# Abnormal left ventricular diastolic function at late follow-up after repair of total anomalous pulmonary venous drainage: The impact of altered ventricular loading in utero

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**Background:** Assessment of diastolic function has not been described after repair of total anomalous pulmonary venous drainage (TAPVD), but studies of exercise capacity demonstrate impaired performance in this population despite normal systolic function. We postulated that diastolic impairment might contribute to this finding.

**Methods:** We analyzed echocardiographic variables from 28 patients with repaired TAPVD and compared these with data from 32 healthy controls (normals) and 21 subjects with repaired transposition of the great arteries (TGA).

**Results:** Left ventricular (LV) end-diastolic volumes were smaller in the TAPVD group (median, 50 mL/m$^2$ compared with a median of 64 mL/m$^2$ in TGA and 67 mL/m$^2$ in normals; $P < .001$ in each case). LV diastolic function in the TAPVD group was impaired. Mitral early to late ratio was increased (median, 2.7 in TAPVD compared with a median of 1.9 in TGA [$P = .047$] and 2.1 in normals [$P = .021$]). LV isovolumic relaxation time was reduced (median, 50 milliseconds in TAPVD compared with a median of 70 milliseconds in both TGA and normals; $P < .001$ in each case). Late diastolic and systolic tissue Doppler velocities were lower and the E/e′ ratio was higher in the TAPVD group.

**Conclusions:** Patients with repaired TAPVD are usually regarded as having excellent outcomes, but the finding of LV diastolic dysfunction in this population warrants more careful follow-up. We postulate that the diastolic impairment in these patients is the result of relative unloading of the LV during early cardiac development. These findings may also have implications in considering therapeutic approaches for hypoplastic ventricles in attempting to achieve biventricular repair. (J Thorac Cardiovasc Surg 2014;148:238-44)

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Total anomalous pulmonary venous drainage (TAPVD) represents a heterogeneous group of congenital heart defects in which the pulmonary veins fail to connect with the left atrium during embryologic development, leading to the persistence of primitive connections.[1] The resulting drainage of all the pulmonary veins directly or indirectly to the right atrium is associated with smaller left atrial dimensions and altered left ventricular geometry at presentation.[2,3] Although operative mortality has decreased in the recent era, low cardiac output after surgery and a long postoperative length of stay are still frequently encountered. These have been attributed to lack or delayed adaptation of the left side of the heart to the postoperative increase in volume loading.[4,5]

Long-term follow-up of repaired TAPVD has been mainly limited to the assessment of systolic function, residual pulmonary venous stenosis, and pulmonary arterial hypertension. Good long-term outcomes are usually reported; however, studies of exercise capacity demonstrate impaired exercise performance, even in asymptomatic patients.[6,7] The assessment of diastolic function has not been described as part of the long-term follow-up of repaired TAPVD. We hypothesized that abnormalities of left ventricular diastolic function, documented in the early postoperative period, persist into adolescence and early adulthood; if so, this may be a contributing factor to the previously reported impairment in exercise capacity in these patients.

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**Abbreviations and Acronyms**

ASD = atrial septal defect
BSA = body surface area
DT = deceleration time
E/A = early to late
IVRT = isovolumic relaxation time
LA = left atrial
L/B = LV basal diameter ratio in diastole
LV = left ventricular
MV = mitral valve
RV = right ventricle
TAPVD = total anomalous pulmonary venous drainage
TDI = tissue Doppler
TGA = transposition of the great arteries
TV = tricuspid valve

## METHODS

### Patient Population

The study was approved by the Royal Children's Hospital Research and Ethics Committee. A total of 160 patients who had undergone repair of isolated TAPVD at our institution from 1978 until September 2009 were identified from the departmental database. *Isolated TAPVD* was defined as TAPVD with no associated cardiac defects, except for a patent foramen ovale, atrial septal defect, or ductus arteriosus. Among them, 20 were deceased. From the remaining 140 patients, those registered as having an address in Victoria, Australia, were identified; after excluding patients with residual pulmonary venous stenosis, those with significant extracardiac comorbidities, or those who were born prematurely, a cohort of 53 patients was identified for recruitment. Successful contact (via telephone call and/or recruitment letter) was obtained with 30 patients. Two declined to participate in the study and, therefore, 28 patients were enrolled. Assessment of these patients commenced in September 2009 and was completed after 15 months. All patients were asymptomatic, and none were taking regular medications at the time of the study.

