Role of intraoperative ultrasound examination in patients undergoing a Fontan-type procedure

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Abstract
To determine its potential impact on perioperative surgical management intraoperative ultrasound examination (cross sectional imaging, colour flow mapping, pulsed and continuous wave Doppler) was used in 16 consecutive patients undergoing a Fontan-type procedure. Epicardial cross sectional imaging before bypass defined the precise intracardiac morphology in 15 of 16 patients. The preoperative morphological diagnosis was refined in four patients (25%), and this influenced surgical management in two (12%). Epicardial studies after bypass identified seven residual haemodynamic lesions in five patients (three residual intercardiac shunts, one ventricular outflow obstruction, one pulmonary artery obstruction, two mitral valve regurgitation), and led to immediate revision during a second period of bypass in three (18%). In one patient who required early reoperation residual shunting was not detected after bypass by either colour flow mapping or a contrast study. Final intraoperative studies showed a good surgical result in 14 patients (87%). Flow characteristics and flow velocities within the Fontan circulation could be assessed immediately after the patient came off cardiopulmonary bypass by means of combined pulsed wave Doppler and colour flow mapping in 14 of the 16 patients. Cross sectional studies of the left heart after bypass showed no change in ventricular function and allowed monitoring of volume replacement and ventricular filling.

Intraoperative ultrasound was a valuable monitoring technique in patients undergoing a Fontan-type procedure. It refined preoperative diagnosis, monitored ventricular function, and identified or excluded residual haemodynamic lesions in most patients.

The Fontan procedure or one of its modifications is widely used to correct a wide range of complex congenital heart lesions. Both the operative mortality and reported results in the intermediate term have improved remarkably over the past decade. In several large series of patients, however, residual haemodynamic lesions were common (14–29%) and some caused early deaths in hospital, required early reoperation, or impaired functional capacity. We need an intraoperative monitoring technique for the rapid and accurate identification of important residual lesions immediately after a Fontan circulation has been established. This would allow the repair of important residual lesions during the same operation in a second period of bypass, and might further improve the early results of operation.

During operations for congenital heart disease high resolution epicardial cross sectional imaging can be used to define abnormal cardiac morphology before bypass and a combination of colour flow mapping and spectral Doppler investigations can be used to assess the haemodynamic results achieved by the surgical repair. Epicardial cardiac ultrasound might also be useful for the immediate evaluation of the results achieved by a Fontan-type procedure. To test this premise we used the full range of ultrasound investigations in a series of patients undergoing a Fontan-type procedure.

Patients and methods
Sixteen patients who underwent a Fontan-type procedure at the Department for Cardiothoracic Surgery, Erasmus University, Rotterdam were entered into a prospective intraoperative ultrasound study to determine the impact of such an examination on perioperative surgical management.

PATIENTS
The age at operation ranged from 5 months to 33 years (median age 3 years 6 months) and the body weight ranged from 4400 g to 73 kg. The preoperative diagnosis (table 1) was absent right connection (tricuspid atresia) in 10 patients, double inlet left ventricle in four patients, “criss-cross” heart in one patient (case 3), and a congenitally corrected transposition (discordant-discordant connections) with a straddling tricuspid valve in one patient (case 13). All patients had situs solitus of the atria; four patients had dextrocardia. Two patients (cases 10 and 16) were known to have mild mitral valve regurgitation before operation.

Eleven patients had had palliative procedures (nine left Blalock shunts, one right Blalock shunt, two central shunts, one Waterston shunt, one pulmonary artery banding, one enlargement of a ventricular septal defect (table 1).
Table 1  Patient data, diagnosis, previous palliation, and surgical procedure

