ASPECTS OF SURGERY FOR CONGENITAL VENTRICULAR SEPTAL DEFECT

Goris Bol Raap

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CONTENTS

CHAPTER 1

Introduction

INTRODUCTION

Congenital heart disease (CHD) is reported to be the most frequent congenital cardiac malformation. Although reports on the incidence vary considerably from 0.4 to 5% the most widely accepted estimate of the incidence of congenital heart disease (CHD) is 0.8% of all life births [1]. Of the CHD, isolated VSD is by far the most common diagnosis, accounting for 20% [1] to 30% of all CHD. In the Netherlands, approximately 1500 newborns (out of 190.000 life births) per year have a congenital cardiac malformation, of which approximately 30% (450) have a VSD. This is 0.3% of the living newborns (www.nederlandsehartstichting.nl). The incidence of CHD depends mainly on the number of patients with a small VSD and the timing and accuracy of the diagnosis in these patients. As a rule of thumb it is commonly accepted that the incidence of VSD is 30-40% of all congenital cardiac disease and 0-8% of all living newborns. VSD is found slightly more frequently in females than in males (56% vs. 44%) [2].

In the majority of the patients with an isolated VSD (95%) the defect is not associated with a chromosomal abnormality and the cause is unknown. A multifactorial aetiology has been suggested in which interaction between hereditary predisposition and environmental influences result in the defect [3]. An example of this hereditary predisposition is the high incidence of subaortic VSDs in Japan and China; 35% versus 5% in Caucasians [4].

ASPECTS OF SURGICAL ANATOMY

VSDs arise from failure of growth, alignment or fusion of one or more septal components and are best classified according to their margins and location [5].

A ventricular septal defect is a cardiac anomaly consisting of a connection between the right ventricle and the left ventricle. These defects can be single or multiple. A VSD may occur in any portion of the interventricular septum, including the membranous, muscular, inlet, or outlet septum, or a combination of locations.

Perimembraneous VSD. This is the most common type of VSD (80%). Part of the defect is bordered by the fibrous continuity between the mitral and tricuspid valve. The defect may be partially or completely occluded by the septal leaflet of the tricuspid valve.

Muscular VSD. This comprises 5% of VSDs and this defect is completely surrounded by muscular tissue. These defects are by definition located in the muscular part of the ventricular septum. Spontaneous closure of muscular VSDs frequently occurs in the first 2 years of life.

Outlet VSD. This comprises 5-10% of VSDs and part of the superior border is formed by the continuity between the aortic and pulmonary valves. Acquired aortic regurgita-

tion may be caused by prolapse of (usually) the right coronary leaflet into the defect. This prolapsing leaflet may functionally occlude an anatomically large VSD. A higher incidence of outlet VSDs occurs in Asian populations (25-30%) [4, 6].

Inlet VSD. This exists in the inlet part of the septum that separates the mitral and tricuspid valves, under the tricuspid valve and is least frequent. These VSDs are usually single defects and do not close spontaneously.

PATHOPHYSIOLOGICAL MECHANISMS

Because pulmonary vascular resistance (PVR) is high at birth and may decrease as late as 6-8 weeks, significant left-to-right shunting through the VSD with development of pulmonary overflow often is delayed until the second or third month of life.

The hemodynamic significance of a VSD is primarily determined by 2 factors: the size of the defect, a large VSD will allow more blood flow through the defect than a smaller VSD, and the pulmonary vascular resistance with more blood flowing across a VSD when the pulmonary vascular resistance is low. The diameter of the VSD in relation to the diameter of the aortic valve annulus may provide an indication for the size of the VSD. A VSD with the size of the aortic valve annulus may be regarded as large and carries the risk of a large left to right shunt and secondary pulmonary hypertension.

In large, non-restrictive VSDs the right and left ventricular pressures are equal. Due to pulmonary hypertension progressive pulmonary vascular disease will develop, resulting in a decrease of the degree of left-to-right shunting over time and eventually development of shunt reversal, from left-to-right into right-to-left shunting, leading to Eisenmenger physiology, when pulmonary vascular resistance exceeds systemic levels [7]. Nowadays this is uncommon in the western world because virtually all patients will have been operated upon before this stage.

In moderately restrictive VSDs, often the diameter of the defect is less than the diameter of the aortic annulus [7]. Both right ventricular systolic pressure and pulmonary vascular resistance may be increased to some extent, but not as explicit as for the non-restrictive VSD. Both left atrial and ventricular dilatation due to volume overload may be present. The degree of left-to-right shunting is moderate to severe.

In small VSDs, the size of the defect is often less than one third of the aortic annular size and implicates a significant systolic pressure gradient between the ventricles [7]. In these restrictive VSDs, pulmonary vascular resistance and right ventricular systolic pressure will be normal and the degree of left-to-right shunting is variable.

Most adults with small VSDs can participate fully in physical activities and sporting, but long-term follow-up is recommended to identify spontaneous closure, to

reinforce advice on endocarditis prophylaxis and to monitor for the onset of complications.

ASPECTS OF NATURAL HISTORY

The natural history of non-operated patients differs. Small defects mostly behave benign and have a tendency to become even less important or to close spontaneously. Patients with a spontaneously closed VSD and normal ventricular function probably have a normal life expectancy, as have asymptomatic adults with restrictive VSDs and normal pulmonary vascular resistance (25-year survival rate 96%) [8]. The flow across the VSD may have several direct and indirect deleterious effects. The flow from the left to the right ventricle results in an increased flow in the pulmonary bed. This may be accompanied by left heart enlargement as well as a rise in left ventricular end-diastolic pressure. Symptoms in infants are failure to thrive, shortness of breath and excessive sweating. Arrhythmias may develop on the long term, mostly atrial fibrillation, and often coincides with a late increase in left-to-right shunting. Double chambered right ventricle may occur in relation to a high velocity jet through the VSD into the right ventricle [2].

Patients with a subarterial VSD are more prone to develop aortic regurgitation. Both the absence of anatomic support in some of the outlet VSDs, as well as by a Venturi effect of the VSD jet on the aortic valve leaflets, may cause a prolapse of a cusp of the aortic valve, most often the right coronary cusp, giving rise to aortic valve regurgitation [9]. This injury is not necessarily related to the amount of flow across the VSD. Damage to the aortic valve is not reversible and may have serious consequences. To prevent development of aortic cusp prolapse and aortic regurgitation, any subarterial VSD of ≥5mm should be closed early [6].

Patients with a VSD are at increased risk of endocarditis. Endocarditis prophylaxis is widely being advised. Although rare, sudden cardiac death is also reported [8]. Patients with Eisenmenger physiology are rare nowadays, but have a poor long-term prognosis (25-year survival rate 42%) [8].

DIAGNOSIS

Most VSDs are diagnosed in infancy. Diagnosis is mostly based on physical examination. Congestive heart failure, failure to thrive and recurrent respiratory tract infections are the most frequent presenting clinical conditions. A characteristic pansystolic heart murmur is found. Sometimes a thrill can be felt precordially. On electrocardiogram hypertrophy

of the ventricles can be determined. On chest X-ray in patients with a large VSD signs of mild cardiac enlargement and increased pulmonary vascularity can be detected.

Echocardiography including color Doppler, has become the gold standard in analyzing the morphologic and hemodynamic characteristics of a VSD. This means that it is possible to define the morphologic nature of the margins and shape of the defect. Other anatomic structures such as the tricuspid valve leaflets, the right ventricular outflow tract, and the aortic valve can be displayed in their realistic spatial distribution. The shunting in relation to the size of the defect can also be estimated by assessing the diameter of the defect and the flow signal across it [10].

INDICATIONS AND APPROACH FOR SURGERY

The majority of isolated congenital VSDs close spontaneously. Small muscular and small perimembranous VSDs may close spontaneously in the first few years of life. An inverse relation exists between the age of the patient and the tendency to close spontaneously. Of the patients seen at 1 month of age in 80% the VSD closes spontaneously, as do about 60% of those seen at 3 months of age, 50% of those seen at 6 months, and about 25% of those seen at 12 months [2]. In contrast, in adults spontaneous VSD closure occurs in only 10% of the patients [11, 12].

Classic indications for ventricular septal defect closure have been substantial left-right shunting with Qp: Qs >1.5, congestive heart failure, reversible pulmonary hypertension, aortic valve regurgitation and endocarditis. Mostly this regards infants and children.

In young patients the indication for surgical closure of a VSD are most often volume-overload related symptoms [7]. Surgical closure may decrease the risk of endocarditis, reduce pulmonary artery pressure, improve functional classification and increase long-term survival [13]. With advancing age symptoms are related to secondary effects of a shunt, and persistent defects may predispose to endocarditis, aortic regurgitation and in selected cases to heart failure, arrhythmias and pulmonary hypertension [9].

Less clear remains the indication for congenital VSD in adults when the VSD is small, the right ventricular pressure is normal, the Qp/Qs is less than 1.5 and there is no aortic valve involvement. A VSD is not necessarily a benign anomaly and the course of patients depends on the size of the septal defect, the type of the defect and on possible concomitant anomalies [2].

Nowadays, VSDs are usually repaired through the right atrium and in selected cases through the great arteries. In the past, a right ventriculotomy and sometimes a left ventriculotomy was performed. When the exposure of the VSD through a right atriotomy is insufficient the tricuspid valve can be detached to enhance exposure. Temporary

chordal detachment is an alternative for temporary tricuspid detachment in enhancing exposure of the VSD [14, 15]. All patients are operated upon with cardiopulmonary bypass (CPB) with moderate hypothermia and cardioplegic arrest. CPB is performed with arterial cannulation in the ascending aorta and bicaval cannulation. A (Gore-Tex®) patch is used to close the defect. Caution should be applied to the atrioventricular pathways of conduction in order to avoid complete heartblock. Permanent iatrogenic complete heart block develops in approximately 1% of the patients [16]. In perimembranous defects the bundle of His traverses subendocardially during its course inferoposteriorly to the margin of the defect. In some muscular defects, however this bundle may run anterosuperiorly to the defect [16].

A transcatheter approach for VSD closure is increasingly gaining interest [17]. Percutaneous VSD-closure has been described by Hijazi [18]. This group reported on transcatheter closure of a single muscular VSD using the Amplatzer® muscular VSD occluder and concluded that this is quite a successful procedure with good outcomes at 6 months, however preferably used in muscular VSDs, because of the need for a suitable rim. The close proximity of the aortic valve makes this technique more complicated in VSD closure in perimembranous VSDs. For these patients, there is a potential risk of new or increased aortic or tricuspid regurgitation [19]. A prospective study of the same group reported on transcatheter closure of perimembranous VSD using the new Amplatzer Membranous VSD Occluder®. Serious adverse events were encountered in 8.6% of the patients, whereas the attempt to place the device was successful in 91%. Limitations of this study are that the patients were larger and older than those in whom surgical closure of a VSD is normally considered. The application of the Amplatzer Membranous VSD Occluder® in small infants may carry a higher risk and the results remain to be determined [20]. The most frequent complications after these procedures include rhythm and conduction disturbances [20]. So far, these results do not compare favourably with that of surgical closure [15, 17, 21].

POSTOPERATIVE OBSERVATIONS

Hospital mortality is low (≤1%) for repair of single large VSDs, which are repaired mostly in early infancy [2]. The risk is higher when the VSDs are multiple and when major associated cardiac anomalies coexist. The natural history in operated patients is mainly determined by the moment of operation and absence or presence of pulmonary hypertension. Patients with normal pulmonary vascular resistance and without pulmonary vascular disease have a normal life expectancy, whereas those who underwent relatively late repair may have a degree of pulmonary vascular disease, which may affect long-term outcome [22].

Conduction disturbances are frequently reported after repair of VSDs [16]. Right bundle branch block in repair of a perimembranous VSD through a right atriotomy was found in 34-44% of the patients, probably due to damage to the right bundle by sutures along the inferior border of perimembranous VSDs [23-25]. Serious ventricular arrhythmias and sudden death late after repair of VSDs are rare [26]. The approximate incidence of postoperative complete heart block after surgical VSD closure is less than 1%, and is more prevalent in patients with multiple VSDs and inlet VSDs [27]. Postoperative left-to-right shunts large enough to require reoperation are uncommon, 0.7% to 2% of the patients required reoperation for residual VSD [24].

Repair of VSD during the first 1 or 2 years of life is curative for most patients, resulting in full functional activity and normal or near-normal life expectancy [2]. This is illustrated in personal health assessment and physical health, which are comparable to that of the normal population [23].

AIM OF THE STUDY

The aim of present thesis is to study aspects of surgery for a congenital VSD in early childhood and at adult age. Nowadays, echocardiography is the key diagnostic tool, which may accurately identify the location, size, and spatial relation of the VSD and has made cardiac catheterisation with regard to a VSD hardly ever indicated anymore. The possible role of three-dimensional echocardiography to further improve the diagnostic accuracy with regard to surgical closure of a VSD is studied in Chapter 2. Temporary detachment of the tricuspid valve is studied and discussed in Chapter 3 and 4, with special emphasis to tricuspid valve function and rhythm disturbances during follow-up.

Can techniques of cardio-pulmonary bypass be improved? We studied the effects of hypothermia in two randomized groups in Chapter 5 and compared mild hypothermia (nasopharyngeal temperature ≥32°C during CPB) with moderate hypothermia (nasopharyngeal temperature ≥28°C during CPB).

An attempt to further increase the information on tricuspid valve function after VSD closure is made. In Chapter 6 the value of 3D-echocardiography and virtual reality in the postoperative assessment of surgical closure of a VSD is discussed.

What happens to the residual shunts often seen early after surgery? In Chapter 7 we studied a patient cohort with special emphasis for the residual shunt concerning the post-correction VSD.

The long-term follow-up of symptomatic patients operated at a young age is well studied [23, 28]. The follow-up of patients operated at adult age is less well known [7]. Quality of life of patients undergoing surgical closure during childhood is comparable to that of the normal population [23]. For those operated in adulthood this has not been

studied. Which were the indications for closing the VSDs, in which clinical condition was the patient, and how was the outcome clinically and with regard to quality of life? Therefore we describe the follow-up, including quality of life of patients undergoing surgical closure of a VSD in adulthood. This study is described in Chapter 8.

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CHAPTER 2

Three-Dimensional Echocardiography Enhances the Assessment of Ventricular Septal Defect

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INTRODUCTION

Functional and morphologic assessment of ventricular septal defect (VSD) is routinely done with 2-dimensional (2D) and color Doppler echocardiography.[1–5] Usually, this provides adequate information to decide on surgical repair[6,7]. Nevertheless, the anatomy of the VSD is complex [8,9] and cannot be presented by actual imaging techniques in a single plane.[10] Furthermore, advances in cardiac surgical procedures increasingly demand support of highly accurate imaging techniques.

Three-dimensional (3D) echocardiography has been proposed as a new technique able to simulate the intraoperative visualization of cardiac structures and to improve the understanding of the anatomy of congenital heart disease.[11] An experimental study conducted on animals has shown that 3D echocardiography is feasible for VSD analysis.[12] However, until now, studies on patients for the assessment of VSD with 3D echocardiography are scanty and not validated by intraoperative findings.[13,14]

To define the clinical use of 3D echocardiography, we evaluated whether 3D echocardiography can accurately identify and characterize the morphology of the VSD and assess its geometry and size in patients undergoing surgery.

MATERIAL AND METHODS

Thirty patients (16 males and 14 females) with diagnosis on routine 2D echocardiography of VSD were studied. The mean age was 6 ± 13 years (range 20 days to 61 years). Three patients were adults (age 18 to 61 years) and 27 were children (age 20 days to 6 years). Body surface area was 0.72 ± 0.6 m2 (range 0.22 to 2.1). In 12 patients, the VSD was isolated. In 11 patients the VSD was associated with tetralogy of Fallot and in 3 with pulmonary atresia. In 1 patient the VSD was associated with double-outlet right ventricle and transposition of the great arteries, and in another patient with simple transposition of the great arteries. In the remaining 2 patients the VSD was a residual defect after correction of a complete atrioventricular VSD.

Complete diagnostic transthoracic examination (2D echocardiography, pulsed Doppler wave, and color flow mapping) for clinical assessment was performed using HP 1500 (Hewlett-Packard, Andover, Massachusetts) echocardiographic equipment. Multiple cross sections imaging the VSD were taken from all windows, following a standard procedure.[6] The 3D echocardiographic acquisition was performed with a Toshiba SSH 140-A (Toshiba, Otawara-Shi, Japan) or HP 1500, of which the video output was interfaced to the Echo scan 3.0 (TomTec, Munich, Germany) 3D reconstruction system. Twenty patients were studied by the transthoracic and 10 by the transesophageal approach. Transesophageal echocardiography was performed only in children using the Minimulti

probe (Oldelft, Delft, The Netherlands), which contains 48 transmitting elements and operates at a frequency of 5 MHz. Transthoracic echocardiography was performed with a 3.5-MHz probe. All children were studied under general anesthesia just before surgery or cardiac catheterization. The 3 adult patients were studied in the Department of Echocardiography. Acquisition was performed with rotational scanning at 2° intervals for 90 steps, applying electrocardiography and respiratory gating.[15] During rotation, the VSD was kept in the center of the scan sector and care was taken that other cardiac structures like the tricuspid valve and the aortic valve were also encompassed for further spatial orientation and morphologic definition of the VSD.