### Controls

Data from TAPVD patients were compared with data from a group of age- and sex-matched children with normal hearts who had undergone investigation for murmurs and chest pain in our service during the same period of assessment of the TAPVD group (normals). To control for potential detrimental effects of cardiopulmonary bypass, data were also compared with data from a group of age- and sex-matched children with simple transposition of the great arteries (TGA) who had undergone an arterial switch operation in infancy and had echocardiograms performed on routine outpatient assessment during the study period. *Simple TGA* was defined as TGA with intact ventricular septum and no associated cardiac defects, except for a patent foramen ovale, atrial septal defect, or ductus arteriosus. None of the patients in the TGA group had significant residual lesions, including neoaorta and neopulmonar stenosis or regurgitation. None had wall motion abnormalities suggestive of regional ischemia, and there was no evidence of coronary abnormalities on previous assessments recorded in the medical records. Both cohorts of TAPVD and TGA had operations during the same time era: the TAPVD group from 1989 to 2002 (except from 1 patient who had surgery in 1985) and the TGA group from 1991 to 2003. Therefore, cardiopulmonary bypass and myocardial protection methods did not differ. The mean follow-ups from surgery until the analysis of the echocardiograms in both TAPVD and TGA cohorts were 11.9 ± 4.4 and 12.1 ± 3.7 years, respectively.

To further examine functional changes in the TAPVD group, tissue Doppler (TDI) assessment was performed and compared with published normative data.[8]

### Echocardiography

Measurements were performed using a Vivid 7 echocardiographic machine (GE Healthcare, Milwaukee, Wis) and stored digitally. Transducer frequency was chosen according to the patient size. Offline measurements were made by a single observer (L.M.) using Echo-PAC software (GE Healthcare). All measurements were averaged over 3 cardiac cycles and indexed for body surface area (BSA), as appropriate.

Pulse-wave Doppler interrogation of transmitral inflow included assessment of peak early filling (E) and late diastolic filling (A) velocities, and mitral deceleration time (DT), measured as the time from the peak E wave velocity to return to baseline. The left ventricular isovolumic relaxation time (IVRT) was assessed by placing the cursor of continuous-wave Doppler in the left ventricular outflow tract to simultaneously display the end of aortic ejection and the onset of mitral inflow.

TDI velocities during early diastole, atrial contraction, and ventricular systole were obtained at the basal lateral tricuspid annulus (RV e′, RV a′, RV s), interventricular septum (left ventricular [LV] sep e′, LV sep a′, LV sep s), and lateral mitral valve annulus (LV e′, LV a′, LV s). All measurements were performed according to the recommendations for the evaluation of left ventricular diastolic function from the American Society of Echocardiography.[9]

Morphometric evaluation of the left atrium and left ventricle was performed according to current guidelines.[10] Left ventricular (LV) volume was assessed in end diastole using the area-length (Bullet) method using the following formula: Volume = 5/6 × Short-Axis Basal Area × LV Length. The LV basal (at the level of the mitral valve leaflet tips) and midcavity (at the level of the papillary muscles) diameters were also measured in an apical 4-chamber view at end diastole. The LV length (apex to midpoint of the mitral valve plane) to LV basal diameter ratio in diastole (LV L/B ratio) was calculated. Fractional shortening was measured using M-mode. The left atrial (LA) area was measured by planimetry at ventricular end systole in an apical 4-chamber view. Additional parameters assessed in an apical 4-chamber view included mitral valve (MV) and tricuspid valve (TV) annulus size and right ventricular (RV) midcavity diameter (distance between the medial and lateral endocardial surfaces measured at the level of the LV papillary muscles at end diastole).