<table>
<thead>
<tr>
<th>No</th>
<th>Age</th>
<th>Preoperative diagnosis</th>
<th>Previous palliation</th>
<th>Surgical procedure</th>
<th>Associated</th>
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<tbody>
<tr>
<td>1</td>
<td>4 yr 5 mth</td>
<td>DILV, VA disc, dextrocardia, outlet VSD</td>
<td>Nil</td>
<td>I</td>
<td>Direct TV closure</td>
</tr>
<tr>
<td>2</td>
<td>2 yr 5 mth</td>
<td>TA, VA conc, ASD II</td>
<td>Left Blalock</td>
<td>I</td>
<td>Direct ASD closure</td>
</tr>
<tr>
<td>3</td>
<td>4 yr 5 mth</td>
<td>AV conc, VA disc, (&quot;cross-cross&quot;) multiple muscular VSDs, ASD II</td>
<td>Nil</td>
<td>I</td>
<td>Direct TV closure</td>
</tr>
<tr>
<td>4</td>
<td>3 yr 11 mth</td>
<td>TA, VA disc, dextrocardia, ASD II, restrictive VSD</td>
<td>Nil</td>
<td>I</td>
<td>Direct ASD closure, enlargement VSD</td>
</tr>
<tr>
<td>5</td>
<td>35 yr</td>
<td>DILV, VA disc, outlet VSD</td>
<td>Nil</td>
<td>I</td>
<td>Direct TV closure</td>
</tr>
<tr>
<td>6</td>
<td>3 yr 3 mth</td>
<td>DILV, VA disc, dextrocardia, ASD II</td>
<td>Left Blalock</td>
<td>I</td>
<td>Direct ASD closure</td>
</tr>
<tr>
<td>7</td>
<td>2 yr 9 mth</td>
<td>TA, VA conc outlet VSD, ASD II</td>
<td>Left Blalock</td>
<td>I</td>
<td>Direct ASD closure</td>
</tr>
<tr>
<td>8</td>
<td>2 yr 9 mth</td>
<td>TA, VA conc, ASD II</td>
<td>Left Blalock</td>
<td>I</td>
<td>Direct ASD closure, patch enlargement PA</td>
</tr>
<tr>
<td>9</td>
<td>3 yr 4 mth</td>
<td>TA, VA disc, dextrocardia, ASD II, VSD, peripheral pulmonary stenosis</td>
<td>Left Blalock</td>
<td>I</td>
<td>Direct ASD closure, patch enlargement VSD</td>
</tr>
<tr>
<td>10</td>
<td>15 mth</td>
<td>DILV, VA disc, ASD II, restrictive VSD, mild MR</td>
<td>Banding</td>
<td>I</td>
<td>Direct ASD closure</td>
</tr>
<tr>
<td>11</td>
<td>4 yr 10 mth</td>
<td>TA, VA conc, ASD II</td>
<td>Right and left Blalock</td>
<td>V</td>
<td>Direct ASD closure, patch closure VSD</td>
</tr>
<tr>
<td>12</td>
<td>5 mth</td>
<td>TA, VA conc, ASD II, muscular VSD</td>
<td>Nil</td>
<td>II</td>
<td>Direct ASD closure, patch closure VSD</td>
</tr>
<tr>
<td>13</td>
<td>3 yr 10 mth</td>
<td>AV disc, VA disc, straddling TV, ASD II, perimembranous inlet VSD</td>
<td>Left Blalock</td>
<td>II</td>
<td>Direct ASD closure</td>
</tr>
<tr>
<td>14</td>
<td>1 yr 9 mth</td>
<td>TA, VA conc, ASD II, pulmonary atresia</td>
<td>Waterston</td>
<td>II</td>
<td>Direct ASD closure, patch closure VSD</td>
</tr>
<tr>
<td>15</td>
<td>5 yr 9 mth</td>
<td>TA, VA conc, ASD II</td>
<td>Left Blalock, central shunt</td>
<td>V</td>
<td>Patch/direct closure VSD, direct closure ASD</td>
</tr>
<tr>
<td>16</td>
<td>11 yr 3 mth</td>
<td>TA, VA conc, ASD II, muscular VSDs, mild MR</td>
<td>Left Blalock, central shunt, VSD enlargement</td>
<td>V</td>
<td>Patch/direct closure VSD, direct closure ASD</td>
</tr>
</tbody>
</table>

ASD II, secundum atrial septal defect; AV, atrioventricular; conc, concordance; disc, discordance; DILV, double inlet left ventricle; MR, mitral regurgitation; PA, pulmonary artery; TA, tricuspid atresia; TV, tricuspid valve; VA, ventriculoarterial; VSD, ventricular septal defect; Fontan procedures: I = direct atrio pulmonary anastomosis; II = total cavopulmonary connection; III = modified Kreutzer procedure; IV = valved (homograft) atrio pulmonary connection; V = valved (homograft) atrioventricular connection.