The data were processed off-line and presented as a conical volumetric data set.[15] The 3D data sets were reconstructed and analyzed independently by 2 observers (AD, JMcG). From the volumetric data set, cut planes were selected using anyplane mode to visualize the ventricular septum on its left and right surface and in a longitudinal cross section. A gray level threshold was applied on the computer-generated 2D cut planes to separate the object from the background. Thus, 3D dynamic images with depth perception were created. A third observer (AC-D) analyzed the VSD on 2D echocardiography.

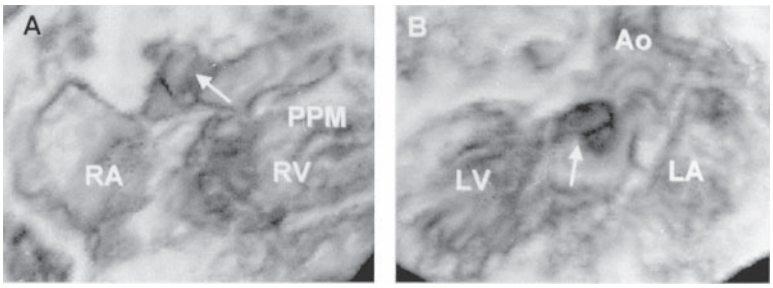

Figure 1. Perimembranous ventricular septal defect (outlet) *(arrow)*. *A,* view of the defect from the right aspect. The location of the defect in relation to the tricuspid valve and the outflow tract is shown. *B,* view of the defect from the left aspect. The location of the defect in relation to the aorta and the mitral valve is shown. Ao = aortic valve; LA = left atrium; LV = left ventricle; PPM = posterior papillary muscle; RA = right atrium; RV = right ventricle.

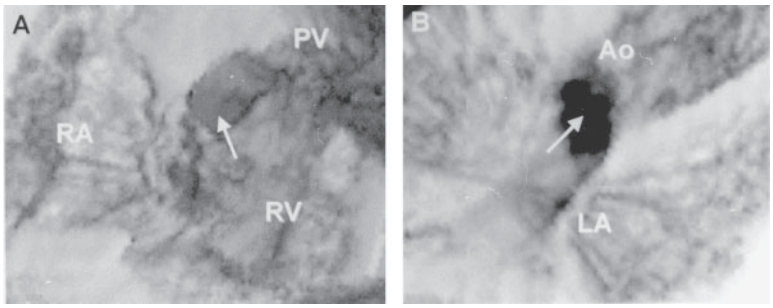

Figure 2. Morphologic aspects of the ventricular septal defect *(arrow)* associated with pulmonary atresia, seen from the right *(A)* and from the left *(B)* surface. PV = pulmonary valve; other abbreviations as in Figure 1.

The location of the VSD (perimembranous, muscular, inlet, outlet), the relation to the tricuspid valve (tethering of the tricuspid valve leaflet, presence of abnormal chordae), and to the aortic valve (degree of overriding) and its size were analyzed on both 2D and 3D echocardiographic images. On the 3D reconstruction, the anteroposterior and superoinferior diameters were measured, whereas on 2D echocardiography only the diameter derived from a 4-chamber view (corresponding to the anteroposterior direction) was measured. The largest anteroposterior diameter of the VSD measured on 3D images was compared with the largest anteroposterior diameter derived from 2D echocardiography. Morphologic accuracy was assessed postoperatively by presenting the dynamic 3D reconstructions of the VSD to the attending surgeon and correlating the data to the annotated intraoperative description.

Measurements are expressed as mean ± SD. Intra-and interobserver variability and comparison between 3D and 2D data were analyzed by linear regression and Bland-Altman analysis of agreement.[16] A p-value < 0.05 was considered significant.

RESULTS

The 3D data sets were adequate for reconstruction in 28 of 30 patients. In the other 2 patients, a wrong gain setting and the presence of a large rotational artefact in the dataset hampered the quality of the final reconstruction. Seventy-nine 3D reconstructions, displaying the VSD from the right and the left aspect, from above the aortic valve and along its longitudinal cross section, were used for analysis. Twenty-four of 28 patients had a single perimembranous VSD with extension to the outlet septum, situated just below the aortic valve (Figures 1 and 2). In 1 of these patients there was an associated aneurysm of the sinus of Valsalva. Two patients had an inlet VSD, 1 a doubly committed VSD. In 1 patient multiple VSDs were visualized: 2 were muscular defects and 1 a perimembranous outlet defect. In 2 patients the tricuspid valve leaflet was tethering the defect and in 6 patients abnormal chordae from the tricuspid valve were attached to the ventricular septum and crossing the defect area (Figure 3). From 28 adequate horizontal 3D cross sections above the aortic valve, overriding of approximately 50% was seen in 12 patients and of >50% in 1 patient (Figure 4).

There was complete agreement on morphology of the VSD between 3D and 2D echocardiography. However, 3D reconstructions were of additional value compared with 2D echocardiography in 6 of 28 patients (21%). Views of the right side of the VSD displayed the presence of abnormal chordae crossing the defect in 3 patients (Figure 3), the amount of tricuspid valve surrounding the defect in 2 other patients, and the number of VSDs in another patient better than 2D echocardiography. Three-D echocardiography did not give better visualization of the doubly committed VSD and of the

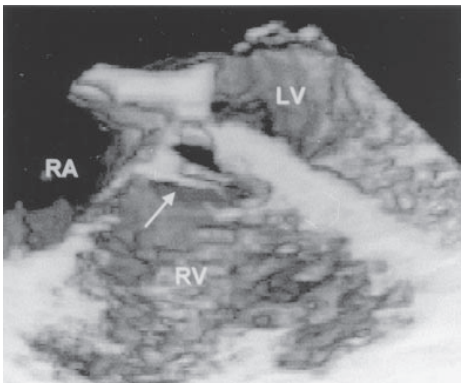

Figure 3. Volume rendered image of the right ventricle (RV) displaying the right aspect of the ventricular septal defect *(arrow)* and abnormal chordae from the tricuspid valve crossing the defect. Abbreviations as in Figure 1.

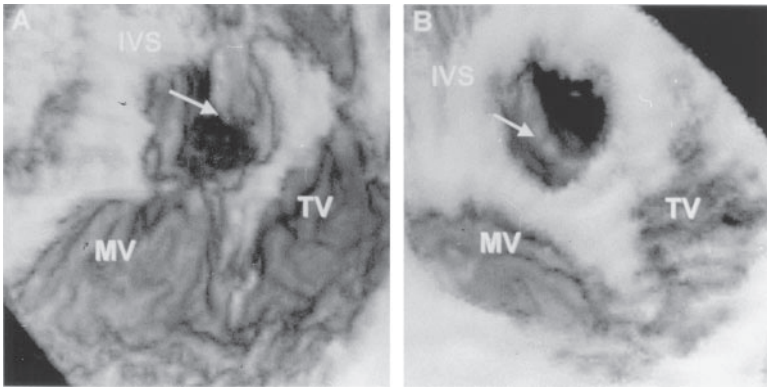

Figure 4. Horizontal cross section through the aortic valve from which it is possible to estimate the degree of overriding aorta *(arrow)*. *A,* aortic valve overrides the ventricular septum (IVS) by <50%; *B,* in a patient with tetralogy of Fallot the overriding aorta is about 50%. MV = mitral valve; TV = tricuspid valve.

VSD in relation to the Valsalva aneurysm. This was most probably due to the small size of the defects and the difficulty in obtaining an optimal 3D acquisition. Twenty-seven of 28 patients underwent surgical correction. The VSD was visualized through the right atrium and the tricuspid valve and closed in all cases with a Gore-Tex® patch (W.L. Gore & Associates, Inc., Flagstaff, Arizona). The agreement on anatomy between 3D reconstructions and intraoperative findings was complete in all patients.

Twenty-two facing views of the VSD were reconstructed and used for diameter measurement. The anteroposterior diameter was 13 ± 8 mm (intraobserver agreement r = 0.9, p< 0.001; interobserver agreement r = 0.9, p <0.001), the superoinferior diameter was 18 ± 6 mm (intraobserver agreement r = 0.7, p <0.001; interobserver agreement r = 0.9, p <0.001). The largest 3D anteroposterior diameter was compared with the corresponding 2D anteroposterior diameter (11.8 ± 4 mm). The correlation coefficient between the measurements was r = 0.6 (p <0.05).

DISCUSSION

In this study we evaluated the accuracy and the potential of 3D echocardiography in the preoperative assessment of VSD. We showed that 3D echocardiography presents an accurate view of the anatomy of the VSD. The creation of cut planes, which display the VSD from its right aspect, reproduce the surgical viewpoint of a right ventriculotomy. From these images it is possible to define the morphologic nature of the margins of the defect, its shape, and the direction in which the defect extends into the ventricular septum. Other anatomic structures such as the tricuspid valve leaflet, the right ventricular outflow tract, and the aortic valve can be displayed in their realistic spatial distribution. More than 2D echocardiography, 3D views facilitate more complete visualization of chordae supporting the tricuspid valve leaflet crossing the defect. The tricuspid valve is sometimes thickened, immobile, and tethering the VSD, thereby limiting visualization of the VSD. Three-D echocardiography offers the possibility of overcoming this limitation, exposing the defect completely by electronically deleting the leaflet or by creating a new cut plane in which the tricuspid leaflet is not present.

Shunt size is a critical factor in management decisions. We are aware that shunt size does not necessarily correlate with the anatomic size of the defect. Nevertheless the dimensions of a defect play a role in the hemodynamic status of a patient with VSD. The most reliable way to size the defect is usually to measure its diameter either by 2D color flow imaging or at cineangiography.[17–19] However, sizing can be difficult when the VSD is associated with another lesion, such as coarctation or pulmonary stenosis. In this study, we demonstrate that 3D echocardiography can be considered a technique for accurate and reliable sizing. On 3D reconstructed images, it was possible to evaluate the exact shape and orientation of the VSD in 1 single plane and consequently to measure its 2 largest diameters in both directions. Sizing the VSD on 3D echocardiography has been shown to have good intra-and interobserver reproducibility.

In summary, this study shows that 3D echocardiography can be considered a valuable diagnostic tool, which may accurately identify the location, size, and spatial relation of a VSD.

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CHAPTER 3

Temporary Tricuspid Valve Detachment in Closure of Congenital Ventricular Septal Defect

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ABSTRACT.

In a consecutive series of 149 patients with congenital ventricular septal defect (VSD), temporary tricuspid valve detachment was applied in 39 (detached group) to facilitate the transatrial approach for closure of the defect. Baseline characteristics showed that, preoperatively, the detached group were younger (1.3 ± 2.3 vs. 3.5 ± 4.1 years, $P = 0.002$), shorter (0.67 ± 0.20 vs. 0.87 ± 0.34 m, $P = 0.001$), lighter (6.9 ± 5.4 vs. 13.5 ± 12.0 kg, $P < 0.002$), and had a higher mean right atrial pressure (6 ± 2 vs. 4 ± 3 mmHg, $P < 0.003$), mean enddiastolic right ventricular pressure (10 ± 3 vs. 8 ± 3 mmHg, $P < 0.01$) and mean pulmonary vascular resistance (267 ± 202 vs. 170 ± 131 dyn s cm^{-5}, $P < 0.02$) on cardiac catheterization. At surgery the aortic cross-clamp time was longer (48 ± 17 vs. 39 ± 15 min, $P = 0.003$). Seven patients died (2 detached, 5 not-detached), from causes not related to either tricuspid detachment or VSD closure.

Follow-up was complete with a mean duration of 2.0 years (range 0.1-5.5). All 142 survivors were investigated by echocardiography, which showed normal tricuspid valve function in all but 29 patients who had trivial regurgitation (6 detached, 23 not-detached). There was no tricuspid stenosis. In 30 patients (8 detached, 22 not-detached) a trivial residual VSD could be detected. One reoperation (not-detached) was performed 12.5 months after the initial surgery for recurrent VSD.

Temporary tricuspid valve detachment for closure of a congenital VSD can be safely applied and does not impair growth of the tricuspid valve, regardless of age and preoperative clinical condition.

INTRODUCTION

A congenital ventricular septal defect (VSD) can usually be closed via the transatrial approach. If surgical exposure of the VSD via this approach is not adequate, a ventriculotomy can be prevented by temporary tricuspid valve detachment, as originally described by Hudspeth et al. [4]. However, this technique has been accepted only hesitantly because of concern about postoperative tricuspid valve competence [8]. Moreover, data on follow-up of the temporarily detached tricuspid valve are rare [1,4,8] and mostly based on only physical diagnosis and incomplete angiocardiography [1,4] or are investigated in selected series [8].

We describe our consecutive series of closure of congenital VSD including all patients with temporary detachment of the tricuspid valve, with a complete echocardiographic follow-up.

MATERIAL AND METHODS

A retrospective study was carried out of all 149 patients (90 male, 59 female) operated upon for a congenital VSD between 1985 and 1992. Excluded were patients with multiple VSDs, those with anomalies otherwise affecting the ventricular septum and those over I6 years of age. Some of these patients have been included in earlier studies [2,3]. Nine patients had been operated upon previously, six for coarctation of the aorta (including three with ductal closure and one with ductal closure and banding of the pulmonary artery), two for ductal closure and one for pulmonary sling, treated with pulmonary artery re-implantation. The mean age for the whole group was 2.9 ± 3.8 years (range 2 weeks- 15.5 years). The mean weight was 11.7 ± 11.0 kg (range 2.3 -63.0) and mean weight percentile 21 ± 27 (range <3 - > 97). The mean height was 0.82 ± 0.32 m (range 0.93-1.77) and mean height percentile 29 ± 30 (range <3 -> 97). In the whole group 48 patients had recurrent respiratory tract infection, 79 patients were on diuretic medication and 55 were hospital-dependent. Thirty patients were in functional class I, 8 in class II, 54 in class III, 57 in class IV and none in class V [6]. Electrocardiographic data were derived from standard 12-lead electrocardiograms. The criteria for left ventricular hypertrophy were met in 85 patients and for right ventricular hypertrophy also in 85. These numbers include 63 patients with biventricular hypertrophy. Preoperative chest X-ray showed cardiomegaly in 132 patients and increased pulmonary vascular markings in 136.

Preoperative echocardiography was carried out in 144 patients and included 2D and color-Doppler investigation. Our analysis was aimed at functional assessment of the tricuspid valve and the VSD. Tricuspid valve regurgitation was graded as none (n = 121),

trivial (*n*=23), moderate (*n*=0) or significant (*n*=0), based on the area and the length of the color jet. Cardiac catheterization was performed in 94 patients preoperatively. The mean right atrial pressure was 5 ± 3 mmHg (range 0-10), the mean systolic right ventricular pressure was 58 ± 22 mmHg (range 18-133) and mean enddiastolic right ventricular pressure 8 ± 3 mmHg (range 0-15). The mean Qp/Qs ratio was 2.8 ± 1.3 (range 0.8-7.0). The mean pulmonary vascular resistance was 187± 150 dyn ·s ·cm^{-5} (range 8-713) and mean systemic vascular resistance 1746 ± 610 dyn ·s ·cm^{-5} (range 618-4680).

All patients were operated with cardiopulmonary bypass and either cardioplegic arrest (*n*= 140) or circulatory arrest (*n*=9, all not-detached, in 4 cases electively and in 5 cases because of concomitant aortic surgery). Extracorporeal circulation (*n*=149) took 75 ± 27 min (range 32- 169). The aortic cross-clamp time (*n*=140) was 41± 16 min (range 18 - 111). In 85 patients one or more concomitant anomalies were managed during the operation for VSD. These anomalies are listed in Table 1. An exclusively transatrial approach to the VSD was used in 116 cases, including all 39 with tricuspid detachment. The transatrial approach was combined with other incisions in 31 cases, which included 6 with right ventriculotomy (made for concomitant pathology in 1 case), 15 with pulmonary arteriotomy (made for concomitant pathology in 7 cases), 3 with both incisions (all 3 made for concomitant pathology), 3 with pulmonary arteriotomy and aortotomy (made for concomitant pathology in 2) and 4 with aortotomy (made for concomitant pathology in 2). An exclusively transaortic approach was used in 1 case, while a right ventricular and transaortic approach was used in another. No left ventriculotomy was used in this series.