### Statistical Analysis

Comparisons between groups were performed using a nonparametric ($\chi^2$) equality of medians test because of a combination of relatively few in each of the TAPVD, TGA, and normals control groups and irregularly shaped distributions. A Pearson correlation was used to estimate correlations between different variables. Inferences for correlations were checked for consistency with those obtained from a nonparametric (Spearman rank correlation) method. Because of the correlated nature of the Doppler and morphometric echocardiographic measurements, together with the moderate number of comparisons performed, adjustment for multiple testing was not feasible. TDI velocities for TAPVD patients were compared with published normalized values[8] by converting velocity values to age- and sex-adjusted z-scores. Inferences for mean z-scores were obtained using standard single-sample estimation of the mean, with $P$ values corresponding to a null hypothesis of 0 mean. Statistical analyses were performed using SPSS statistics package, version 19 (SPSS Inc, IBM Company, Chicago, Ill) and cross-checked using Stata, Release 11 (StataCorp, College Station, Tex).

**TABLE 1. Demographics and patient characteristics**

| Demographics | TAPVD (n = 28) | TGA (n = 21) | Normals (n = 32) |
|---|---|---|---|
| Age at examination, y | 12.2 ± 4.2 | 12.5 ± 3.7 | 13.7 ± 3.8 |
| Male/female ratio | 14:14 | 14:7 | 20:12 |
| BSA, $m^2$ | 1.3 ± 0.39 | 1.3 ± 0.37 | 1.5 ± 0.35 |
| Heart rate, bpm | 72.2 ± 9.7 | 68.8 ± 10.9 | 67.4 ± 6.9 |
| Age at surgery, mo | 2.9 ± 5 | 0.3 ± 0.3 | NA |
| Bypass time, min | 87 ± 29 | 170 ± 50 | NA |
| Obstructed | 82.9 ± 5.8 | NA | NA |
| Unobstructed | 91.2 ± 9.5 | NA | NA |
| Crossclamp time, min | 47 ± 18 | 93 ± 28 | NA |
| Circulatory arrest, no. | 6 | 4 | NA |

Values represent mean ± SD. *TAPVD*, Total anomalous pulmonary venous drainage; *TGA*, transposition of the great arteries; *BSA*, body surface area; *bpm*, beats per minute; *NA*, not applicable.

## RESULTS

Baseline characteristics for the 3 groups are shown in Table 1. There were 28 patients in the TAPVD group, 32 normals, and 21 patients in the TGA group. The different morphologic subgroups of TAPVD are outlined. There were 12 patients with obstructed pulmonary venous drainage at presentation, and 4 needed emergency surgery within the first 48 hours of life. The mean age of surgery for the TAPVD group was 2.9 ± 5 months (0.8 ± 1.7 months for those with obstructed TAPVD and 4.7 ± 5.9 months for the unobstructed subgroup).

The 3 groups were similar regarding age, BSA, and heart rate at the time of the echocardiogram.

### Chamber Sizes and Geometry

Results of morphometric analysis are shown in Table 2, with all measurements indexed to BSA. The LA areas did not differ substantially between the 3 groups. In contrast, the LV volume calculated by the area-length method was substantially lower in the TAPVD group when compared with both control groups (median, 50 $mL/m^2$ in TAPVD compared with medians of 64 $mL/m^2$ in TGA and 67 $mL/m^2$ in normals; $P < .001$ in each case). The LV L/B ratio was smaller in the TAPVD group when compared with normals (median, 1.7 vs 1.9; $P < .001$). The LV midcavity dimension was larger in TAPVD and TGA subjects compared with normals (median, 29 $mm/m^2$ in TAPVD and 31 $mm/m^2$ in TGA compared with a median of 26 $mm/m^2$ in normals; $P = .038$ in each case). There was some evidence of a difference in the LV L/B ratio between TGA and normals ($P = .016$). There were no substantial differences in the MV or TV annulus dimensions between the 3 groups.