OPERATION
The surgical techniques used to achieve systemic venous to pulmonary artery connections (Fontan-type procedures) were (a) direct atrio pulmonary anastomosis (retroaortic) in eight patients, (b) total cavopulmonary connection13 by use of a prosthetic patch (three patients), (c) a Kreutzer procedure (right atrial appendage to main pulmonary artery connection incorporating the pulmonary valve) in one patient, (d) valved atrio pulmonary connection (homograft conduit) in one patient with tricuspid atresia and ventricular to arterial concordance (table 1). Secundum type atrial septal defects in 10 patients with tricuspid atresia were closed by means of a double layer of running sutures in nine patients. The defect was left open in one patient who underwent an operation for total cavopulmonary connection (case 2). Eight patients with tricuspid atresia had concordant ventricular to arterial connections. Three of these underwent an operation to construct a valved atrioventricular connection; this required closure of ventricular septal defect(s) in two (cases 12 and 16). Enlargement of a restrictive ventricular septal defect was required in one (case 4) of two patients with ventriculoarterial discordance. All four patients with double inlet left ventricle had ventriculoarterial discordance. Three of these underwent a direct atrio pulmonary anastomosis. The tricuspid valve was closed with a double layer of interrupted mattress sutures in two patients with an intact atrial septum (cases 1 and 5) and a pericardial patch was used to close both the tricuspid valve and the secundum atrial septal defect in one (case 10). This latter patient also required enlargement of a restrictive ventricular septal defect because of ventriculoarterial discordance. One patient with double inlet left ventricle (case 6) underwent an operation to form a total cavopulmonary connection; the atrial septal defect was left open.

One patient with a preoperative diagnosis of 'cross-cross' heart (case 3) underwent direct atrio pulmonary anastomosis with direct closure of both the tricuspid valve and the atrial septal defect. The patient with congenitally corrected transposition and a straddling tricuspid valve (case 13) underwent a total cavopulmonary anastomosis, without closure of the atrial septal defect.

ECHOCARDIOGRAPHY
Intraoperative epicardial studies were performed with a Toshiba SSH 65 or a Toshiba SSH 160 A ultrasound system in all 16 patients before and after cardiopulmonary bypass. The scanning equipment consisted of multiple standard precordial transducers: a 5 MHz transducer for high resolution cross sectional imaging plus a 3-75 MHz transducer for colour flow mapping and pulsed wave Doppler investigations, and in two patients a 2-5 MHz continuous wave Doppler duplex probe. The probes and wires were packed in sterile tube-shaped plastic bags after about 5 ml of sterile ultrasound coupling gel had been applied to the tip of the transducer. After packing, the probes were passed into the operative field where they remained during the entire operation.

Studies were performed either by a paediatric cardiologist or the cardiac surgeon and were entirely recorded on video tape to allow subsequent off line interpretation. The studies before bypass lasted about 5 minutes and those after bypass about 10 minutes. The studies were interpreted on line and the find-
ings were discussed. Immediately after com-
pletion further off line analysis was carried out
in the echocardiography laboratory.

Pre-bypass studies were performed after
mean sternotomy and pericardiectomy.
Warm saline was poured into the pericardial
cradle to improve contact between the epicar-
dium and the transducer and to reduce
mechanical irritation of the heart. Cross sec-
tional imaging was performed first. Results
were correlated with the preoperative findings
and with the findings at surgical inspection.
Then haemodynamic function was assessed by
colour flow mapping of the entire heart. These
morphological and haemodynamic ultrasound
findings served as a reference for the sub-
sequent studies after bypass.