The type of VSD was determined at surgery: 127 were perimembranous (including 8 with malalignment), 4 inlet, 12 outlet (including 1 with malalignment) and 6 muscular. In 39 patients temporary tricuspid detachment was performed, because of incomplete

Table 1. Concomitant anomalies in temporary tricuspid detachment in closure of VSD

Pulmonary vein stenosis	1
Unroofed coronary sinus	1
Central ASD/OFO	70
Muscular subpulmonary obstruction	10
Valvular pulmonary stenosis	6
Discrete subaortic stenosis	2
Aortic coarctation	5
Pulmonary coarctation	1
Patent arterial duct	6
Tracheal obstruction (pulmonary sling)	1
Banding pulmonary artery	1

ASD = atrial septal defect, OF0 = open foramen ovale, VSD = ventricular septal defect

exposure of the VSD through the right atrium in 38 patients and through right ventriculotomy in 1 case. Depending on the location of the VSD, the septal (*n*=6), the anterior (*n*=24), or both these leaflets (*n*=9) of the tricuspid valve were dissected from the annulus. Closure of the VSD was performed either with a Dacron patch (*n*=29), a pericardial patch (*n*=1), primarily (*n*=23) or with a Gore-Tex patch (*n*=96). The suturing technique was essentially interrupted (*n*=25) or essentially running (*n*=124), with silk (*n*=2), Prolene (*n*=59) or Surgilene (*n*=75), while the suturing material was not established in 13 cases. After closure of the VSD, the tricuspid leaflets were reattached with running 7-0 or 6-0 Prolene.

Intraoperative post-correction epicardial echocardiography (Table 2) was carried out in 84 cases (31 detached, 53 not-detached) and included 2 D and color-Doppler studies as well as assessment of left-to-right shunting by echo-contrast injection into the left atrium [2, 3]. The tricuspid valve function was evaluated in the same way as preoperatively. Residual VSD was defined by a modification of criteria previously published

Table 2. Intraoperative echocardiography (*n* = 84) in temporary tricuspid detachment in closure of VSD

		Detached (*n*=31)	Non-detached (*n*=53)	*P*
Tricuspid regurgitation	none	28	51	ns
	trivial	3	2	
	moderate	0	0	
	significant	0	0	
Residual VSD	none	26	48	ns
	trivial	5	5	
	moderate	0	0	
	significant	0	0	

ns = not significant,VSD = ventricular septal defect

Table 3. Follow-up echocardiography (*n* = 142) in temporary tricuspid detachment in closure of VSD

		Detached (*n* = 37)	Non-detached (*n*= 105)	*P*
Tricuspid regurgitation	none	31	82	ns
	trivial	6	23	
	moderate	0	0	
	significant	0	0	
Tricuspid stenosis		0	0	ns
Residual VSD	none	29	83	ns
	trivial	8	22	
	moderate	0	0	
	significant	0	0	

ns = not significant, VSD = ventricular septal defect

[3]: no residual VSD was defined as no or minimal contrast shunting with no detectable color jet, a trivial residual VSD as minimal contrast shunting with a minimal color jet, a moderate residual VSD as moderate contrast shunting with any color jet and a significant residual VSD as substantial contrast shunting with any color jet.

Follow-up was complete and ended at the last outpatient visit or at reoperation. Follow-up echocardiography (*n*=142) was also aimed at evaluating tricuspid valve function and possible residual VSD (Table 3). The criteria for tricuspid valve regurgitation were the same as used preoperatively and intraoperatively. Special attention was paid to possible tricuspid valve stenosis. The criteria for residual VSD were the same as applied in the intraoperative echocardiography. Only 5 patients had cardiac catheterization during follow-up, for reasons not related to tricuspid valve function or possible VSD.

The analysis of categorical variables, summarized in terms of relative frequencies, was performed using the chi-square test with the Yates correction or using Fisher's exact test. Continuous variables, described as the mean±standard deviation, were analyzed using Student's t-test. Probability values smaller than 0.05 were considered significant.

RESULTS

Differences were found between the groups with and without tricuspid detachment. The group with tricuspid detachment was younger (1.3 ± 2.3 vs 3.5 ± 4.1 years, P= 0.002), lighter in weight (6.9 ± 5.4 vs 13.5 ± 12.0 kg, P < 0.002), lighter in weight percentile (12 ± 19 vs 24 ± 29, P = 0.01), shorter (0.67 ± 0.20 vs 0.87 ± 0.34, P= 0.001), but not in length percentile (22 ± 30 vs 31 ± 30). The patients in the detached group were more often on diuretic therapy (28/39 vs. 51/110, P=0.01), but no significant difference could be found in functional class (class I 5/39 vs 25/110, class II 1/39 vs 7/110, class III 14/39 vs 40/110, class IV 19/39 vs 38/110). In the detached group the preoperative electrocardiogram showed right ventricular hypertrophy more often (28/39 vs 59/110, P=0.03). The preoperative chest X-ray showed cardiomegaly more often in the detached group (38/39 vs 94/110, P= 0.01), but did not differ in pulmonary vascular markings.

On preoperative echocardiogram (*n*=144) tricuspid valve regurgitation did not differ between the two groups (none 30/39 vs 91/105, trivial 9/39 vs 14/105). At preoperative cardiac catheterization (*n*=94) the detached group (*n*=18) showed higher mean pressures in the right atrium (6 ± 2 vs 4 ± 3 mmHg, P < 0.003), higher enddiastolic right ventricular pressure (10 ± 3 vs 8 ± 3 mmHg, P< 0.01) and higher pulmonary vascular resistance (268 ± 202 vs 170 ± 131 dyn ·s ·cm^{-5}, P< 0.02).

Although the duration of cardiopulmonary bypass did not differ significantly for the detached group (79 ± 23 vs 74 ± 28 min), the aortic cross-clamp time (*n*=140) was longer (48 ± 17 vs 39 ± 15 min, P < 0.004). The detached group did not differ from the not-

detached group in the kinds of VSD: perimembranous (37/39 vs 90/110), outlet (2/39 vs 10/110), inlet (0/39 vs 4/110), muscular (0/39 vs 6/110). Malalignment also did not differ between the groups (5/39 vs 4/110).

As shown in Table 2, intraoperative post-correction epicardial echocardiography (*n*=84) showed no difference in tricuspid valve incompetence between the detached and the non-detached groups. There was also no difference in residual VSD between the two groups. There were no cases of complete heart block.

Early mortality occurred in 7 patients (2 detached, 5 non-detached). None were related to tricuspid detachment or VSD closure. The cause of death was pulmonary hypertension (*n*=2, both detached), sepsis (*n*=1), meningo-encephalitis (*n*=1). One patient died 1 week postoperatively during an operation for infected trachea reconstruction.

Follow-up was complete with a mean duration of 2.0 years (range 0.1-5.5). The mean weight percentiles increased for the whole group to 40 ± 33, as did the mean height percentile: to 40 ± 33. The whole group showed a definite improvement in functional class (class I 122, class II 17, class III 1, class IV 2, class V none).

All 142 surviving patients underwent 2 D and color-Doppler echocardiography. As shown in Table 3, normal tricuspid valve function was found in all but 29 patients with trivial regurgitation (6 detached, 23 non-detached, not significantly different). Tricuspid stenosis was absent on continuous wave Doppler echocardiography. In 30 patients (8 detached, 22 non-detached, not significantly different) a trivial residual VSD could be detected. One patient (non-detached) was re-operated for recurrent VSD 12.5 months after the initial surgery.

DISCUSSION

Temporary tricuspid detachment is an attractive surgical alternative for the repair of a congenital VSD in patients in whom transatrial exposure of the VSD is incomplete [1,4,7,8]. Nevertheless, temporary tricuspid detachment has not met with widespread acceptance because of concern about postoperative tricuspid valve function [8]. These reservations mostly concern regurgitation but, in the long-term, growth of the tricuspid annulus might also be impaired, possibly leading to tricuspid valve stenosis. Moreover, in recent textbooks the technique of temporary tricuspid detachment is only described for exceptional situations and is not further analyzed or commented on [5,7].

Because of the lack of comparable series, it is interesting to note how often tricuspid detachment was used. In our consecutive series of 149 patients with a VSD, a right atriotomy was undertaken in 147 patients. In 2 cases one or more other approaches were used and in 31 cases one or more additional approaches were used in closing the VSD (22%), of which 15 were performed for surgery of concomitant pathology. Overall,

in 10 cases (6%) a right ventriculotomy was made (in 6 just to approach the VSD, in 4 to approach a muscular subpulmonary stenosis as well). These right ventriculotomies were performed in the early part of this study and would probably not have been made nowadays, because closure of a VSD as well as surgery for muscular subpulmonary obstruction can well be carried out without right ventriculotomy [7]. In 116 cases an exclusively right atrial approach was used (77%). In 39 of these cases temporary tricuspid detachment was applied (34% of those with an exclusively transatrial approach and 26% of the whole series).

All temporary tricuspid valve detachments in our series were performed for perimembranous or outlet VSDs. Apparently this technique was not necessary in closing VSDs in the inlet or muscular parts of the ventricular septum.

Nevertheless, temporary tricuspid detachment has been described to facilitate closure of inlet VSDs [7,8]. The procedure was significantly associated with patients that were younger, lighter in weight, shorter and more often on diuretic therapy. This was, however, not reflected in a worse functional class. The tricuspid detachment group showed more signs of right ventricular overload on electrocardiogram and cardiac catheterization although these preoperative characteristics were not associated with differences in outcome. Seven patients died in hospital for reasons not directly associated with VSD closure or tricuspid detachment and repair.

Intraoperative epicardial echocardiography was carried out in 84 cases and showed only a trivial residual VSD in 12% and only trivial tricuspid regurgitation in 6%. In the complete follow-up, echocardiography showed only a trivial residual VSD in 21% and trivial tricuspid regurgitation in 20%. Speculations can hardly be made about the differences between intraoperative epicardial and follow-up transthoracic echocardiography, because the intraoperative series was not complete and contrast echocardiography could not be used in both investigations. Furthermore, these echocardiographic studies were carried out by different investigators and under different hemodynamic conditions. However, a selected series with incomplete echocardiographic follow-up also reported only trivial tricuspid regurgitation [8], although these authors found a 45% incidence of tricuspid valve regurgitation [8]. In our study, follow-up echocardiography did not show any signs of tricuspid valve stenosis. As the whole group showed above normal growth according to weight and height percentiles, we assume that tricuspid valve growth was not impaired by tricuspid detachment.

We conclude that, regardless of the age, size and preoperative clinical condition of the patients, and regardless of the right ventricular load, temporary detachment of the tricuspid valve in closure of a congenital VSD can be performed safely, without any negative effect on growth or function of the valve at medium-term follow-up.

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CHAPTER 4

Comment on Temporary Tricuspid Detachment in Closure of Ventricular Septal Defect

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With great interest we read the How to Do It report by Kapoor and colleagues describing temporary detachment of tricuspid chordal attachment to improve exposure in closure of ventricular septal defect in cases with obstructing chordae tendinae of the septal leaflet [1]. Although Kapoor and colleagues do not present any follow-up data, they put temporary chordal detachment forward as an alternative to temporary detachment of the anterior or septal tricuspid leaflet from the tricuspid annulus, as described by us and originally by Hudspeth and colleagues [2,3]. Apparently temporary chordal detachment is applicable, but the arguments being put forward are arguable. We fully agree that optimal exposure is the main goal of these techniques and that these techniques are only to be applied in a limited number of operations. Moreover, in our experience, it is not the inferior rim of the ventricular septal defect that poses a technical problem in situations with a limited exposure.

Exposure through detached leaflet tissue depends on an adequate length of the detachment incision. The location and extent of the detachment incision may vary according to the location of the ventricular septal defect. If, in this regard, a retractor is still necessary instead of stay sutures, it is not to be used for traction as Kapoor and colleagues state, but just for holding.

Any surgical technique should be applied in a technically adequate and accurate way in order to avoid unnecessary "awkward" [1] situations. In this regard, temporary tricuspid detachment intrinsically involves a rim of about 1 mm at the base of the tricuspid annulus, onto which the ventricular septal defect patch as well as the detached tricuspid leaflet is sutured.

Temporary chordal detachment to improve exposure in closure of ventricular septal defect may be useful in selected cases. Arguments in favor, however, should preferably come from obvious advantages or from careful follow-up.

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CHAPTER 5

The Effect of Temperature Management during Cardiopulmonary Bypass on Clinical Outcome in Pediatric Patients Undergoing Correction of Ventricular Septal Defect

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ABSTRACT

Background. Moderate hypothermia of 28°C is widely accepted in cardiac surgery with cardiopulmonary bypass (CPB). Recently however, several studies suggested that normothermic or "tepid" bypass techniques might improve the clinical outcomes for patients undergoing cardiac operations.

Methods. To assess the effect of bypass temperature management strategy in pediatric patients undergoing correction of ventricular septal defect, 26 patients with body weight under 10 kg were randomly assigned to two treatment groups: Group 1, mild hypothermia, patients cooled to nasopharyngeal temperature of 32°C during the bypass; or Group 2, moderate hypothermia of 28°C. Clinical parameters were recorded and blood samples were obtained just before, during, and 24 hours after operation.

Results. All the population characteristics and intraoperative variables were similar in the two groups. Hematologic data after CPB and protamine administration revealed a significantly ($p<0.05$) longer activated partial thromboplastin time in the 32°C group; however, the difference in blood loss did not reach significance.

Conclusion. Our study shows that both perfusion temperatures equally well facilitated CPB for this type of intracardiac surgery

INTRODUCTION.

Until recently, intracardiac repair in pediatric cardiac surgery was mostly performed with moderate (27 - 30°C) to profound (< 25°C) systemic hypothermia. The exceptions to this rule were short procedures for which only mild (30 - 32°C) hypothermia was used.

Systemic hypothermia reduces tissue metabolic rate and oxygen demand and is used to protect the myocardium and the brain against potential ischemic insult [1-3]. Furthermore, it enhances protection of the other organs. Systemic hypothermia allows us to lower the arterial blood flow and promotes better conditions in the operation field as well as less blood trauma occurrence. Hypothermia also causes marked changes in the peripheral circulation, hormonal body response and alterations in organ function. Generalized inflammatory response, involving the complement, coagulation, kallikrein and fibrinolytic cascades, is often a dominant feature of hypothermic bypass [4-6]. Undoubtedly, hypothermia has its positive as well as negative aspects during cardiopulmonary bypass (CPB). Therefore, normothermic CPB with warm cardioplegia in adult cardiac surgery is becoming increasingly popular [7].

In pediatric heart surgery, technical developments and enhanced surgical skills also allow for reduction of depth of hypothermia in most procedures. Nevertheless, comparatively few publications have addressed the issues raised by maintenance of mild or moderate hypothermia during pediatric bypass.

The aim of this study was to compare clinical results between two groups of pediatric patients, operated with short aorta occlusion times and mild or moderate hypothermic CPB.

MATERIAL AND METHODS

Patients

The study population comprised 26 consecutive pediatric patients who underwent closure of ventricular septal defect (VSD) with use of a Gore-Tex® patch. Only children with body weight under 10 kg and without concomitant heart disease were included. Exclusion criteria were: respiratory insufficiency with need of respiratory support; kidney failure; liver failure; and neurological impairment. Patients were equally randomized into two groups: Group 1, mild hypothermia (nasopharyngeal temperature ≥ 32°C during CPB); Group 2, moderate hypothermia (nasopharyngeal temp. ≥ 28°C during CPB). One surgeon performed all operations. The study was conducted according to the regulations of the hospital medical ethical committee. Informed parental consent was obtained for all patients.

Anesthesia

Patients were premedicated with 0.3-mg/kg-midazolam suppositorium 1 hour before induction of anesthesia. Induction of anesthesia was done by inhalation (halothane or sevoflurane) or intravenously (midazolam, pavulon, fentanyl). Patients were intubated with a nasal - endotracheal tube and ventilated with a minute volume of 10 ml/kg/min. Heart rate, ECG, arterial and right atrial blood pressure, nasopharyngeal and rectal temperature, were continuously measured. A bladder catheter was inserted to monitor urine production during and after the operation.

Cardiopulmonary bypass

All patients were operated upon with CPB and cardioplegic arrest. In all patients, the ascending aorta was cannulated with either an 8 or 10 Fr. standard straight-tip cannula, depending upon patient size. In all cases, venous return was provided by bicaval cannulation of the superior and inferior caval veins with angled metal tip 12 Fr. cannulae.

CPB circuit consisted of a membrane oxygenator with integrated venous-cardiotomy reservoir, roller pump with silicone tubing and an arterial line filter. The circuit was primed with Ringer's solution and whole blood to achieve an intraoperative hematocrit of 28% during the bypass period. During CPB, nonpulsatile pump flow with rates of 1.8 -2.4 l/min/m^2 was maintained adequate to metabolic needs of the patient. In-line monitoring of arterial oxygen tension (PaO_2) and venous oxygen saturation (SvO_2) provided conditions for alpha-stat strategy during the whole period of bypass.

