versus epicardial echocardiography

The major advantage of intraoperative esophageal echocardiography is that it interrupts the surgical procedure to a lesser extent than epicardial echocardiography (Table 2). However, the epicardial approach provides more information due to its greater versatility. Epicardial echocardiography is used in patients in whom the probe cannot be introduced, and when logistic problems occur due to the availability or applicability of esophageal transducers. From the esophageal approach, anterior flow masking by previously implanted prosthetic material in the heart, may limit the examination. In these cases, an epicardial study may complete the echocardiographic examination before cardiopulmonary bypass is started.
In general, the preferred 'window' depends on the clinical situation and the indication for the intraoperative echocardiographic examination (Chapter 4.4).
Some technical limitations of esophageal echocardiography may be overcome in the near future, further limiting the role of epicardial imaging. New esophageal transducers are being developed with biplane or multiplane imaging, while currently available transducers provide only a single transverse plane.[14] The major disadvantage of the newly developed biplane probes is that imaging planes are added, or the transducers are miniaturized, at the expense of reduced image quality.

4.2.3 Epicardial contrast versus color Doppler echocardiography.

We used contrast echocardiography extensively, before the introduction of color Doppler echocardiography. The technique appeared useful for the assessment of residual regurgitation following mitral valve repair in adult patients. For this application, the technique was validated against angiocardiography by Mindich and Egueras.[6,7] However, when comparing contrast echocardiography with intraoperative color Doppler echocardiography, we found the latter technique to be more practical in patients undergoing mitral valve surgery.[19] It indicates the site of residual regurgitation and is less demanding than contrast echocardiography. The predictive value of epicardial color Doppler echocardiography for the assessment of residual mitral regurgitation was shown by the groups of Maurer and Stewart.[20,21]

We encountered false positive studies using contrast echocardiography in both children and adults after aortic valve surgery, and therefore we did not explore the procedure further for these indications. Epicardial color Doppler echocardiography is felt to be a major adjunct after reconstructive aortic valve operations, aortic valvotomy and aortic valve replacement by homograft or pulmonary autograft. With the technique, residual aortic regurgitation or left ventricular outflow tract obstruction can be assessed.[22,23]

The application of color Doppler flow mapping was shown to be of direct value in patients after repair of the tricuspid valve.[24,25]

It should be remembered, however, that color Doppler examination gives qualitative data on regurgitant valves[26] and are very sensitive to machine settings and patient characteristics.[27] Added to these problems are the rapid changes in left ventricular geometry and hemodynamics after termination of cardiopulmonary bypass. In particular, the changes in afterload after mitral or tricuspid reconstruction influence the driving force of residual regurgitation.[28] In our hands, contrast echocardiography was not useful in small-sized patients to assess mitral regurgitation. Major problems related to high heart rates were the correct timing of the injection of contrast material, and the interpretation of images. Assessment by color Doppler echocardiography of residual mitral regurgitation after correction of atrio-ventricular septal defects in small children is advocated by some authors,[29,30] but predictive value for the immediate postoperative period was not evident in our clinic.[31]

The major current indication for intraoperative contrast echocardiography is the assessment of the severity of a residual shunt. We showed that the technique is of value after closure of congenital septal defects (Chapter 3.9) and in these patients both color Doppler and contrast echocardiography should be used.[32] The interpretation of color Doppler maps is influenced by turbulence due to patch material, it is more prone to interobserver variability, and flow masking is likely if only the esophageal approach is used.[32] The ability to locate additional or residual defects is the major advantage of color Doppler echocardiography. Our experience suggests that ischemic septal defects should also be assessed by both color Doppler and contrast echocardiography.

4.3 The value of intraoperative echocardiography.

Since 1984, approximately 1300 intraoperative echocardiographic examinations have been performed in our institution. From 1984 until the end of 1987, two-dimensional and contrast echocardiography were used. We studied 674 patients with these techniques, including 282 patients (42%) who were operated upon for acquired heart disease and 392 (58%) who underwent correction of congenital heart defects. Since 1988, 452 patients were studied using color Doppler echocardiography, 105 patients with acquired (23%) and 347 patients with congenital heart disease (77%). Intraoperative esophageal echocardiography has been used since late 1988.