Post-bypass studies were performed after
the removal of all cannulas for cardiopulmo-
ary bypass, because these may cause
unpredictable flow patterns, and as soon as
haemodynamic function was relatively stable.
Cross sectional imaging was used to assess the
surgical repair and together with M mode
tracings to monitor ventricular function.

Post-bypass flow mapping of the entire heart and
the Fontan circulation was used to detect any
flow obstructions across the anastomoses,
residual intracardiac shunting, incompetence of
atrioventricular valves, or ventricular out-
flow obstructions. Pulsed wave Doppler inves-
tigations were performed to trace and measure
flow velocities across the Fontan circulation.
Continuous wave Doppler was used to assess
blood flow through the ventricular septal
defect in two patients with ventriculoarterial
discordance. Contrast echocardiographic
studies, for the exclusion of residual
intracardiac shunting, were performed to con-
firm the findings at colour flow mapping.
Routine 2–5 ml of hand-agitated patient’s
blood was used as the contrast medium. This
was injected via a right atrial line while a
modified four chamber view was scanned from
the mid-portion of the right ventricle.

Results

STUDIES BEFORE BYPASS

A combination of high resolution cross sec-
tional echocardiographic imaging and colour flow
mapping confirmed the preoperative diagnosis in
11 of the 16 patients. The diagnosis was refined in
four patients (25%), and this influenced sur-
gical management in two (12%) (table 2). In
one of these patients (case 3) both atrioven-
tricular valves and their tensor apparatus were
shown to be entirely connected to the left
ventricle, changing the preoperative diagnosis
of "criss-cross" heart to double inlet left ven-
tricle. This new finding was, however, of no
surgical relevance. In one patient (case 7) with a
seconund type atrial septal defect an additional
low posterior fenestrated defect was detected.
In two patients (cases 11 and 16) with ven-
triculoarterial concordance epicardial cross
sectional imaging clearly showed a right ven-
tricular chamber of moderate size and good
function plus the absence of any valvar or
subvalvar obstruction. This information, in
both patients scheduled for construction of a
direct atrio pulmonary connection, allowed the
outlet chamber to be incorporated into the
Fontan circulation.

The information obtained by cross sectional
imaging before bypass was verified at surgical
inspection whenever feasible, and was found to
be exact and complete in 15 out of 16 patients.
In one patient with multiple muscular ven-
tricular septal defects (case 16) the epicardial
study before bypass showed only one large
muscular defect and did not identify the
additional defects. These were only identified at
surgical inspection after the muscular obstruct-
ion between the trabecular and outlet portions
of the right ventricle had been relieved. Colour
flow mapping before bypass allowed assessment
of haemodynamic function immediately before
the repair and, even more importantly, served
as the reference for interpretation of the sub-
sequent study after bypass.

STUDIES AFTER BYPASS

Table 3 lists the residual lesions identified and
their surgical consequences.

Atrial septal defects

After repair the perfect closure of atrial septal
defects was assessed by colour flow mapping
along a series of foreshortened four chamber
views from the right ventricular and right atrial
epicardium. A residual defect at the postero-
inferior border of the surgical closure site
(direct suture) was detected in one patient (case
7; table 2) in whom an additional low posterior
fenestrated defect was found before bypass.
Colour flow mapping showed its precise site and
the restrictive flow pattern of the continuous
right-to-left shunt. Residual shunting was
reconfirmed by contrast injection into the right
atrial line. Immediate revision during a second
period of bypass effected closure of the defect;
this was confirmed by colour flow mapping and a
contrast study (fig 1).