Anticoagulation of the patient and the CPB circuit were achieved with initial patient heparin dose of 300 IU / kg body weight and prime heparin dose of 4.2 IU/ml. total prime volume. Assessment of anticoagulation during operation was done by measurement of the kaolin activated clotting time (ACT). The ACT values were maintained ≥ 480 sec by administration of additional heparin when necessary. After discontinuation of the CPB, heparin was neutralized by protamine chloride with a standard dose of 4 to 5 mg/ kg body weight. Adequacy of protamine reversal was ascertained with the use of heparin-protamine titration. No aprotinin was administrated to patients in the study population.

Patient mean arterial blood pressure was maintained between 30 - 65 mmHg during the bypass. Continuous recording of the pump flow, arterial blood temperature, along with patient nasopharyngeal and rectal temperatures, oxygen and airflow, PaO_2, SvO_2, arterial line pressure, as well as patient pressures, was provided by "Odis", a perfusion registration system [8, 9].

Myocardial preservation was achieved by antegrade administration of cold (4°C) St.Thomas Hospital cardioplegic solution delivered by gravity at the dose of 10 - 15 ml/ kg of body weight after application of the aortic cross-clamp. No topical cooling was

used. All patients were weaned from bypass with infusion of dopamine 2 µg / kg min and nitroglycerin 1 µg / kg /min.

Measurements and calculations

In both groups arterial and venous blood gas samples were obtained before bypass, during CPB after 5 min, 20 min, and at the end (± 50 min). The last sample was obtained after administration of protamine chloride. During CPB, oxygen consumption index (Vo_2I) and systemic vascular resistance (SVR) were calculated as follows:

$$SVR = \frac{\text{mean arterial pressure - central venous pressure}}{\text{cardiac output}} \times 80 \text{ dynes.sec.cm}^{-5}$$

$$Vo_2I = \text{cardiac index} \times [(\text{arterial saturation - venous. saturation}) \times Hgb \times 2.32] \text{ ml/min m}^2$$

Coagulation factors were platelet count, fibrinogen, activated partial thromboplastin time (APTT), and thrombin time (TT), which were measured before the bypass, after protamine chloride administration, and 24 hours after the operation.

Other measured and recorded variables include: occurrence of electrical activity (ECG) during the aortic cross clamping, spontaneous cardiac conversion after releasing of the clamp, and existence of any sort of rhythm disturbances. Also, the amount of administrated blood products, diuresis, blood loss, length of the respiratory support and stay in the intensive care unit (ICU) were recorded.

Intraoperative postcorrection epicardial echocardiography [10] was carried out with color-Doppler studies to assess left-to-right shunting by echo-contrast injection into the left atrium. After 24 hours postoperative, left ventricular function was determined by echocardiography and follow-up was completed at the discharge visit.

Data analysis

All values are presented as mean ± standard deviation (SD) of the mean. Two-way analysis of variance (ANOVA) for repeated measurements was used for comparison between the groups at specific points in time. p-Values were obtained for the over-all group effect. Other data were compared by paired t-test between the two groups. p-Values ≤ 0.05 were considered statistically significant.

RESULTS

There were no significant differences in the baseline data between the two groups (Table 1). Mean nasopharyngeal (N) and rectal (R) temperatures after 5 min on CPB were not significantly different (Group 1; N: 32.5 ± 0.0 R: 33.0 ± 0.1 vs. Group 2; N: 31.9 ± 0.0 R:

Table 1. Characteristics and perfusion data of the study population.

	Group 1 (32°C)	Group 2 (28°C)	p- value
Age (mo)	3.5 ± 1.6	5.0 ± 3.2	NS
Weight (g)	4250 ± 817	4958 ± 1245	NS
Height (cm)	56.8 ± 15.8	60.0 ± 4.5	NS
BSA (m^2)	0.27 ± 0.03	0.30 ± 0.05	NS
Calc. Pump flow (ml/min)	641 ± 83	713 ± 116	NS
Mean pump flow (ml/min)	592 ± 12	597 ± 129	NS
CPB time (min)	54.5 ± 2.0	56.1 ± 16.0	NS
Crossclamp time (min)	31.5 ± 2.0	31.4 ± 15.0	NS
Cardioplegic solution (ml)	65 ± 30	65 ± 18	NS

All values reported as mean ± SD; NS, not significant
CPB, cardiopulmonary bypass.
Calculated pump flow = BSA (dm^2) x 24 (ml/min/dm^2)
Mean pump flow = mean flow during CPB

33.2 ± 0.1°C, NS). After 20 min on bypass, a significance occurred (Group 1; N: 31.6 ± 0.0 R: 32.3 ± 0.1 vs. Group 2; N: 29.2 ± 0.0 R: 30.9 ± 0.0°C with p = 0.008 and p = 0.01, respectively). After 50 min on CPB and rewarming in progress, rectal temperature in Group 2 was still significantly lower (Group 1 R: 34.0 ± 0.1 vs. Group 2 R: 33.2 ± 0.0°C, p = 0.02), but nasopharyngeal temperatures were similar in the groups (Group 1; N: 35.8 ± 0.1 vs. Group 2; N: 35.3 ± 0.0°C, NS, Figure 1).

Hemodynamic parameters measured and calculated during CPB revealed no significant differences between recorded mean arterial pressure (Figure 2); on the other hand,

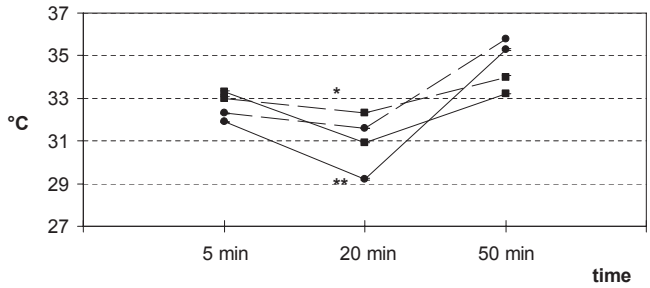

Figure 1. Changes of temperature during CPB.
---●--- Group 32°C - N
---■--- Group 32°C - R
—●— Group 28°C - N
—■— Group 28°C – R
* p = 0.01
** p = 0.0008

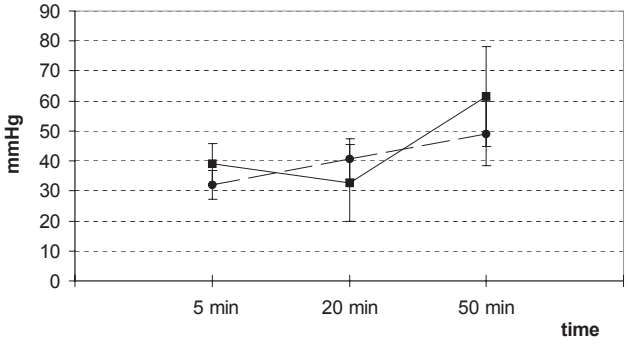

Figure 2. Mean arterial pressure during CPB
---●--- Group 32°C
—■— Group 28°C

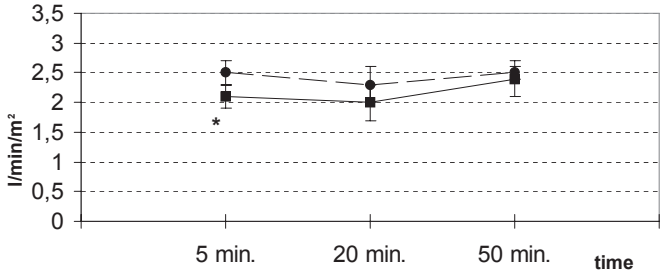

Figure 3. C.I. during CPB.
---●--- Group 32°C
—■— Group 28°C
* p = 0. 0006

the overall cardiac index was significantly higher in mild hypothermia group (Group 1; 2.43 ± 0.2 vs. Group 2; 2.16 ± 0.2, p = 0.02, Figure 3).

During CPB, the moderate hypothermic group had significantly higher over-all systemic vascular resistance (Group 1; 1164 ± 389 vs. Group 2; 1703 ± 420 dynes.sec.cm^{-5}, p = 0.04, Figure 4). Oxygen consumption was not significantly different in both groups at the time of measurements (Figure 5).

Venous oxygen saturation remained relatively steady in each group during the CPB period, and there was a significant difference between the groups only at the 5-min bypass time (Group 1; 75% vs. Group 2; 66%, p = 0.01, Figure 6).

Atrial electrical activity (P wave) during aortic cross clamping was observed in four patients in Group 1 and in one in Group 2 (p= 0.04). No action was taken in any of these situations. All patients in both groups converted spontaneously to sinus rhythm after aorta declamping. AV block was temporarily observed in two patients in Group 1. The external pacing was applied before sinus rhythm returned.

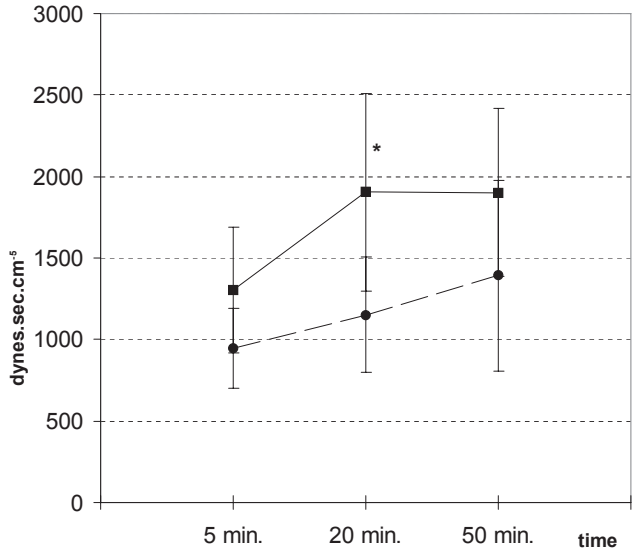

Figure 4. SVR during CPB.
---●--- Group 32°C
—■— Group 28°C
* p = 0. 01

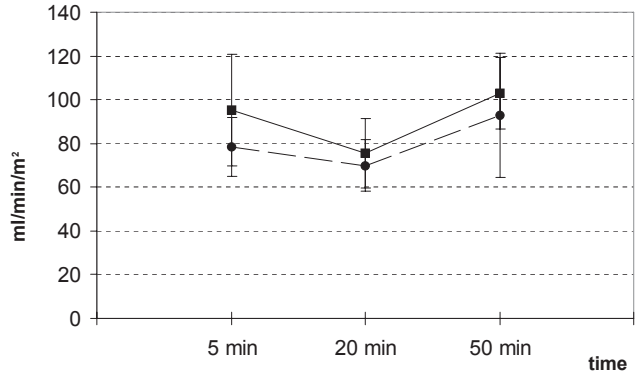

Figure 5. Oxygen consumption during CPB.
---●--- Group 32°C
—■— Group 28°C

Initial dose of heparin used before the start of CPB was not significantly different between both groups (Group 1; 1222 ± 290 vs. Group 2; 1500 ± 409 IU, NS). During CPB, two patients from Group 1 and one from Group 2 required additional heparin to sustain ACT ≥ 480 sec. Standard protamine dose given in compliance with protocol was not significantly different. In each group, four patients required additional protamine (Group 1; 2.2 ± 3.4 mg. vs. Group 2; 2.4 ± 3.5 mg., NS). Preoperative measurement of

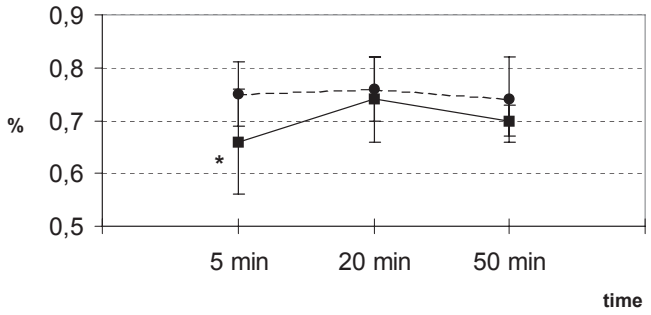

Figure 6. SvO_2 during CPB.
---●--- Group 32°C
—■— Group 28°C
* p = 0. 01

coagulation factors as well as baseline ACT in both groups were not significantly different. After administration of protamine, the ACT values were still higher if compared with baseline values but did not show any significant difference between groups; whereas, APTT values (Group 1; 55 ± 18 vs. Group 2; 41 ± 3 s, p = 0.045) were significantly higher in mild hypothermia group (Table 2). There was no difference in diuresis, blood loss and the amount of blood products used during the period of 24 hours post CPB (Table 3).

Table 2. ACT values and plasma coagulation factors pre- and post- CPB.

	Group 1 (32°C)	Group 2 (28°C)	p- value
Pre CPB			
ACT (sec)	127 ± 16	132 ± 9	NS
APTT (sec)	48 ± 11	51 ± 17	NS
APTT ratio	1.6 ± 0.4	1.7 ± 0.6	NS
TT (sec)	19 ± 7	16 ± 2	NS
Fibrinogen (mg/dl)	220 ± 70	220 ± 50	NS
Platelets (x1000/mm^3)	287 ± 55	315 ± 78	NS
Post CPB			
ACT (sec)	144 ± 35	141 ± 23	NS
APTT (sec)	55 ± 18	41 ± 3	0,045
APTT ratio	1.5 ± 0.1	1.4 ± 0.1	NS
TT (sec)	15 ± 2	15.9 ± 3	NS
Fibrinogen (mg/dl)	160 ± 30	180 ± 40	NS
Platelets (x1000/mm^3)	177 ± 61	183 ± 50	NS

All values reported as mean ± SD; NS, not significant
ACT, activated clotting time; APTT, activated partial thromboplastin time
APTT ratio = patient's APTT/ normal population APTT
TT, thrombin time

Table 3. Urine production and blood balance in 24 hours after CPB

	Group 1 (32°C)	Group 2 (28°C)	p– value
Urine excretion (ml)	345 ± 44	350 ± 111	NS
Blood loss (ml)	109 ± 106	95 ± 24	NS
Use of homologous blood (ml)	175 ± 39	145 ± 53	NS
Use of FFP (ml)	63 ± 117	106 ± 90	NS

All values reported as mean ± SD; NS, not significant
FFP, fresh frozen plasma.

Table 4. Postoperative use of the respiratory support.

	Group 1 (32°C)	Group 2 (28°C)	p- value
Respiratory supp. (h)	22.8 ± 18	16.5 ± 19	NS
Highest FiO2 (%)	48.8 ± 11	46.0 ± 10	NS
PEEP (cm H2O)	3.5 ± 0.8	3.7 ± 1.0	NS

All values reported as mean ± SD; NS, not significant
FiO2, inspiratory fraction of oxygen
PEEP, positive end expiratory pressure

Also, the mean duration of postoperative ventilatory support, as well as the highest percentage of oxygen used in inspiratory fraction (FiO_2 %), and applied positive end expiratory pressure (PEEP) were similar (Table 4).

The mean duration of stay at the ICU by patients in both groups was not significantly different.

Intraoperative epicardial echocardiography revealed a residual VSD with insignificant leakage of contrast in two patients from Group 1 and three patients from Group 2. At discharge, two patients in Group 1 displayed a hemodynamically insignificant residual VSD as well as one patient in Group 2. No residual VSDs were observed on subsequent follow-up visits. Intraoperative postcorrection epicardial echocardiography assessed left ventricular function in all patients as normal. Echocardiographic examination after 24 hours estimated left ventricular function as "diminished" in three patients in Group 1 and one patient in Group 2; nevertheless, at discharge, all patients regained normal left ventricular function.

DISCUSSION

Use of moderate (28°C) systemic hypothermia improves operating conditions and allows lower arterial flow rates. This, in turn, reduces collateral coronary circulation and contributes to myocardial protection as well as protection of other vital organs. Therefore, moderate hypothermia is widely carried out, although the effects of skin and, perhaps, muscle ischemia related to this temperature and the increased sympathetic effects may

balance out any potential advantages [11]. Another effect of hypothermia is that blood viscosity increases so that use of appropriate hemodilution is required to reduce the systemic vascular resistance during CPB [12]. Hypothermia together with hemodilution disturbs coagulation and fibrinolitic cascades; this is assumed to be responsible for enhanced blood loss during and after operation [13]. In certain operations, the selection of CPB temperature is dependent on the complexity of the operation; for example, deep hypothermia during circulatory arrest. Therefore, questions may be raised as to what the best temperature is in the case of short (under 1h of CPB time) surgical procedures for small pediatric patients with body weight less than 10 kg. [14]. According to the surgeon's opinion, use of moderate (28°C) or mild (32°C) hypothermia during correction of the ventricular septal defect had no influence on the technical complexity of the operation.