From this experience and from that of others, the application of intraoperative ultrasound in acquired heart disease will be discussed in terms of the situations in which these studies were of value, the indications that stood the test of time and the indications supported by clinical evidence from other centers. The preferred approach, epicardial or esophageal, will be indicated (Chapter 4.4).

For patients with congenital heart disease, it is unclear whether intraoperative echocardiography should be used routinely or when there is a specific indication. The current approach with intraoperative ultrasound in these patients requires a separate discussion (Chapter 4.5).

4.4 Indications for intraoperative echocardiography in acquired heart disease.

4.4.1 Prebypass study.

Unexpected findings on surgical inspection:

A complete intraoperative echocardiographic examination is useful if visual inspection of the heart casts doubt on the (completeness of) the preoperative diagnosis (Chapter 3.1 and 3.6). In this uncommon situation, the preoperative diagnosis may be revised. The limited versatility of intraoperative esophageal echocardiography and the logistic problems of introducing the esophageal probe in the acute situation in the fully draped patient, makes the epicardial approach the preferred one.

Mitral valve disease:
Mitral valve morphology is visualized better by epicardial imaging than by the transthoracic or the esophageal approach.[33,34] In patients with pure mitral regurgitation, the information which the technique provides, helps the surgeon to assess the suitability of the valve for reconstruction (Chapter 3.4). The improved visualization supports the surgeon in his learning phase of valve repair. It assists in the understanding of valve pathology in patients with a small left atrium (visual inspection is impaired) or a collapsed valvar apparatus (due to cardioplegic arrest). The limitations of single plane esophageal echocardiography are due to tangential cross-sections through the valve leading to problems of interpretation and incomplete visualization of the posteromedial area[33,35].
In patients with mitral stenosis or mixed valve disease, epicardial echocardiography provides detailed information on the structure of the mitral valve apparatus. We consider this information not important to the surgeon during the operation. The stiffness of the leaflets is an essential element of the mechanism leading to valve dysfunction, but it is assessed better by visual inspection. These patients have a large left atrium, and access to the valve for visual inspection does not pose any problems.
Aortic valve disease:
The indications for an epicardial echocardiographic study are assessment of the suitability of the patient for aortic valve replacement by homograft or pulmonary autograft, and measurement of the aortic annulus. The annular size obtained with echocardiography correlates well with conventional intraoperative measurements. Thus, in patients with inadequate transthoracic estimates of annular size, homograft selection may be facilitated[22]. Esophageal echocardiography fails to provide these data due to tangential cross-sections.
Aortic disease:
Three areas are hidden from view on single plane esophageal echocardiography: the distal part of the ascending aorta, the outer curvature of the arch and the abdominal aorta.[36-38] Therefore, exact localization of an intimal flap, and its extension into the arch in a case of "DeBakey" Type II dissection, or the retrograde extension of dissection into the arch in Type III dissection, are often incompletely understood on esophageal echocardiography alone. The exact site of entry may be unclear from the preoperative diagnostic study, and the exact site of re-entry, for example in a patient with DeBakey Type II dissection extending into the arch, may also be unclear[39]. In acute dissections involving the ascending aorta (DeBakey Types I and II), esophageal echocardiography is usually the only definitive investigation leading to operation. In chronic dissection, other diagnostic procedures (CT, angiography) may fail to determine the site of entry and re-entry.[36,37] Thus,

epivascular echocardiography is relevant to the surgeon when determining the site of cannulation, the choice of deep or moderate hypothermia, and the conduct of the procedure (Chapter 3.6, [39,40]). Biplane transesophageal transducers may be a partial solution to these current limitations for this specific disease.

Post-infarction septal rupture:

The exact site of rupture is often not established with preoperative investigations including esophageal echocardiography. The location of the defect may influence the surgical approach, since defects located high in the septum can be reached through the right atrium instead of the left ventricle. In these patients epicardial imaging can provide this information. Esophageal echocardiography is limited in the assessment of the entire interventricular septum.