Ventriculoatrial communications

Colour flow mapping studies after bypass
showed a residual ventriculoatrial communica-
tion in one patient (case 5). A high velocity jet

<table>
<thead>
<tr>
<th>No</th>
<th>Preoperative</th>
<th>Study diagnosis before bypass</th>
<th>Influence on surgical management</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Criss cross heart</td>
<td>Double inlet left ventricle</td>
<td>No influence</td>
</tr>
<tr>
<td>7</td>
<td>Seconund ASD</td>
<td>Additional low posterior fenestrated ASD</td>
<td>No influence</td>
</tr>
<tr>
<td>11</td>
<td>Size and morphology of RV chamber unknown, intact IVS</td>
<td>RV of good size, no infundibular stenosis, normal PV</td>
<td>Valved atrioventricular connection</td>
</tr>
<tr>
<td>16</td>
<td>Size and morphology of RV chamber unknown</td>
<td>RV chamber of good size</td>
<td>Valved atrioventricular connection</td>
</tr>
</tbody>
</table>

ASD, atrial septal defect; IVS, interventricular septum; PV, pulmonary valve; RV, right ventricle.
Studies after bypass were limited by the altered geometry of the right atrium and the flow masking properties of the prosthetic material used in the repair. Contrast studies with injection into the right atrial line gave one false negative and one false positive result. Postoperative studies in the intensive care unit (contrast and oxygen saturations) showed residual shunting in one patient (false negative result after bypass), who subsequently underwent reoperation. At reoperation residual communications through the small trabeculations were found between the base of the right atrial appendage and the lines terminalis. The suture line of the patch was found to be intact.

Ventricular septal defects
In seven of the eight patients with ventriculoarterial discordance, colour flow mapping and pulsed and continuous wave Doppler studies after bypass showed an unobstructed ventricular outflow. In one patient the ventricular septal defect was found to be severely restrictive after bypass, whereas it had been shown to be unrestrictive both before operation and during studies before bypass. The maximal flow velocity measured by continuous wave Doppler was about 3.8 m/s, representing a pressure gradient of about 58 mm Hg. Immediate revision during a second period of bypass reduced the pressure gradient to 12 mm Hg.

Two of three patients with tricuspid atresia and ventriculoarterial concordance who had valved atrioventricular connections had patch closure of a ventricular septal defect. In one of these patients (case 16) additional muscular defects were found at surgical inspection and subsequently closed. The cross-sectional imaging study after bypass showed a small residual muscular defect. Off-line analysis of the study after bypass showed systolic left-to-right shunting and diastolic right-to-left shunting (fig 2) caused by raised right atrial and ventricular pressures.

Fontan circulation
Cross-sectional imaging did not show any anatomical obstruction to the pulmonary artery flow in 14 of 15 patients with satisfactory studies. In one patient (case 14) the study was incomplete after total cavopulmonary connection. Evidence of homograft valve closure was found in all three patients with an atrioventricular connection (cases 11, 12, and 16) and pulmonary valve closure in the patient with a Kreutzer procedure (case 7). The valve leaflets originating from the site of primary closure of the right atrioventricular valve was shown to reach far into the cavity of the right atrium. Immediate revision during a second period of bypass (pericardial patch closure) achieved perfect closure of the tricuspid valve. In the remaining three patients who underwent closure of a right sided atrioventricular valve colour flow mapping excluded any residual communication; this was reconfirmed by contrast studies (left atrial injection) in two.

Leakage from intra-atrial tunnels
In three patients a total cavopulmonary connection was created. Cross-sectional imaging after bypass showed the course of the tunnel, both venae cavae, and the anastomoses with the pulmonary artery system in two of the three patients. The colour flow mapping studies that were used to exclude residual shunting were judged to be satisfactory in only one patient.