The hemodynamic data obtained from both groups showed no differences in adequacy of the CPB. Mean arterial pressure and venous oxygen saturation were kept constant during the bypass without any difficulty, although patients from Group 1 (32°C) required significantly higher CI to achieve this. On the other hand Group 2 (28°C) had significantly higher over-all systemic vascular resistance during the CPB, which might be caused by moderate hypothermia. Oxygen consumption in the two groups was not significantly different, which can be explained by the negligible differences of patient's temperatures during long times on CPB.

Myocardial protection in both groups was the same, and there was spontaneous return of sinus rhythm in all the cases. In Group 1 (32°C) atrioventricular block occurred twice, which had to be resolved by temporary use of a pacemaker. Those adverse events could be related to less adequate myocardial protection, but also could be associated with the surgical procedure itself. There were no clinical consequences of these events, and the echocardiographic control of the left ventricular function showed no difference between the patients from both groups. Kidney function assessed by urinary output and lung function assessed by duration of ventilatory support did not differ in both groups.

The amount of heparin and protamine used showed no difference in the two groups. Postoperative, after administration of protamine, both groups still had prolonged ACT values and significantly lower plasma fibrinogen concentration when compared to the "baseline" values, but Group 1 (32°C) also had significantly longer APTT in comparison to Group 2 (28°C). Mean blood loss was least in the moderate hypothermia group, but the difference did not reach significance. Hematologic data suggested increased fibrinolitic potential in the mild hypothermia group [15].

CONCLUSIONS

Our study documented no difference in organ preservation depending on type of hypothermia, mild or moderate, used during the reconstruction of VSD in pediatric patients. The chosen temperatures did not impair adequacy of CPB. There was no difference in technical complexity of the operation. Moreover, the clinical outcome of the patients did not depend on the type of hypothermia. There were suggestions of more activation of fibrinolitic potential in the 32°C group.

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CHAPTER 6

Virtual Reality 3D Echocardiography in the Assessment of Tricuspid Valve Function after Surgical Closure of Ventricular Septal Defect

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ABSTRACT

Background: This study was done to investigate the potential additional role of virtual reality, using three-dimensional (3D) echocardiographic holograms, in the postoperative assessment of tricuspid valve function after surgical closure of ventricular septal defect (VSD).

Methods: 12 data sets from intraoperative epicardial echocardiographic studies in 5 operations (patient age at operation 3 weeks to 4 years and bodyweight at operation 3.8 to 17.2 kg) after surgical closure of VSD were included in the study. The data sets were analysed as two-dimensional (2D) images on the screen of the ultrasound system as well as holograms in an I-space virtual reality (VR) system. The 2D images were assessed for tricuspid valve function. In the I-Space, a 6 degrees-of-freedom controller was used to create the necessary projectory positions and cutting planes in the hologram. The holograms were used for additional assessment of tricuspid valve leaflet mobility.

Results: All data sets could be used for 2D as well as holographic analysis. In all data sets the area of interest could be identified. The 2D analysis showed no tricuspid valve stenosis or regurgitation. Leaflet mobility was considered normal. In the virtual reality of the I-Space, all data sets allowed to assess the tricuspid leaflet level in a single holographic representation. In 3 holograms the septal leaflet showed restricted mobility that was not appreciated in the 2D echocardiogram. In 4 data sets the posterior leaflet and the tricuspid papillary apparatus were not completely included.

Conclusion: This report shows that dynamic holographic imaging of intraoperative postoperative echocardiographic data regarding tricuspid valve function after VSD closure is feasible. Holographic analysis allows for additional tricuspid valve leaflet mobility analysis. The large size of the probe, in relation to small size of the patient, may preclude a complete data set. At the moment the requirement of an I-Space VR system limits the applicability of virtual reality 3D echocardiography in clinical practice.

INTRODUCTION

As recently described the mental conceptualization and evaluation of the intracardiac anatomy from multiple two-dimensional (2D) echocardiographic images, is complicated by cardiac dynamics [1-4]. Three-dimensional (3D) echocardiography facilitates simplification of this process by offering a direct representation of the cardiac anatomy throughout the cardiac cycle [4]. To appreciate the full 3D potential of these datasets, virtual reality technology can be applied and used for further interpretation of the data of cardiac echocardiography [4-9]. In this regard we applied holographic analysis of intraoperative epicardial echocardiography in order to further contribute to the discussion of tricuspid valve function after surgical closure of ventricular septal defect (VSD) [10-13].

MATERIAL AND METHODS

Patients and data sets.

12 data sets from intraoperative epicardial echocardiographic studies in 5 operations (patient age at operation 3, 6, 7 weeks, 9 months and 4 years and bodyweight at operation 3.8, 3.9, 4.5, 5.2 and 17.2 kg) were included in the study. Epicardial echo was indicated in these patients on clinical grounds to obtain additional 2D imaging on top of the pre-operative echo assessment. During the epicardial echocardiography, the 3D data sets were obtained as well.

All operations concerned closure of VSD, in 1/5 as isolated defect, in 3/5 in the setting of correction of tetralogy of Fallot, in 1/5 in combination with a double-chambered right ventricle. In none of the operations the technique of temporary tricuspid detachment was used. In 3 of the operations sutures of the VSD patch were anchored in the base of the tricuspid valve annulus. The postcorrection epicardial echocardiography was performed as previously described [14].

Three-dimensional echocardiographic data acquisition.

In the setting described previously [4] the data sets were acquired with the iE33 ultrasound system equipped with 3D data acquisition software (Philips Medical Systems, Andover, MA, USA), using an X3-1 broadband matrix array transducer (Philips Medical Systems, Andover, MA, USA) that was used epicardially after the surgical correction. Epicardial echocardiography took 4- 5 minutes in each patient and included 2D echo analysis and acquisition of the 3D data sets. The echocardiographic study, including real-time 3D acquisition, was done with ECG gating.

Data processing consisted of the creation of a Cartesian volume in DICOM 3.0 format by interpolating the original data using the export module of the Q-lab ultrasound data analysis application (Philips Medical Systems, Andover, MA, USA), using the highest quality settings.

The 3D image data were transferred to an SGI Prism computer (Silicon Graphics, Mountain View, CA, USA) driving the I-space virtual reality (VR) system. A simple format conversion was required to be able to load the data in the I-Space software. In total the processing and the conversion only took 1-2 minutes per dataset. Holographic analysis took 15-18 minutes for a single data set

Visualisation in the virtual reality environment.

The BARCO I-space (Barco, Kortrijk, Belgium) installed at the Erasmus MC (Erasmus MC, Rotterdam, The Netherlands) is a so-called four-walled CAVE™-like VR system[15]. In the I-Space researchers are surrounded by computer-generated stereo images, which are projected by 4 high quality DLP-projectors on three walls and the floor of the projection room. The CAVORE volume rendering application [16] is used to investigate 3D ultrasound images during the cardiac cycle [10]. In the I-Space, this results in an animated hologram of the dataset being visualised, floating in space in front of the viewers. The viewers wear a pair of lightweight glasses with polarising lenses that allows seeing the hologram with depth. A wireless 6 degrees-of-freedom (DOF) controller which emits a virtual pointer is used for manipulation of and interaction with this hologram. A cutting plane attached to the pointer allows assessment of the interior of the heart. A transfer function widget operated by the pointer controls the contrast and transparency of the rendered image.

The cardiothoracic surgeon performed the virtual reality 3D echo analysis.

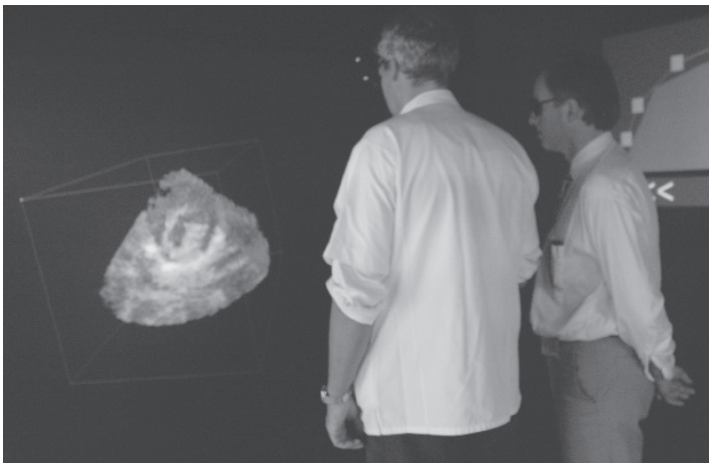

Figure 1. A 3D hologram of a right atrial view of the tricuspid valve after VSD closure.

RESULTS

In the 2D representation of the datasets the area of interest could adequately be visualized in all of the 12 data sets. The data sets were used intraoperatively for clinical assessment of the result of the operation. In none of the data sets 2D analysis showed tricuspid stenosis or regurgitation. Mobility of the anterior and septal tricuspid valve leaflets was considered to be normal in all data sets. In 4 data sets, the posterior leaflet was not included, because of the limitations of epicardial access of a large probe in a small patient. In the other 8 data sets no abnormalities of posterior leaflet motion were noted.

All the 3D datasets could be adequately analyzed in the I-Space. Virtual reality of the datasets allowed a complete assessment of the area of interest and easy investigation of the area of the reconstruction. The holograms of the area of closure of the VSD were adequately visualised from the right side of the ventricular septum.

Assessment of the tricuspid valve leaflet motion could well be accomplished from a right atrial view. In 3 data sets (in 3 different patients) a restriction of the mobility of the septal leaflet was noted, that was not appreciated in the 2D analyses. In all these 3 patients the VSD patch was anchored in the base of the septal leaflet of the tricuspid valve. No abnormalities in anterior leaflet motion were noted. In the limited nearfield of the epicardial echocardiography only 8 posterior leaflets could be assessed, their mobility was considered normal. The holograms confirmed that the papillary apparatus in these 4 data sets was incompletely acquired.

DISCUSSION

A virtual reality approach is presented to analyse the results of surgery for congenital VSD. The 3D echocardiographic data sets acquired epicardially and generated by a commercially available echo system were used to construct a dynamic hologram inside an I-Space. All the datasets could be adequately analyzed in the I-Space, in which a single 3D dataset is sufficient to create every view of interest.

Currently, large-scale VR facilities like the I-Space are only available in a limited number of research centres throughout the world. Desktop applications are being developed, for instance the Personal Space Station PSS™ (Personal Space Technologies, Amsterdam, The Netherlands). Therefore, the representation and analysis of diagnostic 3D echocardiography by virtual reality has only been described very recently [4]. As a new application, this experience is extended to postoperative control of the results of surgery for congenital VSD, in datasets derived epicardially. This is a relevant topic because in closure of a VSD, the sutures of the patch are often anchored in the base of

the septal and anterior tricuspid valve leaflet and sometimes the tricuspid valve may be temporarily detached in the area of the septal and anterior leaflets in order to optimise the surgical approach [10-12]. Until now, tricuspid valve function was shown not to be affected by these techniques [10,11]. Recently, temporary tricuspid detachment was even advocated to avoid early postoperative tricuspid valve function due to inadvertent traction [12]. As a consequence tricuspid valve function and growth are matters of interest in this regard.

However, because the area of interest is in the nearfield of the echoprobe, a complete data set may be precluded, especially because of the large size of the probe that was available at the time of the study in relation to the small size of the patients and the limited exposure of the heart in them. Although no tricuspid valve stenosis or regurgitation was found in our series by 2D analysis of the data sets, in 3 of them a restricted mobility of the septal leaflet was found by holographic analysis. This suggests that holographic analysis may provide additional data beyond conventional analysis. In general, differences in interpretation between 2D and 3D echo can well be explained [17]. In 2D echocardiography, tricuspid valve analysis only allows analysis of two leaflets per image plane. Usually these are the anterior and septal leaflets, or the anterior and posterior leaflets. Hardly ever the posterior and septal leaflets can be visualized in one image plane and never all three leaflets. In contrast, 3D echocardiography allows all three leaflets to be seen in one view.

The virtual reality analysis can be done by the anatomy-expert, for instance the cardiothoracic surgeon performing the operation, and depends to a lesser extent on the echocardiography-expert, for instance the cardiologist making the diagnosis.

Virtual reality in this regard provides an additional resource for postoperative quality control as well as for education with regard to the intracardiac repair of congenital VSD.

With the I-Space technology the complex postoperative cardiac anatomy of the closed congenital VSD, in relation to tricuspid valve function, can be appropriately visualised in virtual reality. Unfortunately, at present the colour-Doppler data cannot yet be transferred to the I-Space, as the data is only available in a proprietary format.

For the clinical practice, virtual reality 3D echocardiography should be implemented on smaller systems, like desktop displays or single screen projection systems, to allow bedside use or application in the operating theatre or conference room.

In conclusion, epicardially derived data sets may be incomplete for nearfield structures, especially when probe size mismatches with patient size. Still, the resulting 3D data sets nicely provide holographic data, which may provide additional information on tricuspid valve function after VSD closure.

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CHAPTER 7

Follow-up after Surgical Closure of Congenital Ventricular Septal Defect

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ABSTRACT

Background: The purpose of this retrospective study was to assess long-term outcome of children after surgical closure of a ventricular septal defect (VSD).

Methods: Between January 1992 and December 2001 a consecutive series of 188 patients (100 females) were operated for closure of a VSD. Temporary tricuspid valve detachment (TVD) was applied in 46 patients (24%) to enhance exposure of the defect using transatrial approach. Pre-operative baseline characteristics showed that the detached group was younger (0.79 ± 1.8 vs 2.1 ± 3.5 years, $p = 0.002$) and had a lower weight (6.5 ± 6.4 vs 10.0 ± 11.0 kg, $p = 0.009$).

Results: There was no difference in cross-clamp time (temporary TVD 36.2 ± 11.3 vs non-temporary TVD 33.6 ± 13.1 min, $p = 0.228$). Postoperative echocardiography showed that 67 patients (36%) had trivial/minimal regurgitation, 10 patients (22%) from the temporary TVD group vs 57 patients (40%) from the non-detached group ($p = 0.02$). There was no tricuspid stenosis. Hospital mortality comprised two patients (1%). One patient died due to a pulmonary hypertensive crisis and one in relation to an acute patch dehiscence for which an emergency reoperation was necessary. At first postoperative echocardiography no shunting was detected in 113 patients, trivial shunting in 73 and significant shunting in none. Multivariate logistic regression analysis revealed that weight at operation was a predictive factor for the occurrence of residual shunting (OR 0.95, C.I. 0.91 – 0.99). One patient with conduction disturbances needed a permanent DDD-pacemaker. Three patients were lost to follow-up. Mean follow-up time was 2.6 years (range 0.1 -9.4). During follow-up no reoperations were necessary for closing a residual VSD. One patient died 7 months postoperative due to a bronchopneumonia. During follow-up in 37 (51%) of the 73 patients the trivial shunting disappeared spontaneously at a median time of 3.9 years. According to actuarial analysis all trivial shunting had disappeared at 8.4 years.

Conclusion: Trivial residual shunting disappeared spontaneously at a median follow-up time of 3.9 years. During follow-up no patient needed to be reoperated for residual VSD. TVD proved to be a safe method to enhance the exposure of a VSD.

INTRODUCTION

The most frequent congenital cardiac anomaly is a ventricular septal defect (VSD) [1,2]. Many VSDs are small, asymptomatic and are assumed to close spontaneously [3]. In the VSDs that need closure, surgical treatment is aimed at prevention of pulmonary hypertension, endocarditis or in some instances of progressive aortic valve regurgitation[4].

After surgical closure of a VSD trivial residual shunting is nowadays easily detected with modern sensitive echocardiographic techniques. However, the natural history of these small shunts is yet unknown especially with regard to temporary tricuspid valve detachment (TVD) [5]. In closing a VSD temporary TVD may provide better exposure of the defect in the usual transatrial approach [6-8]. Details of follow-up after surgical VSD-closure using TVD are scarce with regard to tricuspid valve function and residual shunting. In this regard we report our analysis of patients who underwent surgical closure of a VSD under 17 years of age, between January 1992 and December 2001 with special emphasis on temporary TVD and spontaneous closure of residual trivial shunting.