Subaortic obstructive pathology:

The relevance of intraoperative echocardiography in patients with hypertrophic obstructive cardiomyopathy is well described in a recent paper.[41] Our experience in a limited number of patients supports these observations. In patients with poor acoustic properties for transthoracic echocardiography, esophageal echocardiography is not suitable, because it cannot provide the data required by the surgeon in such patients. This information can be obtained with epicardial echocardiography: septal thickness, the site of major septal hypertrophy (used to guide myectomy), or the confirmation of minimal hypertrophy in the septal outflow area (which is an indication for mitral valve replacement as the sole procedure). Additionally, uncommon pathology should be sought for (Chapter 3.7).

Uncommon pathology:

In many instances, it is useful to the cardiac surgeon to obtain high quality images of uncommon pathology, since these improve his or her understanding of the cardiac pathology. We believe this improves the quality of surgery.

Prebypass baseline study:

In some patients, the indication for intraoperative prebypass echocardiography is to obtain baseline values for comparison with the situation after cardiopulmonary bypass.

4.4.2 Postbypass study.

Valve reconstruction, allograft and autograft replacement:

Currently, more surgeons have to become familiar with reconstructive valve surgery, aortic valve replacement with a homograft or pulmonary autograft, and aortic valve resuspension in aortic dissection. Mastery of these skills is improved by intraoperative imaging of pathology and also by assessment of the immediate result,[42] which may have improved long-term results as a consequence. Therefore, the most common indication for intraoperative echocardiography after cardiopul-

monary bypass in acquired heart disease, is the assessment of valvar function. For mitral valve repair, the technique is sensitive and conveniently performed with esophageal echocardiography.[12,33,43,44] When the data from esophageal echocardiography indicate that the result is unsatisfactory, we use the greater versatility of epicardial imaging to localize residual valve lesions and to assess serially left ventricular outflow gradients (Chapter 3.5, [33,41,43]).
Residual tricuspid regurgitation is most easily assessed from the esophagus. The assessment after aortic valve reconstruction or implantation of a homograft or autograft is best performed with epicardial echocardiography.[45,46]
Other acquired heart disease:
The relevant questions after closure of ischemic ventricular septal rupture - residual ventricular septal defect, left ventricular function, and mitral valve competence can be answered with esophageal echocardiography. Examples of other conditions in which it is worthwhile to document the post-repair result intraoperatively, are aortic dissection and idiopathic hypertrophic subaortic stenosis.

4.5 Intraoperative echocardiography in congenital heart disease.

The indications for the application of intraoperative ultrasound and the preferred approach (epicardial or esophageal) seem to be settled in patients with acquired heart disease. However, in patients with congenital heart disease, there are strong arguments in favor of the routine application of intraoperative echocardiography (Chapter 3.8). Epicardial echocardiography is the preferred approach in these patients (Chapter 4.5.1 and 4.5.2), but this standard may be challenged by use of esophageal echocardiography in the future (Chapter 4.5.3).

4.5.1 Prebypass epicardial echocardiography.

We showed retrospectively that the data obtained using two-dimensional echocardiography in patients with congenital heart disease, led to a change in the planned surgical procedure in 2% of the patients and added surgically relevant information in 10% of the patients (Chapter 3.8). Using color Doppler echocardiography in a prospective study, Ungerleider found that in 15% of patients unsuspected findings influenced the surgical procedure.[47] This information can be obtained before the heart is made ischemic and opened. To what extent this information influences the surgical procedure depends on the experience of the surgeon, but even experienced surgeons consider that the results of the prebypass study are helpful during the repair. This is the consequence of the clear presentation of the intracardiac defects and their spatial distribution to the surgeon just before repair. Although the routine use of prebypass imaging may meet with

skepticism, the application of epicardial echocardiography in patients with unexpected external morphology of the heart upon visual inspection is an important adjunct to congenital cardiac surgery (Chapter 3.7, [47]).
The additional value of color Doppler echocardiography in these patients lies in its direct depiction of intracardiac shunts, and disturbed flow around valves and in outflow tracts, before and after cardiopulmonary bypass.[12,18,30,48]
In small infants the occasional diagnostic problems due to the large size of the commercially available transducers in small infants may be solved by miniaturization of epicardial transducers.[49]