Table 3

<table>
<thead>
<tr>
<th>No</th>
<th>Diagnosis</th>
<th>Surgical procedure</th>
<th>Residual lesion</th>
<th>Immediate revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>DILV, AV disc, unrestrictive VSD</td>
<td>Atrioluminaly conn, direct closure of TV</td>
<td>Venticuloarterial shunt, restrictive VSD</td>
<td>Patch closure TV, VSD enlargement</td>
</tr>
<tr>
<td>7</td>
<td>TA, VA conc, VSD, ASD II,</td>
<td>Modified Kreutzer, direct suture ASD</td>
<td>Venticuloarterial shunt at posteroinferior border</td>
<td>Re-closure</td>
</tr>
<tr>
<td></td>
<td>additional fenestrated ASD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>DILV, VA disc, ASD II, restrictive VSD, mild MR</td>
<td>Atrioluminaly conn, single patch TV, ASD, enlargement VSD</td>
<td>Residual interarterial shunt ASD</td>
<td>MR (increased)</td>
</tr>
<tr>
<td>15</td>
<td>TA, VA conc, ASD II, VSD</td>
<td>Atrioluminaly conn, direct suture ASD</td>
<td>Compression of left pulmonary artery</td>
<td>No</td>
</tr>
<tr>
<td>16</td>
<td>TA, VA conc, ASD II, muscular VSDs, mild MR</td>
<td>Atrioluminaly conn, direct closure ASD, patch closure large VSD, direct suture apical VSD</td>
<td>Residual muscular VSD, MR</td>
<td>Patch enlargement of bifurcation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DILV, double inlet ventricle of left ventricular morphology; TA, tricuspid atresia; ASD II, secundum type atrial septal defect; VA, ventriculoarterial; conc, concordance; disc, discordance; VSD, ventricular septal defect; TV, tricuspid valve; conn, connection; MR, mitral regurgitation.
Residual interventricular atresia, (encoded in LV, ventriculoarterial concordance, mid-diastolic blue) frame flow velocities occurred during late diastole and of 0-6 and 0-9 m/s during ventricular systole, indicating the contribution of the right ventricle to pulmonary blood flow. In the third patient with a valved atrioventricular connection (case 16) no ventricular augmentation was noted.

Mild mitral valve regurgitation
Mild mitral valve regurgitation was shown by colour flow mapping in two patients immediately after bypass. One patient (case 10) showed atrioventricular dissociation, necessitating epicardial pacing. The regurgitant jet was considerably larger than that shown during the study before bypass. In the second patient (case 16) the severity of mitral regurgitation was judged to be unchanged.

Ventricular function
Left ventricular function was assessed before and after bypass by a series of short axis scans through the left ventricle. No regional wall motion abnormalities were noted in any patient and ventricular function was unchanged compared with the studies before bypass. In four patients short axis scans were used to monitor volume replacement and ventricular filling while the patient was weaned from cardiopulmonary bypass. In a further two patients the studies helped to determine the dosage of inotropic support.

Complications
Complications induced by direct contact epicardial imaging, apart from occasional episodes of self terminating short runs of ventricular extrasystoles (maximum five in succession), were not encountered. Medical treatment or electrical cardioversion were never required. Sterility was preserved by packing the probes into long sterile plastic bags. No episode of endocarditis, pericarditis, or mediastinitis was reported during the study period.

Discussion
We studied the impact of intraoperative echocardiography in patients undergoing a Fontan-type procedure on perioperative surgical management.

Cross sectional imaging before bypass allowed detailed insights into the individual intracardiac morphology and contributed to surgical management in 12% of the patients. In one case the diagnosis before bypass was incomplete because additional muscular ventricular septal defects were not shown; turbulent flow in the entire small right ventricular cavity prevented the recognition of multiple individual jets by colour flow mapping.
Ultrasound studies after bypass proved to be a valuable technique for the assessment of the surgical repair performed, for monitoring left ventricular filling and function, and for the exclusion of residual haemodynamic lesions. The modern range of Doppler ultrasound techniques, in particular colour flow mapping, are sensitive methods for the detection of abnormal intracardiac flow patterns. The use of these techniques immediately after bypass can detect even slight flow abnormalities. In most patients undergoing total correction of congenital heart disease these minimal flow disturbances are not of surgical importance, whereas when the Fontan operation or one of its modifications is performed in patients with complex intracardiac anatomy or in younger patients, even small residual lesions can be clinically important. The immediate detection of these lesions and the subsequent repair during the same operation can improve the early surgical results.