MATERIAL AND METHODS

Between January 1992 and December 2001, 188 consecutive patients younger than 17 years of age were operated upon for closure of a congenital VSD. The study group consisted of 100 female (53%) and 88 male (47%) patients. Although the mean age at operation was 1.8 years (range 2.5 weeks – 14.8 years) the median age was only 0.4 years. None of them had previously been operated upon. The Wolff Parkinson White syndrome in 2 patients was medically controlled. One hundred and thirty-nine patients (75%) had one or more concomitant cardiac defects that were surgically corrected during the same operation. Patients' characteristics are described in Table 1. Exercise intolerance was regarded present in the younger children when feeding times were reported to be prolonged and in the older children when ability to exercise was less compared to siblings. All patients were operated upon with cardiopulmonary bypass (mean duration of 64 ± 25 min, range 31 – 311 min). Mean cross-clamp time was 34 ± 13 min (range 14 – 74 minutes). In all patients the VSD was approached through a right atriotomy. To enhance the exposure, the tricuspid valve was detached in 46 cases (24%): the anterior leaflet in 22 patients (48%), the septal in 10 (22%) and both leaflets in 14 (30%). TVD was selectively applied in cases with multiple chordal attachment to the rim of the VSD. The technique was exactly as described in our previous paper [6]. Essentially, the incision for detachment is made in the leaflet, about one millimeter inside the annulus. After closure of the VSD, a separate continuous suture line 7-0 or 6-0 polypropilene was used to reattach the leaflets. In addition to a right atriotomy, two patients (both non-TVD)

Table 1: Pre-operative baseline characteristics

	n	Mean	Range
Age		1.8 years	2.5 weeks – 14.8 years
Weight		9.1 kg	2.2 – 49 kg
Percentile		29	1 –99
Height		0.72 m	0.35- 1.64 m
Percentile		16	1 – 99
Diuretics	140 (74%)		
Decreased exercise tolerance	143 (76%)		
Concomitant syndromal anomalies	32		
Down's syndrome	26 (14%)		
Jacobsen syndrome	1 (0.5%)		
Melas syndrome	1 (0.5%)		
Sotos syndrome	1 (0.5%)		
VACTERL association	1 (0.5%)		
Electrocardiogram			
Left ventricular hypertrophy	25 (13%)		
Right ventricular hypertrophy	39 (21%)		
Biventricular hypertrophy	71 (38%)		
A-V-conductance disorders	0		
Wolff Parkinson White syndrome	2 (1.1%)		
Echocardiography			
Tricuspid valve insufficiency			
Normal	129 (69%)		
Minimal/trivial	56 (30%)		
Severe	3 (1%)		
Catheterization	35 (19%)		
Associated cardiac defects			
ASD	103 (55%)		
PAD	5 (3%)		
ASD and PAD	29 (15%)		
Aortic coarctation with ASD and PAD	1 (0.5%)		
Aortic coarctation wit PAD	1 (0.5%)		

ASD, atrial septal defect; PAD, patent arterial duct.

required a second approach: one needed an additional left ventriculotomy for an apically situated central muscular VSD, the other an additional pulmonotomy to enhance the exposure of an outlet VSD. TVD was used more frequently in the first half of the series (32 out of 94, 34%) compared to the second half (14 out of 94, 15%).

The type of VSD was finally determined at the time of surgery: 173 (92%) were perimembranous, four inlet (2%), four outlet (2%) and seven central muscular (4%). One VSD

complicated by endocarditis was closed with autologous pericardium, all the others were closed with a Gore-Tex® patch. Postoperative echocardiography was performed with 2D and color-Doppler and used to assess tricuspid valve function as well as possible residual shunting. Tricuspid valve regurgitation was graded as none, trivial or severe, based on the area and the length of the color jet. Residual shunting was defined as no residual shunting as no detectable color jet; trivial residual shunting as a minimal color jet and significant residual shunting as detectable VSD with an important color jet.

Follow-up concerning the presence of a residual shunting and evaluation of the tricuspid valve was complete in 177 patients (95%). Endpoints with respect to residual shunts were reoperation for residual VSD or spontaneous closure of the shunt as evaluated by echocardiography at the outpatient clinic. Three patients were lost to follow-up because they left the country shortly after operation. Hospital mortality was defined as death within 30 days postoperative. The mean follow-up time was 2.6 years (range 0.1 – 9.4 years).

Statistical analysis

The analysis of categorical variables was performed with X^2-test. Continuous variables, described as the mean ± standard deviation were analyzed using the independent Student's t-test. Logistic regression analysis was used to analyze predictive values for residual shunt at discharge. A significant difference was found when probability values were smaller than 0.05.

RESULTS

At operation the group with TVD was younger (mean age 0.8 ± 1.8 (median 0.38) vs 2.1 ± 3.5 years (median 0.41), $p = 0.002$), had a lower weight (6.5 ± 6.4 vs 10.0 ± 11.0 kg., $p = 0.009$) and were shorter in length (0.63 ± 0.17 vs 0.75 ± 0.31 m, $p = 0.004$) compared to the non-TVD group. There were no significant differences between the two groups concerning pre-operative use of diuretics ($p = 0.24$), failure to thrive ($p = 0.29$) or exercise intolerance ($p = 0.14$). Cardiopulmonary bypass time was not significantly different (TVD group 62 ± 14 min vs non-TVD group 64 ± 28 min, $p = 0.61$). The groups also did not differ in cross-clamp time (TVD 36 ± 11 min vs non-TVD 33 ± 13 min, $p = 0.23$). Two patients died during their hospital stay. One patient (TVD group) with pulmonary hypertension died during the operation because of a pulmonary hypertensive crisis. One patient (non-TVD group) died on the first postoperative day in relation to acute patch dehiscence, despite an emergency reoperation. One patient needed a resternotomy because of persistent blood loss. Two other patients needed prolonged postoperative ventilation support (both 10 days) and in two more the sternum was closed secondarily because of

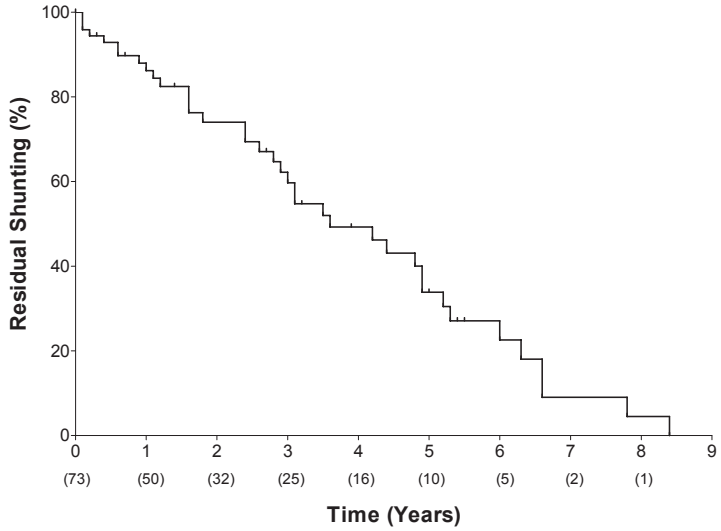

Figure 1. Prediction of residual shunting after surgical closure of a ventricular septal defect.

initial hemodynamic instability. Because of persistent complete atrioventricular block in one patient a permanent VVI-pacemaker was implanted. There were 186 early survivors; one patient died 7 months postoperative due to a bronchopneumonia.

The types of VSD in the TVD and non-TVD groups did not differ (perimembranous n=43, 93% vs n=130, 92%; inlet n=1, 2% vs n=3, 2%; outlet n=0, 0% vs n=4, 3% and central muscular n=2, 4% vs n=5, 4%).

The postoperative echocardiographic assessment of tricuspid valve function was: 121 patients (64%) had no tricuspid valve regurgitation, 67 patients (36%) had trivial regurgitation and none had severe tricuspid valve regurgitation. From the 67 patients with trivial/minimal regurgitation 10 (22%) were from the TVD group and 57 (40%) from the non-detached group ($p = 0.02$).

Postoperative echocardiography showed residual shunting in 73 patients, all trivial. The median time of echocardiographically proven spontaneous closure was 3.9 years. The incidence of a residual shunt did not differ (TVD vs non-TVD 17 vs 56, p=0.48). During follow-up 37 (51%) of the residual shunts closed spontaneously. As illustrated in Fig.1 all residual shunts are expected to close within 10 years. In a univariate logistic regression both lower age and lower weight at operation were predictive of residual shunting at hospital discharge (see Table 2). In the multivariate logistic regression only lower weight at operation was predictive (odds ratio 0.95, confidence limits 0.91 – 0.99)

At mid-term follow-up there was no significant (p = 1.0) difference in incidence of trivial tricuspid valve regurgitation between the non-TVD group (n = 15, 11%) and TVD-group (n=15, 11%). The presence of left ventricular hypertrophy on electrocardiogram was reduced from 25 patients to two (92% reduction); right ventricular hypertrophy was

Table 2. Logistic regression analysis for residual VSD

	Univariate	
Variable	Odds Ratio	C.I.
Age	0.86	0.76 – 0.97
Date of operation	1.04	0.93 – 1.15
Weight at operation*	0.95	0.91 – 0.99
Length at operation	0.99	0.97 – 1.00
Detachment of tricuspid valve	0.87	0.43 – 1.74
Female sex	0.99	0.55 – 1.82
Non-perimembranous VSD	0.95	0.32 – 2.78
Cross-clamp time	0.99	0.96 – 1.01
Associated cardiac defect	1.38	0.68 – 2.78

C.I., confidence Interval; VSD, ventricular septal defect

* Significant in multivariate analysis.

reduced from 38 to 4 (89% reduction) and a complete reduction in hypertrophy was seen in patients with biventricular hypertrophy (71 patients). Use of diuretics showed a 92% reduction (from 127 patients to 10) and failure to thrive and exercise intolerance were reduced with 94% (from 134 to 8). The mean weight percentiles increased for the whole group from 16 ± 23 to 40 ± 30 as did the mean height percentile: 29 ± 28 to 40 ± 30.

DISCUSSION

Detachment of the tricuspid valve may improve visualization of the margins of a VSD and can thereby diminish the chance of a residual shunt, creation of a heart block or distortion of the tricuspid valve. Gaynor et al. [9] reported TVD in 21% of the patients in closing an isolated VSD, previously we reported 26% [6]. In the present study we used TVD in 24% of the patients, in the second half of the series this technique was applied in 14%. TVD was applied to the surgeons' choice only in cases with multiple chordal attachments to the rim of the VSD. This study confirms that tricuspid valve detachment can be performed without additional complications and does not lead to a longer cross-clamp time [6]. Nonetheless, concern exists whether tricuspid valve detachment may lead to temporarily or permanent dysfunction of the tricuspid valve. In the long-term, growth of the tricuspid annulus might also be impaired, possibly leading to tricuspid valve stenosis [10]. In this series detachment of the tricuspid valve did not cause tricuspid insufficiency or tricuspid stenosis. Postoperative echocardiography showed that tricuspid insufficiency in the detached group was even considerably lower compared to the non-detached group. In the detached group the valve will keep its original strength and elasticity. In the non-detached group, however, the valve may experience mechanical

stress by stretching the chordae or the leaflets that could lead to temporarily insufficiency [9].

With color-Doppler small residual shunts are frequently noted after repair of a VSD [5,11,12]. In an earlier study we found an incidence of 20% in this regard [6]. Echocardiography at discharge showed that 73 (39%) of the 186 hospital survivors had a trivial residual shunt across the septum, during follow-up in 37 patients the shunt closed spontaneously. The exposure of the VSD was improved by TVD, the incidence of residual shunting was comparable in the TVD group (N= 56, 40%) and the non-TVD group (n= 17, 38%). Detachment of the tricuspid valve was not a significant factor in relation to residual shunting in the logistic regression analysis (OR 0.87; C.I. 0.43 – 1.74). Weight at operation was the only independent predictive factor for a residual shunt. The smaller the child the more likely a residual shunt existed at discharge. Obviously, in closing a VSD in a smaller patient, the balance between prosthesis compliance and tissue friability is different.

Tatebe et al. [13] in their study concluded that detachment of the tricuspid valve should be avoided in patients with Down's syndrome and small infants because of a higher incidence of tricuspid valve regurgitation. In our series 26 patients (nine TVD, 17 non-TVD) had Down's syndrome. There was no significant (p = 0.613) difference in regurgitation between the TVD group (four patients (44%) with trivial TI) and the non-TVD group (eight patients (47%) with trivial TI). This suggests that TVD in patients with Down's syndrome can be performed safely.

In contrast to the finding of Tatebe et al. [13] in the group of small children with a pre-operative weight under the 10th percentile (122, 33 detached, 89 non-detached) postoperative tricuspid valve regurgitation was significantly (p = 0.009) higher in the non-detached group (38, 43%) vs the detached group (6, 18%).

Patients with VSD demonstrate satisfactory bodyweight gain after VSD-closure [14]. This study also showed an increase in weight and length percentile postoperatively. Total energy expenditure is 40% higher in children with a VSD compared to healthy controls [15]. This study confirms that closure of a VSD results in a catch-up growth after closure.

This study illustrates that closure of a VSD can be performed with a low complication rate. Tricuspid valve detachment is a safe method to enhance the exposure of a VSD. TVD results in less early postoperative tricuspid valve regurgitation and does not result in tricuspid valve dysfunction during follow-up. TVD results in comparable residual shunting as non-TVD. The incidence of trivial residual shunting is higher in small children irrespective of tricuspid valve detachment. Trivial residual shunting is expected to disappear spontaneously.

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CHAPTER 8

Long-term Follow-up after Closure of Ventricular Septal Defect in Adults

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Submitted

ABSTRACT

Background. Little is known about the results of surgical closure of a ventricular septal defect (VSD) in patients presenting at adult age.

Methods. A retrospective study was carried out of 28 patients (15 male) operated upon between 1980 and 2004. Patients were investigated by echocardiography, ECG and assessed for quality of life by a questionnaire.

Results. The indication for surgery was volume overload in11 patients, endocarditis in 8, aortic valve regurgitation in 8 and the combination of a VSD with subvalvular aortic stenosis in one. One patient was lost to follow-up after eleven years. Follow-up was complete with a mean duration of follow-up of 13 years. There was no early or late mortality. One patient was reoperated for recurrent VSD. Twenty-six patients are in NYHA class I, one is in class III. Twenty-five patients underwent echocardiography and revealed trivial residual VSD in 2. One patient had persistent pulmonary hypertension with right ventricular hypertrophy. Mild aortic regurgitation was detected in 10 patients (40%).

The same twenty-five patients underwent ECG. One patient was in atrial fibrillation and the remainder were in sinus rhythm.

Health related quality of life in the dimensions cognitive functioning and sleep differed significantly from that of the general population.

Conclusion. With a relative difference in indications for closure of a VSD in adulthood, surgical closure of VSD at adult age is an adequate and safe procedure, with good results on long-term follow-up. Progression of aortic valve regurgitation is a matter of concern.

INTRODUCTION

The majority of isolated congenital ventricular septal defects (VSD) close spontaneously. In 80% of the patients with a VSD seen at the age of 1 month, the VSD will close spontaneously. Also before closure the majority of these patients were entirely asymptomatic. Patients who develop symptoms due to substantial left-to-right shunting are operated upon in the first year of life [1]. The long-term results of surgical closure of VSD in infancy are very good and are well documented in terms of survival, morbidity and quality of life [2-4]. In contrast, little is known about surgical VSD closure at adult age.

In patients with a VSD, the clinical course depends on the size of the defect, the localisation of the defect and on concomitant anomalies [1]. In young patients the indication for surgical closure of a VSD are most often left-to-right shunting related symptoms [5]. Surgical closure abolishes the left-to-right shunt, prevents development of pulmonary vascular disease, decreases the risk of endocarditis, improves functional classification and increases long-term survival [6].

If spontaneous closure of a VSD did not occur in childhood or adolescence, the chance that it will close in adult life is small. In adults spontaneous VSD closure is reported to occur in only 10% of the patients [1, 7, 8]. With advancing age, symptoms are related to secondary effects of a shunt, and persistent defects may predispose to endocarditis, aortic regurgitation and in selected cases to heart failure, arrhythmias and pulmonary hypertension [9]. Very few data exist on indication for VSD closure at adult age, on postoperative course and there are almost no data on long-term follow-up of patients with a VSD operated upon at adult age [5].

Quality of life of patients undergoing surgical closure during childhood is comparable to that of the normal population [3]. For those operated in adulthood this has not been studied. Therefore we describe the follow-up, including quality of life of patients undergoing surgical closure of a VSD in adulthood.

MATERIAL AND METHODS

A retrospective study was carried out of a consecutive series of 28 adult patients (15 male, 13 female), operated upon for a single congenital VSD over the age of 16 years between January 1980 and January 2004. The mean age at the time of surgical closure was 34 years (range 19-50 years). Excluded were patients with other cardiac anomalies affecting the ventricular septum.

Diagnosis and hemodynamic assessment was performed by echocardiography. In the early part of the series, before ultrasound was available for clinical use, diagnosis was confirmed with cardiac catheterization in 14 patients.