4.5.2 Postbypass epicardial echocardiography

The main advantage of epicardial echocardiography is that it provides the surgeon with direct information on the repair performed, in the functioning heart immediately after termination of cardiopulmonary bypass. With the exception of direct visual inspection during the repair, all conventional measurements like pressure readings, saturation studies and green dye curves are an indirect assessment of the result. The results of saturation studies are obtained with considerable delay, and green dye studies may only be 'positive' in patients with large residual defects.[47,50]
Significant residual shunts can be detected, and their origins determined, with contrast and color Doppler echocardiography (Chapter 3.9, [32]). Severe residual valve regurgitation requiring additional repair can be differentiated from less severe valve insufficiency. Left ventricular function can be assessed, and this may lead to adjustments in anesthetic management (Chapter 3.8, [30]). The cause of residual outflow tract obstruction, can be determined. It is the virtue of epicardial echocardiography that all these data can be obtained from one relatively short intraoperative study.
Intraoperative echocardiography after bypass provides an immediate feed-back to the surgeon who performed the repair, and this has a strong learning effect in the long term. Although an "echo-perfect" result is not always necessary for a good clinical outcome, it may serve as a new standard in cardiac surgery.[47] It is important to document "less than perfect echo results", since these make it easier to understand eventual problems in the post-operative period. Sometimes, echocardial serves as the major source of important information used to decide that immediate reintervention is required, especially in an patient who cannot be weaned from cardiopulmonary bypass.

4.5.3 Intraoperative esophageal echocardiography

The question of the preferred approach is more complex in patients with congenital heart disease than in patients with acquired heart disease.[18] The limitations of the esophageal approach are more pronounced in these patients. Approximately 25% of our operated patients are under the age of 4 months, preventing the introduction of an esophageal transducer. In many patients the intracardiac pathology is complex, and we and others have found a high proportion of patients presenting with unexpected pathology. The single imaging plane of the esophageal probe compares unfavorably with the versatility of epicardial echocardiography. Another advantage of epicardial echocardiography is that the surgeon can perform the echocardiographic examination and study those aspects of the intracardiac pathology of special interest for the surgical procedure.

These considerations mean that the epicardial approach is preferred over the esophageal approach.[47,51] However, experience with esophageal echocardiography in congenital heart disease, including small infants, is increasing rapidly and further progress using this modality can be expected.[52,53]

4.6 Epilogue

The questions raised by the objectives of this study are answered in the preceding chapters. Some of the inferences drawn are surpassed by new technical developments. Two-dimensional epicardial echocardiography is an instrument that can be used by the surgeon, independently, to assess intracardiac morphology and many aspects of cardiac function.

The introduction of color Doppler and esophageal echocardiography has widened the scope of intraoperative ultrasound, but requires a concerted effort by cardiologist, anesthesiologist and cardiac surgeon. Intraoperative echocardiography improves the quality of surgical care in our patients.

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SUMMARY

The present generation of cardiac ultrasound systems provide good cross-sections of the heart and its chambers. The mobility of the equipment allowed its introduction into the operating room and when the transducer is applied directly to the exposed surface of the heart, the quality of the echocardiographic images is considerably improved, compared with the precordial approach. The technique of epicardial two-dimensional and contrast echocardiography allows the surgeon to assess, intraoperatively, the intracardiac morphology and aspects of cardiac function before and after termination of cardiopulmonary bypass.

At the end of 1983 both phased array and mechanical sector scanners were tested on open-chested pigs. We preferred the mechanical sector scanner because of the quality of the images which were produced, thereby accepting the limitations of increased maintenance and large transducer size compared to phased array systems. Electrical safety was tested in accordance with the existing regulations for equipment used in the operating room. We prepared 2 meter long plastic bags to wrap around the transducer and connecting cable to prevent transducer failure and ensure sterility.