### Doppler Analysis

Results of the Doppler analysis are shown in Table 2. The mitral valve E-wave velocity was higher in the TAPVD group when compared with normals (median, 114 vs 100 cm/s; $P = .041$). The early to late (E/A) ratio was higher in the TAPVD group when compared with both control groups (median, 2.7 in TAPVD compared with a median of 1.9 in TGA [$P = .047$] and a median of 2.1 in normals [$P = .021$]), with no substantial difference observed between the 2 control groups. The mitral valve DT was significantly shorter in the TAPVD group compared with both control groups (a median of 139 milliseconds in TAPVD compared with a median of 160 milliseconds in each of TGA and normals); however, these differences may be due to chance. The LV IVRT was also shorter in the TAPVD patients when compared with both control groups (a median of 50 milliseconds in TAPVD compared with a median of 70 milliseconds in each of TGA and normals; $P < .001$ in each case).

TDI z-scores are shown in Table 3. All RV velocities (s, e′, and a′) were substantially lower in the TAPVD group. Septal and LV lateral wall early diastolic velocities did not differ between the groups, but late diastolic and systolic velocities were lower in the TAPVD group. The E/e′ ratios using both septal and LV lateral wall early diastolic velocities were higher in the TAPVD group.

### Comparison Between Obstructed and Unobstructed TAPVD

To determine whether the significant changes previously identified were different in those presenting with obstructed pulmonary venous drainage, subgroup analysis was performed. None of the parameters analyzed showed a statistically significant difference. The LV end-diastolic volume indexed to BSA was 56 ± 8.3 $mL/m^2$ in the obstructed group and 60 ± 9.9 $mL/m^2$ in the unobstructed group ($P = .26$). DT was 136.3 ± 31.5 milliseconds in the obstructed group and 132.9 ± 32.4 milliseconds in the unobstructed group ($P = .78$), and IVRT was 52.8 ± 13.4 milliseconds in the obstructed group and 49.1 ± 9.6 milliseconds in the unobstructed group ($P = .40$), and E/A ratio was 2.7 ± 1 in the obstructed group and 3 ± 1.2 in the unobstructed group ($P = .45$).

### Correlations

We sought to evaluate the association between ventricular size and diastolic Doppler parameters. When combining the results from all 3 groups of subjects, the E/A ratio showed a weak, but significant, negative correlation with LV volume indexed to BSA ($r = -0.28$, $P = .011$; Figure 1, *A*). IVRT showed a weak, but significant, positive correlation with LV volume indexed to BSA ($r = -0.34$, $P = .002$; Figure 1, *B*).

## DISCUSSION

There are limited data available in the literature concerning long-term follow-up of repaired TAPVD. Most

**TABLE 2. Echocardiographic analysis**

| Variable | TAPVD (n = 28) | TGA (n = 21) | Normals (n = 32) | TAPVD vs TGA (*P* value)* | TAPVD vs normals (*P* value)* | TGA vs normals (*P* value)* |
|---|---|---|---|---|---|---|
| LA area, $cm^2/m^2$ | 9.3 (8.0-10.2) | 9.8 (8.1-10.7) | 9.2 (8.1-10) | .49 | 1.00 | .34 |
| LV volume (area-length), $mL/m^2$ | 50 (44-53.5) | 64 (56-72) | 67 (60.5-70.5) | **<.001** | **<.001** | .95 |
| LV length, $mm/m^2$ | 45.5 (38.5-54) | 51 (43-59) | 46 (42.5-50.5) | .56 | .65 | **.049** |
| LV sax area, $cm^2/m^2$ | 11.8 (11-12.9) | 11.6 (9.6-12.9) | 11.2 (9.9-12.1) | .87 | .20 | .40 |
| LV mid, $mm/m^2$ | 29 (24-32) | 31 (26-36) | 26 (24-30.5) | .22 | **.038** | **.038** |
| Ratio L/B | 1.7 (1.6-1.8) | 1.8 (1.6-1.8) | 1.9 (1.8-2.0) | .069 | **<.001** | **.016** |
| LV FS, % | 34 (31.5-37.5) | 33 (32-37) | 35 (33-39) | .56 | .94 | .26 |
| MV annulus, $mm/m^2$ | 18.3 (16.3-20.8) | 17.1 (15-20) | 17.2 (15.5-20.1) | .46 | .12 | .87 |
| TV annulus, $mm/m^2$ | 18.8 (16.8-22.1) | 18.3 (16.1-22.7) | 17.9 (16.4-20.8) | .87 | .60 | .69 |
| RV mid, $mm/m^2$ | 19 (16-23.5) | 21 (18-26) | 18.5 (16-22) | .32 | .97 | .34 |
| MV E wave, cm/s | 114 (101-127) | 100 (80-120) | 100 (86-110) | .080 | **.041** | .96 |
| MV A wave, cm/s | 42 (32.5-51.5) | 50 (45-58) | 48.5 (41-54.5) | .22 | .067 | .87 |
| MV E/A ratio | 2.7 (1.9-3.8) | 1.9 (1.6-1.4) | 2.1 (1.8-2.5) | **.047** | **.021** | .61 |
| MV DT, ms | 139 (122-163) | 160 (135-190) | 160 (150-168) | .51 | .067 | .23 |
| IVRT, ms | 50 (43.5-58.5) | 70 (60-79) | 70 (62.5-73.5) | **<.001** | **<.001** | .53 |
| TR Vmax, m/s | 2.1 (2.0-2.3) | 2.3 (2.1-2.5) | 2.0 (0.6-2.3) | .15 | .23 | **.004** |