All patients were operated with cardiopulmonary bypass. The mean extracorporeal circulation time was 76 minutes (range 37-124 minutes) and the mean aortic cross-clamp time 43 minutes (range 20-87 minutes). In 7 patients one or more concomitant anomalies were treated. In one the aortic valve was replaced by a mechanical valve, in 2 a secundum atrial septal defect (ASD) was primarily closed, in one a persistent arterial duct was ligated and in one patient both a secundum ASD was closed and a persistent arterial duct was ligated. In one patient a stenosis of the left pulmonary artery was treated with patch augmentation with autologous pericardium and in one a discrete subaortic stenosis was enucleated. See Table 1.

A right atrial approach to the VSD was used in 27 patients. An additional right ventriculotomy and an additional aortotomy were performed in 2, and an additional pulmonotomy in one patient. An exclusively right ventriculotomy was used in only one. To improve the exposition of the VSD the septal leaflet of the tricuspid valve was temporarily detached in 2 patients [10, 11].

Closure of the VSD was performed either with a Gore-Tex® patch (n=13, 46%), a Dacron® patch (n=8, 29%), a pericardial patch (n=5, 18%) or primarily (n=2, 7%). See Table 1.

Table 1 Patient and Operation Characteristics

	n =28	%	Mean	Range
Cross Clamp time (mean, range)			43	20-87
Bypass time (mean, range)			76	37-124
Concomitant anomalies	7	25		
Atrial septal defect (secundum type)	2			
Persistent arterial duct	1			
Persistent arterial duct and atrial septal defect (secundum type)	1			
Discrete subaortic stenosis	1			
Stenosis left pulmonary artery	1			
Indication for Surgery				
Left to right shunt>1.5	12	42		
Endocarditis	8	29		
Aortic regurgitation	8	29		
Method of closure				
Gore-Tex patch	13	46		
Dacron patch	8	29		
Pericardial patch	5	18		
Primarily	2	7		

One patient went abroad 11 years post-operatively in good clinical health and was included as lost to follow-up from that time on. Two patients, who were in good clinical health, refused to undergo echocardiography and ECG. They agreed in being interviewed by telephone. All 25 remaining patients were seen at our outpatient clinic with a mean follow-up time of 13 years. Patients underwent echocardiography, ECG and quality of life assessment. Echocardiographic data were analyzed by one cardiologist. Echocardiographic data were available for 25 patients, and included chamber dimensions, valve regurgitations, pulmonary systolic pressure, and flow through a residual VSD. Quantification of the chamber dimensions was performed according to the ASE guidelines [12]. Regurgitant severity of the aortic, pulmonary, and tricuspid valve was graded as none/trivial to severe (0 to 4+) on the basis of color flow imaging [13]. Pulmonary systolic pressures were calculated on the basis of tricuspid regurgitant jet velocities and estimated right atrial pressures using inferior vena caval dimension [12, 13]. A pulmonary systolic pressure > 35 mmHg was considered pulmonary hypertension.

The electro-cardio graphic data were also analysed by one cardiologist.

Health related quality of life was determined with the TAAQOL-questionnaire [14]. It consists of 45 questions divided into 12 domains. Each domain contains two to four questions (the actual number per domain is given in parentheses): gross motor functioning (4), fine motor functioning (4), pain (4), sleeping (4), cognitive functioning (4), social functioning (4), daily activities (4), sexual activity (2), vitality (4), happiness (4), depressive moods (4), and aggressiveness (3). Scores of each subscale are normalised to a scale ranging from 0 to 100, with higher scores indicating better quality of life. For each item, the frequency of occurrence of a health status problem is assessed. If such a problem is reported, the emotional reaction to this problem is also determined [14, 15]. TAAQOL data of the Dutch general population are available [14].

Categorical variables, summarized in terms of relative frequencies, were analysed using the chi-square test with the Yates correction or using Fisher's exact test. Continuous variables, described as the mean and range, were analysed using Student's t-test. P-values < 0.05 were considered significant. The participants' health related quality of life (as measured by the TAAQOL) was compared with that of a random sample of the general Dutch population in 4410 persons using analysis of variance with adjustment for age and sex. After comparison, the data were summarised as mean values and 95% confidence intervals.

RESULTS

Indications for surgical closure of the congenital ventricular septal defect were substantial left-to-right shunt (12/28, 42%), endocarditis (8/28, 29%) and aortic regurgitation (8/28, 29%).

Seven of the 12 patients with a substantial left-to-right shunt presented relatively late and were in NYHA class II. Of these, 2 patients (2/7) came from developing countries and in two others the parents of the patients had declined diagnostic procedures at pediatric age. The remaining three patients came from referring centres and were presented late; one patient with pulmonary hypertension, one had Down's syndrome and the third was not operated upon in the past because of presumed high operative risk.

The indication for surgical closure was endocarditis in 8 patients (29%). In none of these patients the VSD was haemodynamicilly important. In 4 patients it concerned an endocarditis lenta and in 4 the VSD was closed after successful medical treatment of a second episode of endocarditis. Identified organisms were Streptococcus Viridans (2), Streptococcus Mutans (1), Enterococcus Faecalis (1), Streptococcus species with undetermined isotype (3) and Staphylococcus Aureus (1). Endocarditis was more prevalent in males than in females (7 vs. 1).

Progressive aortic valve regurgitation was the indication for closing a perimembraneous ventricular septal defect in 8 other patients (29%). In one patient the aortic valve was replaced, in 2 a fenestration in the right coronary cusp was closed, and in 5 a mild aortic regurgitation was left untreated.

At presentation 17 patients (61%) were in NYHA class I and 11 (39%) in NYHA class II.

At surgery the VSD was found to be perimembraneous in 24 (86%), outlet type in 2 (7%) and muscular in 2 (7%).

Early postoperative complications were mediastinal exploration for persistent blood loss in 3 and adult respiratory distress syndrome in one patient.

Follow-up

Follow-up was complete in 27 patients with a mean duration of 13 years (range 1 - 23 years). No patient died. One patient was reoperated because of a residual VSD 2 years after the initial procedure, in which the indication was aortic regurgitation. No recurrent episodes of endocarditis were reported.

At last follow up, 26 of the 27 patients were in NYHA class I. One patient, preoperatively in NYHA class II with pulmonary hypertension, was in NYHA class III still suffering from pulmonary hypertension. In addition she was in atrial fibrillation.

Echocardiographic findings at follow-up are listed in table 2. Tricuspid regurgitation grade 1+ was present in 8 (32%) patients and grade 2+ in 4 (16%) patients, including

Table 2 Echocardiographic findings at a mean follow-up of 12 years postoperatively

Echocardiographic variables	N=25
Residual VSD	2 (8%)
Peak velocity residual VSD (m/s)	4.6±0.7
Left atrium (mm)	39±8
Left atrial dilatation (>40 mm)	12 (48%)
LV end-diastolic diameter (mm)	52±7
LV dilatation (>55 mm)	7 (28%)
LV end-systolic diameter (mm)	35±6
Fractional shortening (%)	32±6
Fractional shortening<25%	3 (12%)
Interventricular septum (mm)	10±2
LV posterior wall (mm)	9±2
RV diameter (mm)	39±5
Tricuspid regurgitation	
None/ trivial	13 (52%)
1+	8 (32%)
2+	4 (16%)
Pulmonary regurgitation	
None/ trivial	18 (72%)
1+	4 (16%)
2+	3 (12%)
Aortic regurgitation	
None/ trivial	15 (60%)
1+	9 (36%)
2+	1 (4%)
Peak velocity tricuspid regurgitation (m/s)	2.2±0.4
Pulmonary hypertension (>35 mmHg)	1 (4%)

the patient with pulmonary hypertension. No tricuspid regurgitation was present in the two patients with temporary tricuspid valve detachment. The aortic valve was normal in 15 (60%) patients, grade 1+ aortic regurgitation was present in 9 (36%) and grade 2+ in one (4%) patient. Six of the 8 patients in whom the indication for closure of the VSD was aortic regurgitation had grade 1+ aortic insufficiency at follow-up, the other 2 had no aortic insufficiency. Left ventricular dilatation was present in 7 (28%) patients, in all but one (6/7) the indication for closure of the VSD was a left-to right shunt.

The electro-cardiographic data revealed that one patient was in atrial fibrillation, all other were in sinusrhythm (96%). The mean PQ-interval for the patients in sinusrhythm

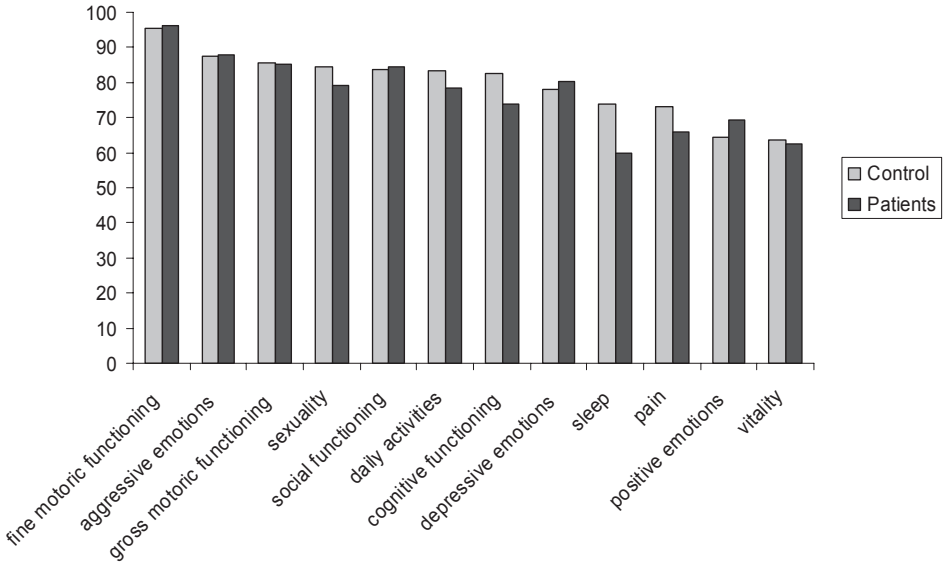

Figure 1. Quality of life in different domains compared to the average Dutch population

was 160 ms (126-232). The mean duration of the QRS-complex was 107 ms (72-148), QT-interval 390 ms (350-460) and QTc was 411 ms (353-489).

In seven patients (26%) the ECG showed a right bundle branch block. One patient with a right bundle branch block was also in atrial fibrillation. None of the patients had signs of sinus node dysfunction, none had a complete A-V block.

Figure 1 gives the average TAAQOL scores of the patients compared to the general population sample. The patients had significantly lower health related quality of life in cognitive functioning (score 74 vs. 83 in controls, $p<0.045$) and sleep (60 vs. 74 in controls $p<0.006$).

Scores of each subscale are normalised to a scale ranging from 0 to 100, with higher scores indicating better quality of life.

DISCUSSION

This study shows that surgical closure of a congenital VSD at adult age can be done without mortality and without major early or long-term complications. Nevertheless, some residual lesions were found, e.g. one patient with substantially elevated RV-pressure indicating pulmonary vascular disease due to long-standing pulmonary overflow had persisting pulmonary hypertension after the operation. Moreover, in the group of patients operated upon because of clinically important left-to-right shunting, 7 out of 25 patients (28%) had signs of persisting left ventricular dilatation. In none of these

patients there were signs left ventricular failure up to 24 years after surgery. This seems to indicate that avoiding of development of left ventricular failure is achieved by surgical closure of the VSD. However, continued long-term follow-up is necessary to further substantiate this.

More important is the finding that a substantial portion of patients operated upon at adult age did not show a normalisation of intra-cardiac dimensions after VSD closure, which is hardly ever seen after surgical closure of a VSD in childhood. The long-term follow-up after surgical closure of a VSD in infancy is documented extensively [2-4] in contrast to surgically VSD closure at adult age. This suggests that these patients probably would have benefited from an earlier operation.

In addition to closure of the VSD, one patient had aortic valve replacement 18 years after initial indication for closure at the age of 12 years, when the parents refused the operation. In none of the remaining 7 patients, for whom indication for surgical closure was a subaortic, perimembranous localisation of the VSD in combination with development of aortic regurgitation, aortic regurgitation progressed to a degree beyond mild. In the natural history of these defects development of moderate or even severe aortic regurgitation is reported to be frequent [7]. These results show once more that surgery without mortality may be a preferable option for these patients.

The prevalence of arrhythmia in this study – less than 10% of the study population- is in line with that of other reports [7]. Theoretically, atrial fibrillation can be expected in those patients with long-standing left atrial dilatation due to substantial left-to-right shunting. Arrhythmias, ascribed to intracardiac surgery performed through a right atrial incision, due to a "macro" re-entry tachycardia around the surgical scar, presenting as atrial flutter are rare. This might indicate that the theoretically pro-arrhythmogenic surgical right atrial scar does not lead to clinically significant arrhythmias up to 24 years after surgery. It is evident that longer follow-up is necessary in this matter.

Quality of life of this operated adult VSD group is comparable with general population. In 10 out of twelve domains they had an equal score. In 2 domains, cognitive functioning and sleep, our population differed from the general population with regard to the quality of life. This can be interpreted as the quality of life of our patient group being practically equal to the normal population.

Looking at the very good results in terms of mortality and complication rate of surgical closure of VSD's at adult age, realizing that patients operated upon because of left-to-right shunting might had benefited from earlier surgery and knowing the cumulative risk of endocarditis in this population of over 10% [7] with a mortality rate of 15-25% [7, 16, 17] even in the modern era of sophisticated antibiotic therapy, one might consider closure of all VSD's that have not closed spontaneously in the first 2 decades of life.

Apart from these considerations, the results of this study provide a benchmark for the emerging experience of device closure of a VSD [18].

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CHAPTER 9

Discussion, Conclusions and Perspectives

ASPECTS OF DIAGNOSIS

Ample information is available concerning, anatomy, (patho-) physiology, clinical course, diagnostic tools and surgical therapy of the congenital ventricular septal defect. With regard to echocardiographic diagnosis, only recently 3D echocardiography and additionally virtual reality 3D echocardiography, is starting to build up.

Preoperatively, 3D echocardiography shows an accurate view of the anatomy of the VSD with a good intra-and interobserver reproducibility and reveals that the functional anatomy of the tricuspid valve, the right ventricular outflow tract, and the aortic valve can be displayed in their actual spatial distribution. Besides anatomy, pathophysiology of a VSD is a critical factor in management decisions, pulmonary vascular resistance being an important factor in the shunting of the VSD. At present, analytic methods to assess shunt size are lacking for 3D echocardiography and therefore also for virtual reality 3D echocardiographic analysis.

Currently, I-Space technology is only available in a limited number of research centres throughout the world. Therefore, the representation and analysis of 3D echocardiography datasets by virtual reality has only been described very recently. As a new application, virtual reality is extended to postoperative control of the results of surgery for congenital VSD, in datasets derived epicardially. An important finding is that motion abnormalities of the tricuspid valve leaflets were found, that were not appreciated in 2D echocardiography. Virtual reality provided a unique resource for postoperative quality control as well as for education with regard to the intracardiac repair of congenital VSD. The virtual reality analysis can be done by the practical expert in the relevant anatomy, for instance the cardiothoracic surgeon performing the operation, and depends to a lesser extent on the expert in echocardiographic imaging, for instance the cardiologist making the diagnosis. Virtual reality in this regard provides an additional resource for postoperative quality control as well as for education with regard to the intracardiac repair of congenital VSD.

With the growth of minimal invasive cardiac surgery and interventional procedures, the interest for simulation by a hologram of the area of interest as a training tool will increase. In this regard both the area of interest before surgery or intervention as well as the result after therapy can be analysed and compared.

With the I-Space technology, the complex postoperative cardiac anatomy of the closed congenital VSD can be appropriately visualised in virtual reality.

3D technology is evolving towards smaller, cheaper, and more flexible 3D visualization and interaction systems with greater resolution.

Indeed, virtual reality 3D echocardiography should be able to run on smaller systems, either based on miniaturization of the system (desktop format, either off location

or on top of the echomachine) or advanced projection (adapted aviation helmet screen projection or advanced monitor screen).

In this way, virtual reality is no longer restricted to VR specialists in VR centers. Desk top applications then allows 3D visualization and interaction to be accessible not only to engineers, but to all scientists working with 3D and 4D data.

Moreover, desktop systems and I-space VR systems can be used as complementary tools. Scientists are able to design applications for the virtual reality on the desk top modality in their office. Users of 3D and 4D data sets will no longer exclusively need a VR system for the analysis of their data, but can apply them both for specific matters and questions.

ASPECTS OF SURGERY

Surgery is the gold standard in closure of a congenital ventricular septal defect. It is associated with low mortality and morbidity and is well established, especially in young patients, resulting in a correspondingly long life expectancy. Recently, percutaneous devices were introduced for closure of a congenital ventricular septal defect. The technique of device closure has been shown to be feasible but extensive experience is lacking. Closing the VSD with a device may also limit the treatment of associated anomalies that need surgical correction.