The epicardial approach for intraoperative echocardiography leads to an increased versatility of transducer locations compared to the transthoracic approach. However, interpretation of the images is facilitated by some form of standardization. The basic epicardial and epivascular locations for the transducer are described in Chapter 2. For assessment of residual regurgitation and shunt, agitated saline was used as the echocardiographic contrast material. The methods of data acquisition and analysis are described in Chapter 2.

In the first 200 patients evaluated with epicardial two-dimensional echocardiography before the start of cardiopulmonary bypass, a new, unsuspected diagnosis was found in 7 patients (3.5%) (Chapter 3.1). In 32 patients (16%) additional morphologic information was obtained by the technique, which proved to be relevant for the surgeon. After termination of cardiopulmonary bypass, the investigation provided in 15 patients (7.5%) important information on residual shunting or atrioventricular valve regurgitation and left ventricular function. In 1 patient, a retained segment of a pressure monitoring line could be located and removed during a second pump run.

In this period it seemed timely to determine the specific indications for an intra-

operative echocardiographic study in patients with acquired heart disease. The technique provided detailed information in patients with complicated native and prosthetic aortic valve endocarditis, much better than with existing diagnostic methods (Chapter 3.2). However, during this same period, the application of (trans)esophageal echocardiography in the awake patient increased rapidly and had the same potential of improving the diagnosis of infectious endocarditis as was obtained with the epicardial approach (Chapter 3.3). It is obvious that esophageal echocardiography in the awake patient is the preferred technique in these patients. For visualization of mitral valve pathology in patients with valve regurgitation, epicardial echocardiography is superior to transthoracic or esophageal echocardiography. Leaflet closure, leaflet motion abnormalities and annulus size can be analyzed in detail (Chapter 3.4). Traditionally, echocardiographic analysis of regurgitant mitral valves has concentrated on the description of abnormalities of leaflet motion such as prolapse, while surgical correction aims to restore coaptation of the edges of the leaflets. Classification of valve pathology according to the pattern of leaflet closure, with description of leaflet motion and annulus size offered a direct relationship between echocardiographic findings and the type of reconstructive technique to be applied by the surgeon.

After reconstructive mitral valve surgery using Carpentier techniques, an undetermined proportion of patients has systolic anterior motion (SAM) of the anterior mitral leaflet. This complication is more disturbing if it is associated with a persistent left ventricular outflow tract obstruction (LVOTO). Epicardial echocardiography is a suitable technique to detect SAM and LVOTO after valve repair and invites to immediate reintervention. However, we reported 2 patients (Chapter 3.5) who developed SAM and transient, severe LVOTO immediately after termination of cardiopulmonary bypass. Without further intervention, neither patient had persistent LVOTO at follow-up, either at rest or during exercise.

Epivascular echocardiography, can provide relevant information to the surgeon, in patients with diseases of the thoracic aorta (Chapter 3.6). However, the introduction of preoperative esophageal echocardiography in the awake patient has changed the role of epicardial echocardiography in these patients (Chapter 4).

Our findings in patients with subvalvular aortic obstruction and their impact on the surgical procedure are described in Chapter 3.7.

An important application of the technique was found in 195 patients with congenital heart disease (Chapter 3.8). In 4 patients (2%) the echocardiographic findings before the start of cardiopulmonary bypass resulted in modifications of the surgical approach, and in 18 patients (10%) these echocardiographic findings were judged to contribute to a refinement of the surgical management. The adequacy of cardiac repair was assessed before closure of the chest and this information contributed in

17 patients (9%) to the subsequent operative or non-operative treatment.
The value of epicardial contrast echocardiography for the recognition of residual ventricular septal defect is described in Chapter 3.9.
In the 6 years since we started our investigations of the value of epicardial two-dimensional echocardiography and contrast echocardiography, new developments had a strong influence on intraoperative echocardiography. The introduction of preoperative esophageal echocardiography in the awake patient, intraoperative esophageal and color Doppler echocardiography reduced the role of epicardial echocardiography but broadened the scope of intraoperative ultrasound. Increased application of aortic homografts and autografts (Ross' procedure) with more valve repairs been done, popularized intraoperative ultrasound to a level where the echocardiographic study is a routine procedure in many cardiac operations.
In Chapter 4, the results from the studies in this thesis will be contrasted and compared with other reports and a short review of the state of the art of intraoperative echocardiography will be given.