Values represent medians (interquartile ranges). Bold indicates *P* values <.05. *TAPVD*, Total anomalous pulmonary venous drainage; *TGA*, transposition of the great arteries; *LA*, left atrium; *LV*, left ventricle; *LV sax area*, LV short-axis basal area; *LV mid*, LV midcavity diameter; *L/B ratio*, LV length to LV basal diameter ratio in diastole; *FS*, fractional shortening; *MV*, mitral valve; *TV*, tricuspid valve; *RV mid*, right ventricular midcavity dimension; *E wave*, early diastolic filling velocity; *A wave*, late diastolic filling velocity; *E/A ratio*, ratio between transmitral early (E) and late (A) filling velocities; *DT*, deceleration time; *IVRT*, isovolumic relaxation time; *TR*, tricuspid regurgitation; *Vmax*, peak velocity. *Test of equality of medians according to a nonparametric $\chi^2$ test.

publications focus on survival analysis, risk factors, and early postoperative complications.[11,12] In addition, controversy still exists regarding the development of the left atrium and ventricle after surgical repair. There is a general consensus that the left-sided structures are relatively small before surgery, which is likely to be because of unloading of the left ventricle during development in utero and in the early postnatal period.[2,13] Most studies support the idea that the left-sided structures regain their normal shape and size after surgical correction and normalization of the loading conditions.[14-16] However, these studies addressed early postoperative left ventricular volumes either immediately after or within days of surgery. One study assessed 5 patients with angiography after 1 to 2 years following TAPVD repair, and the left-sided structures were reported as being normal.[17] Assessment of the development of these structures at long-term follow-up has not been reported.

**TABLE 3. TDI z-scores**

| Variable | No. | Mean z-score (95% CI) | *P* value |
|---|---|---|---|
| RV s | 23 | −2.4 (−2.7 to −2.0) | **<.001** |
| RV e′ | 23 | −2.3 (−2.8 to −1.9) | **<.001** |
| RV a′ | 23 | −1.8 (−2.0 to −1.6) | **<.001** |
| LV sep s | 25 | −1.0 (−1.3 to −0.7) | **<.001** |
| LV sep e′ | 25 | −0.3 (−0.7 to 0.1) | .13 |
| LV sep a′ | 25 | −1.2 (−1.5 to −1.0) | **<.001** |
| LV sep E/e′ | 25 | 1.2 (0.7 to 1.8) | **<.001** |
| LV s | 25 | −0.9 (−1.2 to −0.6) | **<.001** |
| LV e′ | 25 | 0.1 (−0.4 to 0.6) | .64 |
| LV a′ | 25 | −1.6 (−1.8 to −1.3) | **<.001** |
| LV E/e′ | 25 | 0.6 (0.2 to 0.9) | **.005** |

Values represent means (95% CIs). Bold indicates *P* values <.05. *TDI*, Tissue Doppler; *CI*, confidence interval; *RV*, right ventricle; *s*, systolic TDI velocity; *e′*, early diastolic TDI velocity; *a′*, late diastolic TDI velocity; *LV*, left ventricle; *sep*, septal; *E/e′*, TDI e wave velocity.