Longer and more extensive observation is necessary to determine whether or not percutaneous closure will be an alternative for the surgical closure or should be performed in selected patients.

Despite the well-established results of surgery for congenital ventricular septal defect, improvements with intraoperative conditioning can be investigated. Surgical closure of a VSD in small patients with body weight less than 10 kg. is often performed with moderate (28°C) systemic hypothermia. We investigated whether or not this closure could also be safely performed with mild (32°C) hypothermia. This in relation to surgical exposure, myocardial protection, renal function, ventilatory support and the fibrinolysis. No differences were found, the conclusion was made that mild hypothermia is safe in closure of a congenital ventricular septal defect in our setting.

Temporary tricuspid detachment is an attractive surgical alternative for the repair of a congenital VSD in patients in whom transatrial exposure of the VSD is incomplete. This procedure turned out to be associated with patients that were younger, lower in weight, shorter and more often on diuretic therapy. This was, however, not reflected in a worse functional class. Apparently temporary chordal detachment is applicable as well, but, arguments in favour, however, should preferably come from obvious advantages or from careful follow-up, as does any alternative approach.

We observed this population for a long period with special emphasis to residual shunt and impairment of the tricuspid valve in relation with detachment or not. In the long term, growth of the tricuspid annulus might be speculated to be impaired, possibly leading to tricuspid valve stenosis. In this series detachment of the tricuspid valve did not cause tricuspid insufficiency or tricuspid stenosis, both early postoperative as well as on long term follow up.

With color-Doppler small residual shunts are frequently noted after repair of a VSD. Weight at operation was the only independent predictive factor for a residual shunt. The smaller the child the more likely a residual shunt existed at discharge. Obviously, in closing a VSD in a smaller patient, the balance between prosthesis compliance and tissue friability is different. Because the clinical condition of the patient determines the timing of surgery, it can be accepted that in young patients the trivial residual shunt may have an increased incidence. In this perspective, the fact that this study confirms that closure of a VSD results in a catch-up growth after closure is not to be neglected.

Trivial residual shunting is expected to disappear spontaneously, for this reason one should reconsider to subject a patient with a residual shunt after closure of a VSD on lifelong endocarditis-prophylaxis. For this reason, these patients can only be discharged from follow-up after complete closure of the residual shunt.

FOLLOW UP

The long-term follow-up after surgically VSD closure in infancy is well documented with respect to survival, morbidity and quality of life in contrast to surgically VSD closure at adult age.

Concerning the quality of life, our study confirms that quality of life of this adult VSD group is comparable with that of the general population. Quality of life testing with the TAAQOL questionnaire showed that in 10 out of twelve domains they had an equal score as in general population. In 2 domains, cognitive functioning and sleep, our population differed from the general population with regard to the quality of life.

Concerning the very good results in terms of mortality and complication rate of surgical closure of a congenital VSD at adult age and realizing that patients operated upon because of left-to-right shunting might had benefited from earlier surgery and knowing the cumulative risk of endocarditis in this population we conclude that, even in the modern era of sophisticated antibiotic therapy, one might consider closure of all VSDs that have not closed spontaneously in the first 2 decades of life.

Apart from these considerations, the results of our study provide a benchmark for the emerging experience of device closure of a VSD.

CHAPTER 10

Summary

Samenvatting

SUMMARY

In **Chapter 1,** an outline of the thesis is given. This thesis focuses on aspects of surgical closure of a congenital ventricular septal defect.

In **Chapter 2**, the accuracy and the potential of 3D echocardiography in the preoperative assessment of a congenital VSD were evaluated. 3D echocardiography can be considered a valuable diagnostic tool, which may accurately identify the location, size, and spatial relations of a VSD.

Chapter 3 presents a surgical alternative by temporary tricuspid valve detachment, in the approach for the repair of a congenital VSD in patients in whom transatrial exposure of the VSD is inadequate. The procedure was significantly associated with patients that were younger, lighter in weight, shorter and more often on diuretic therapy. Regardless of the age, size and preoperative clinical condition of the patients, and regardless of the right ventricular load, temporary detachment of the tricuspid valve in closure of a congenital VSD can be performed safely, without any negative effect on growth or function of the valve at medium-term follow-up.

Chapter 4 comments on temporary chordal detachment as an alternative to temporary detachment of the anterior or septal tricuspid leaflet from the tricuspid annulus in repairing a congenital VSD in patients in whom transatrial exposure of the VSD is incomplete. This technique may be useful in selected cases; however, arguments in favour should preferably come from obvious advantages or from careful follow-up.

Chapter 5 focuses on the differences between mild (32°C) and moderate (28°C) systemic hypothermia during the reconstruction of a congenital ventricular septal defect in paediatric patients. No differences were found regarding organ preservation and adequacy of cardio pulmonary bypass, nor in surgical exposure and clinical outcome.

Chapter 6 demonstrates the clinical application of real time 3D echocardiography in patients with a surgically corrected congenital ventricular septal defect. With I-Space technology, the complex postoperative cardiac anatomy of the closed congenital VSD can be appropriately visualised in virtual reality and provides a unique resource for postoperative quality control as well as for education with regard to the intracardiac repair of a congenital VSD.

Chapter 7 provides a long-term follow-up study after surgical closure of a congenital ventricular septal defect. To enhance surgical exposure of the congenital ventricular

septal defect in selected patients, the tricuspid valve was temporary detached from the tricuspid annulus and proved to be a safe method. Closure of a congenital ventricular septal defect can be performed with a low complication rate. Tricuspid valve detachment (TVD) results in less early postoperative tricuspid valve regurgitation and does not result in tricuspid valve dysfunction during follow-up. TVD results in comparable residual shunting as non-TVD. The incidence of trivial residual shunting is higher in small children irrespective of tricuspid valve detachment. Trivial residual shunting is expected to disappear spontaneously

Chapter 8 provides a long-term follow-up study after surgical closure of a congenital ventricular septal defect at adult age with special emphasis to quality of life. The need for surgical closure of a congenital ventricular septal defect in adulthood is rare, but on the right indication, surgery is an adequate and safe procedure, with good results on long-term follow up. Quality of life of this adult VSD group is comparable with general population. In 10 out of twelve domains of the TAAQOL-questionnaire they had an equal score. Merely in 2 domains, cognitive functioning and sleep, our population differed from the general population with regard to the quality of life. The question is raised whether or not all ventricular septal defects at adult age should be closed.

Chapter 9 contains a general discussion regarding aspects of surgery of a congenital ventricular septal defect at paediatric and adult age.

SAMENVATTING

In **Hoofdstuk 1** wordt een overzicht gegeven van het proefschrift. Dit proefschrift behandelt aspecten van chirurgie voor een aangeboren ventrikel septum defect.

In **Hoofdstuk 2**, worden de betrouwbaarheid en de mogelijkheden van 3D echocardiografie in de preoperatieve analyse van een aangeboren ventrikel septum defect geëvalueerd. 3D echocardiografie kan beschouwd worden als een waardevol diagnostisch instrument, waarmee nauwkeurig de locatie, de grootte en de ruimtelijke verhoudingen van een VSD kunnen worden geïdentificeerd.

Hoofdstuk 3 beschrijft het tijdelijk losmaken van de tricuspidalisklep uit de annulus als chirurgisch alternatief in de benadering om een aangeboren ventrikel septum defect te sluiten bij patiënten waar de transatriale expositie van het VSD onvoldoende is. Deze techniek werd significant vaker toegepast bij patiënten die jonger, lichter in gewicht en kleiner waren en die vaker diuretica gebruikten. Ongeacht de leeftijd, lengte en gewicht en preoperatieve klinische conditie van de patiënten en ongeacht de rechter ventrikel belasting kon het tijdelijk losmaken van de tricuspidalisklep uit de annulus bij het sluiten van een aangeboren VSD veilig worden uitgevoerd, zonder nadelige effecten op de groei of functie van de tricuspidalisklep op middellange termijn.

Hoofdstuk 4 becommentarieert het tijdelijk losmaken van de aanhechting van de chordae als een alternatief voor het tijdelijk losmaken van de anterieure of septale tricuspidalisklepslip uit de tricuspidaalklep annulus in de chirurgische benadering om een aangeboren ventrikel septum defect te sluiten bij patiënten waar de transatriale expositie van het VSD onvoldoende is. Deze techniek kan toegepast worden in geselecteerde patiënten; echter de argumenten hiervoor zouden bij voorkeur moeten komen van duidelijke voordelen of van zorgvuldige follow-up.

Hoofdstuk 5 legt zich toe op de verschillen tussen milde (32°C) en matige (28°C) systemische hypothermie gedurende de reparatie van een aangeboren ventrikel septum defect bij kinderen. Er werden geen verschillen gevonden in orgaan bescherming en de werking van de cardio pulmonale bypass, noch in chirurgische expositie, noch in klinische uitkomst.

Hoofdstuk 6 demonstreert de klinische toepassing van real time 3D echocardiografie bij patiënten met een chirurgisch gesloten ventrikel septum defect. Met behulp van I-space technologie kan de complexe postoperatieve cardiale anatomie van het gesloten aangeboren ventrikel septum defect naar behoren gevisualiseerd worden in

virtual reality. Bovendien voorziet deze techniek in een unieke bron voor postoperatieve kwaliteitscontrole en voor demonstratie met betrekking tot de intracardiale correctie van een aangeboren ventrikel septum defect.

Hoofdstuk 7 bespreekt lange termijn follow-up na chirurgische correctie van een aangeboren ventrikel septum defect. Om bij geselecteerde patiënten de chirurgische expositie te verhogen van het aangeboren ventrikel septum defect, werd tijdelijk de tricuspidalisklep uit de annulus losgemaakt en dit bleek een veilige methode. Chirurgische correctie van een aangeboren ventrikel septum defect kan worden verricht met een lage kans op complicaties. Het tijdelijk losmaken van de tricuspidalisklep uit de annulus resulteert in minder vroege postoperatieve tricuspidalisklepinsufficiëntie en resulteert niet in tricuspidalisklep dysfunctie tijdens follow-up. Het tijdelijk losmaken van de tricuspidalisklep uit de annulus resulteert in een vergelijkbare incidentie van restshunting als bij niet losmaken van de tricuspidalisklep uit de annulus. De incidentie van een onbelangrijke restshunt is hoger bij kleine kinderen, ongeacht het wel of niet tijdelijk losmaken van de tricuspidalisklep uit de annulus. Verwacht kan worden dat de onbelangrijke restshunt uiteindelijk spontaan zal verdwijnen.

Hoofdstuk 8 bespreekt een lange termijn follow-up studie na chirurgische correctie van een aangeboren ventrikel septum defect op volwassen leeftijd met speciale aandacht voor de kwaliteit van leven. De noodzaak voor chirurgische correctie van een aangeboren ventrikel septum defect op volwassen leeftijd is er zelden, maar op de juiste indicatie, blijkt chirurgie een adequate en veilige procedure met goede lange termijn resultaten. De kwaliteit van leven van deze volwassen VSD groep is vergelijkbaar met die van de algemene populatie. In 10 van de 12 domeinen van de TAAQOL-vragenlijst hadden ze dezelfde score. Slechts in 2 domeinen, cognitief functioneren en slaap, verschilde onze VSD groep met die van de algemene populatie met betrekking tot kwaliteit van leven. De vraag kan gesteld worden of niet alle ventrikel septum defecten op volwassen leeftijd gesloten dienen te worden.

Hoofdstuk 9 bevat een algemene discussie met betrekking tot aspecten van chirurgie voor een aangeboren ventrikel septum defect op kinderleeftijd en op volwassen leeftijd.

DANKWOORD

Een proefschrift is uiteindelijk een gevolg van jarenlange sociale en professionele vorming. Het begint met de sociale vorming tijdens de jeugd en wordt uiteindelijk geaccentueerd tijdens de professionele ontwikkeling.

Ik richt mijn dankwoord aan een groot aantal mensen, die op enigerlei manier in verschillende fases van de totstandkoming van dit boekje belangrijk voor mij zijn geweest. Ik realiseer me dat ik mogelijk een aantal mensen te kort doe of vergeet, maar zij weten zelf welke bijdrage zij direct, dan wel indirect geleverd hebben aan de vorming van de persoon die ik ben.

Dit proefschrift is een uitvloeisel van teamwerk en teamgeest van de afdeling Thoraxchirurgie aan het Erasmus MC te Rotterdam en is een illustratie van de cohesie binnen de thoraxchirurgische staf.

Hooggeleerde heer Bogers, beste Ad, het is gelukkig niet zo dat jij met deze titulatuur wenst te worden aangesproken, maar voor mij is het een manier om mijn respect voor jou en jouw manier van werken uit te drukken. Jij bent de motor en grote inspirator achter dit proefschrift. Als student-assistent kwam ik binnen op de afdeling net nadat jij daar als staflid was aangesteld. Als keuze co-assistent heb ik toen onder jouw leiding mijn eerste artikel kunnen schrijven. Ik heb mijn opleiding afgerond en ben direct aansluitend aangesteld als staflid binnen jouw afdeling als cardio-thoracaal chirurg. Vervolgens heb jij mij in staat gesteld mezelf niet alleen professioneel, maar ook in bredere zin te ontwikkelen. Ad, het moge duidelijk zijn, mijn dank voor je vertrouwen en vriendschap is groot.

Weledelzeergeleerde heer Kappetein, beste Arie Pieter, samen het bestuur vormend van de juniorkamer van de Nederlandse Vereniging voor Thoraxchirurgie is onze samenwerking begonnen. Deze heeft de basis gelegd voor onze vriendschap. Vele en lange avonden hebben we doorgebracht filosoferend over het vak en "het leven", waarbij je ook Ineke en de kinderen niet vergat. Ik ben er trots op dat jij mijn co-promotor wilt zijn.

Hooggeleerde heer Haas, beste Felix, tijdens de EACTS in Leipzig in 2004 was onze eerste kennismaking. Dit was een paar maanden voor jouw aanstelling als kinderhartchirurg in Utrecht. Het feit dat jij als Duitser met een Nederlands voetbalteam aantrad tegen jouw "Heimat" en deze wedstrijd winnend afsloot zegt voldoende over jouw persoonlijkheid.

Hooggeleerde heer de Feyter, beste Pim, als assistent kreeg ik van mijn collegae assistenten reeds te horen "voor een complex klinische casus waarbij je een PTCA overweegt moet je bij de Feyter zijn". Dat klopt en daar heb ik jarenlang mijn voordeel mee gedaan. Ik heb veel van je geleerd, ook dat geen interventie goed voor een patient kan zijn.

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Weledelzeergeleerde heer Meijboom, beste Folkert, dank voor de opbouwende kritiek op mijn manuscript. Het heeft even geduurd en er zijn verschillende versies van manuscripten over heen gegaan, maar met jouw heldere en logische visie op het geheel heb jij de "finetuning" fraai kunnen reguleren.

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Deskundige thorax anesthesiologie vormt de basis voor een goed operatieresultaat. Jan Hofland, Yvon Deryck, Dries van der Woerd, Thierry Scohy, Carsten Preis, Christian Lüthen en René Hagenouw dank voor jullie deskundige inbreng en dank voor de samenwerking.

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De samenwerking met de afdeling Cardiologie en met de "Rijnmond cardiologen" kenmerkt zich niet alleen door het streven naar hoge medische kwaliteit, maar is ook intercollegiaal uiterst aangenaam, zoals vooral blijkt bij gezamenlijk congres bezoek. Hier

wordt het nuttige met het aangename gecombineerd. De frequentie van deze gemeenschappelijke kennisvergaring is helaas te laag.

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CURRICULUM VITAE

Goris (John) Bol Raap was born August 18, 1964 in Rotterdam, the Netherlands. After graduating at Gymnasium Erasmianum in Rotterdam he studied medicine at the Erasmus University Rotterdam. In 1992 he obtained his medical degree and started as a resident in cardio-thoracic surgery at the Dijkzigt Hospital Rotterdam (head prof. dr. E. Bos), in which period he also was in charge of the Heart Valve Bank. In order to show that he could also live outside Rotterdam, he started his training at the Department of General Surgery at the Medical Centre Alkmaar, 1993-1995, head dr. A.B. Bijnen. During this period he lived in Bergen.

He finished his training in cardio-thoracic surgery at the Erasmus MC Rotterdam, formerly called Dijkzigt Hospital Rotterdam, chairmen subsequently prof. dr. E. Bos, dr. B. Mochtar and prof. dr. A.J.J.C. Bogers. After completing his training in cardio-thoracic surgery in 1999, he stayed in the Erasmus MC Rotterdam, being appointed as consultant at the Department Cardio-Thoracic Surgery.

The author is married to Ineke Happel. They have three children, Fleur, Joris and Pieter.