SAMENVATTING

Sedert het begin van de jaren tachtig is het mogelijk met ultrageluid goede tweedimensionale afbeeldingen van het hart te verkrijgen. Het doordringend vermogen van ultrageluid wordt sterk beperkt door de structuren van de thoraxwand. Door het ultrageluid uitzendende en ontvangende deel van de apparatuur (transducer) tijdens operaties direct op het hart te plaatsen, bleek de kwaliteit van de beeldvorming veel beter dan tijdens conventioneel gebruik. Op deze wijze is het mogelijk, vóór en ná interventie door de hartchirurg, in het functionerende hart te kijken met apparatuur die tevens goed verplaatsbaar is. De beeldkwaliteit van de indertijd beschikbare apparatuur werd beoordeeld tijdens dierexperimenten. Op basis hiervan werd gekozen voor een mechanische sector scanner met een 5 MHz transducer. De elektrische veiligheid van deze apparatuur bij toepassing op de operatiekamer werd beoordeeld volgens de daarvoor geldende normen. De steriliteit werd gewaarborgd door de transducer in een lange plastic zak te plaatsen.
Vanaf eind 1983 werd deze techniek door ons toegepast tijdens operaties aan het hart en de grote vaten. Voor het epicardiaal echocardiografisch onderzoek staat de gehele voorzijde van het hart ter beschikking. In hoofdstuk 2 worden de echocardiografische doorsneden beschreven die voor een goede beoordeling van het hart vereist zijn. Voor de beoordeling van klepfunctie en residuele shunt werd gebruik gemaakt van contrast materiaal. Patienten met verworven en aangeboren hartafwijkingen werden vóór en ná het aansluiten van de hart-long machine echocardiografisch onderzocht. De onderzoeksmethoden staan beschreven in hoofdstuk 2.
Bij de eerste 200 onderzochte patienten bleek tijdens epicardiaal echocardiografisch onderzoek vóór het aansluiten van de hart-long machine, de oorspronkelijke diagnose bij 5 patienten niet geheel juist en bij 2 patienten geheel onjuist (3.5%) (Hoofdstuk 3.1). Voor de chirurg belangrijke aanvullende gegevens betreffende intracardiale anatomie werden verkregen bij 32 patienten (16%). Na beeindigen van de extracorporale circulatie was het epicardiaal echocardiografisch onderzoek bij 15 patienten (7.5%) van belang ter beoordeling van resterende shunt, van resterende lekkage na klepreconstructie en van de linker ventrikel functie. Bij 1 patient was echografie van belang voor het oplossen van een iatrogeen probleem.
In deze fase van de studie leek het belangrijk om te identificeren welke afwijkingen speciaal in aanmerking komen voor een aanvullend epicardiaal echocardiografisch onderzoek. Bij patienten met endocarditis van de aortaklep, werden