Colour flow mapping allows the detection or definite exclusion of residual intracardiac shunting in most patients. The technique not only shows the existence of residual shunting but also defines the site of origin, which is impossible by any other technique. But the presence of prosthetic material used in the repair causes flow masking. After the creation of a total cavopulmonary connection both the change of the geometry of the right atrium and the use of prosthetic material precluded reliable colour flow mapping studies performed to exclude residual shunting in two of three patients. Thus after bypass the exclusion of leakage from the intra-atrial tunnel relied entirely on contrast studies. In retrospect we believe that one false positive contrast finding was related to the position of the right atrial line outside the tunnel; because there was an atrial septal defect the line was in what was functionally a pulmonary venous atrium. Sampling for oxygen saturations showed no desaturation and no further steps were taken. The second patient had only one contrast injection into a right atrial line, after which only a few microbubbles appeared in the left atrium after a considerable delay. The finding, though ambiguous, was interpreted as being caused by either pulmonary venous return of microbubbles or generation of an ultrasound contrast effect within the left atrium. A 24 hour postoperative study on the intensive care unit (contrast study and oxygen saturations) showed an important leakage. At reoperation residual communications were identified and subsequently closed. At present only the combination of colour flow mapping, multiple contrast studies, and sampling for oxygen saturations seems to be of value for the reliable exclusion of shunting after the creation of total cavopulmonary connections. Paediatric transoesophageal probes or "fingertip" probes that allow imaging and colour flow mapping studies from the lateral and posterior aspects of the right atrium may
solve some of the difficulties of obtaining complete information after this type of operation. To date, however, our experience with these techniques in the intraoperative monitoring of Fontan procedures is limited.

Assessment of blood flow patterns and flow velocities by pulsed wave Doppler allows the immediate exclusion of flow obstruction within the Fontan circulation. Immediately after a direct atroventricular connection was established pulsed wave Doppler echocardiography showed biphasic, bidirectional pulmonary blood flow. The biphasic nature of blood flow showed that both the atrial contraction and the left ventricular relaxation contributed to pulmonary blood flow in these patients. In two of three patients in whom the right ventricular chamber was incorporated into the Fontan circulation the pulmonary artery blood flow was greatest during ventricular systole. This finding showed right ventricular augmentation of pulmonary blood flow immediately after bypass, which may be beneficial in the early postoperative period, as was suggested in earlier studies. In the third patient, who had extensive resection of muscular trabeculations between the outlet and the trabecular portions of the right ventricle, pulsed wave Doppler examination did not show a ventricular contribution to pulmonary blood flow. Under these circumstances, and especially when the right ventricle is small, it may become functional some time after repair.

Intraoperative ultrasound provides the surgeon with detailed information on the immediate results of the repair because it can detect slight flow disturbances. It does not measure their haemodynamic importance, however, and this can be misinterpreted. After adequate volume replacement residual obstruction of the outflow tract or interventricular shunting are readily identified. Whereas their severity is often overestimated, the severity of atroventricular valve regurgitation is more likely to be underestimated when compared with follow-up studies. Findings immediately after bypass must be interpreted against the background of the complexity of the pre-existing anomaly and the method of repair. The surgeon must decide whether or not residual haemodynamic lesions need further revision during a second period of bypass. Three of the five patients with documented residual lesions had immediate revision and in all of them the surgical results were good. Studies after bypass and just before closure of the chest in 15 patients and after early reoperation in one patient showed good surgical results in 14. Precordial studies performed before hospital discharge and clinical follow up excluded significant residual lesions in all patients who had good surgical results as assessed by the final post-bypass study. One patient who required epicardial pacing for atrioventricular block and in whom mitral regurgitation was increased after the Fontan procedure died soon after operation; thus the early hospital mortality in this series was 6%.

In patients with a Fontan circulation even small residual lesions can be detrimental and thus require immediate surgical intervention. Intraoperative ultrasound is useful in assessing the quality of the Fontan repair and the need for reintervention. Its use may further reduce both the need for reoperation and early hospital mortality. In addition, the immediate detection and revision of residual lesions should improve functional results in the longer term.

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