complicerende annulus pathologie en septum abcessen of intracardiale fistels veel beter gedetecteerd dan met destijds bestaande onderzoektechnieken (Hoofdstuk 3.2). In deze periode begon preoperatieve slokdarm echocardiografie een snelle opmars. Zoals uit hoofdstuk 3.3 blijkt, had slokdarm echocardiografie het potentieel om dezelfde verbetering in diagnostiek tot stand te brengen. Dit potentieel is inmiddels volledig gerealiseerd voor deze groep van aandoeningen.
Beschrijving van mitralisklep morfologie bij patienten met mitralisklep insufficientie is met epicardiale echocardiografie beter mogelijk dan met transthoracale of slokdarm echocardiografie. De sluiting van de klepbladen, afwijkingen in de klepbeweging en de diameter van de mitralisklep annulus kunnen nauwkeurig geanalyseerd worden. De chirurg die een mitralisklep wil repareren heeft zo een duidelijk inzicht in het pathologisch functioneren van de mitralisklep. Het is van groot belang om te bepalen welke reparatietechniek aangewezen is speciaal wanneer de mitralisklep slecht toegankelijk is voor visuele inspectie na openen van het hart. Het bleek noodzakelijk de bestaande terminologie voor het beschrijven van mitralisklep afwijkingen te herzien (Hoofdstuk 3.4).
Na reconstructie van de mitralisklep onstaat soms een voorwaartse beweging van het voorste klepblad, die tot blijvende obstructie van de linker ventrikel uitstroombaan kan leiden. In hoofdstuk 3.5, staan 2 patienten met een dynamische linker ventrikel uitstroom obstructie beschreven. Dynamische obstructies verdwijnen kortere of langere tijd na het beeindigen van de extracorporale circulatie en zijn geen indicatie voor onmiddellijke reinterventie. Overigens lijkt voorwaartse beweging van het voorste klepblad, direct na reconstructie met technieken volgens Carpentier, veel vaker voor te komen dan vermoed.
Bij patienten met een dissectie, aneurysma of iatrogene afwijking van de aorta kan epivasculaire echografie belangrijke additionele informatie leveren aan de hartchirurg (Hoofdstuk 3.6). Echter, door de opkomst van preoperatieve slokdarm echocardiografie is de rol van intraoperatieve echocardiografie geheel veranderd (Hoofdstuk 4).
In hoofdstuk 3.7 worden de bevindingen bij patienten met linker ventrikel uitstroom obstructies beschreven.
Een belangrijke toepassing van epicardiale echocardiografie bleek uit de analyse van de bevindingen bij 190 patienten met een aangeboren hartafwijking (Hoofdstuk 3.8). Bij 4 patienten (2%) leidde de bevindingen bij echocardiografisch onderzoek vóór het aansluiten van de hart-long machine tot een wezenlijke verandering van de gevolgde chirurgische procedure. Bij 18 patienten (10%) werden de additionele echocardiografische bevindingen beoordeeld als belangrijk voor de chirurg. Na beeindigen van de extracorporale circulatie bleek bij 17 patienten (9%) de echocardiografische informatie van belang voor de verdere behandeling.

De betekenis van contrast echocardiografie voor de beoordeling van de ernst van resterende shunting wordt beschreven in hoofdstuk 3.9.
In de 6 jaar die verlopen zijn sedert het begin van deze studie naar het belang van epicardiale twee-dimensionale echocardiografie en contrast echocardiografie vonden enkele belangrijke ontwikkelingen plaats. De introductie van kleuren Doppler echocardiografie, preoperatieve en intraoperatieve slokdarm echocardiografie hadden een sterke invloed op het intraoperatief gebruik van ultrageluid. Ook het toenemende gebruik van allografts en autografts, met een steeds groter aantal klepreparaties, leidden tot een steeds intensiever gebruik van intraoperatieve echocardiografie. De bevindingen beschreven in de publicaties uit dit proefschrift moeten dan ook in het licht van deze nieuwe ontwikkelingen worden bezien. Hoofdstuk 4 geeft een overzicht van de huidige stand van zaken bij intraoperatieve echocardiografie.

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Jos Roelandt heeft mij blootgesteld aan een internationaal forum en een essentiele bijdrage geleverd aan het tot stand komen van de publicaties.
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CURRICULUM VITAE

Geboren op 6 januari 1949 te Bussum.

1968 Eindexamen HBS-B aan het Willem de Zwijger Lyceum te Bussum.

1975 Doctoraal examen Geneeskunde aan de Universiteit van Amsterdam.

1977 Artsexamen.

1978 Arts-assistent afdeling Cardio-pulmonale chirurgie Wilhelmina Gasthuis te Amsterdam.

1978 Vooropleiding op de afdeling Algemene Heelkunde van het Juliana Ziekenhuis te Zaandam (opleider Dr.S.Bouma).

1980 Opleiding op de afdelingen Cardiopulmonale Chirurgie van het Wilhelmina Gasthuis te Amsterdam (opleider Prof.dr.N.G.Meijne) en het Dijkzigt Ziekenhuis te Rotterdam (opleider Prof.dr.J.Nauta).

1984 Inschrijving in het specialisten register cardio-pulmonale chirurgie.

1984- Werkzaam op het Thorax Centrum als cardio-pulmonaal chirurg.