Echocardiographic evaluation of these patients has concentrated mostly on the detection of pulmonary venous obstruction and systolic function, with no data regarding diastolic function.[18,19] As with previous reports, in our study, the fractional shortening was preserved in all the patients, with no difference between the groups (Table 2). Normal subjects were patients referred to the Cardiology Service for investigation and found to have structurally normal hearts (normals). To control for the potential deleterious effect of cardiopulmonary bypass in early infancy, we also used data from a group of patients who had undergone repair of isolated TGA.

## Chamber Sizes and Geometry

We found that the LV volume indexed to BSA was smaller in the TAPVD group when compared with both control groups, with no evidence for a difference between the TGA and the normals (Table 2). Furthermore, the LV assumed a more globular geometry, as evidenced by a smaller length to base ratio (L/B ratio) and greater midventricular diameter.

LA size was assessed using planimetered areas measured in apical 4-chamber view only. There was no evidence that the areas differed between the 3 groups. Although left atrial enlargement is recognized as one of the markers of long-standing diastolic dysfunction,[9] the presence of suture

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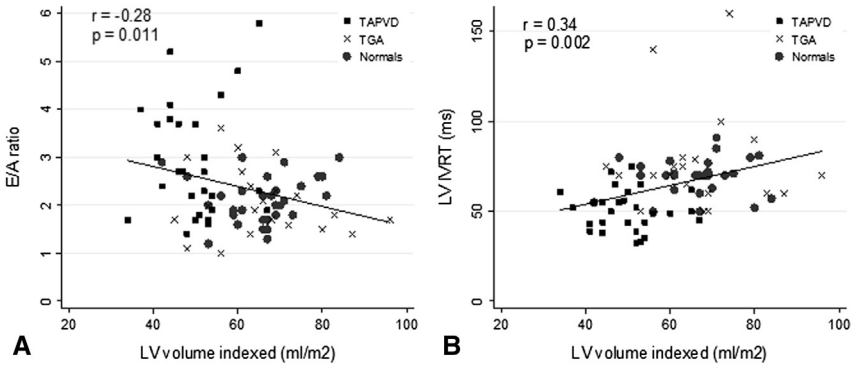


**FIGURE 1.** A, Correlation between transmitral early diastolic to late diastolic (*E/A*) filling velocity ratio and left ventricular (*LV*) volume. The LV volume indexed was indexed to body surface area. B, Correlation between isovolumic relaxation time (*IVRT*) and LV volume. *TAPVD*, Total anomalous pulmonary venous drainage; *TGA*, transposition of the great arteries.

lines and scars in the left atrium of repaired TAPVD patients could potentially modify changes in atrial size.

### Doppler Parameters

Left ventricular diastolic function in the TAPVD group was impaired with increased E/A ratio, shortened LV isovolumic relaxation times, and rapid mitral valve inflow deceleration time (Figure 2, *A*). We did not have sufficient pulmonary venous flow data in the control groups for direct comparison, but it was observed that all the TAPVD subjects had blunting of the pulmonary systolic wave, a relatively low systolic/diastolic ratio (0.52 ± 0.36), and elevated pulmonary venous A wave reversal velocity (32.8 ± 13 cm/s), with values exceeding the ones used as reference values in our laboratory[20] (Figure 2, *B*). These findings are consistent with reduced LV diastolic function and a restrictive filling pattern.

The IVRT and E/A ratio correlated with the LV volume, a trend that was also observed for the DT, although this relationship was not statistically significant. These findings support our hypothesis that underdevelopment of the LV and diastolic impairment are related. Because these abnormalities were not observed in the TGA group, these changes do not appear to be the result of cardiopulmonary bypass.

None of the patients had more than mild tricuspid regurgitation, and the velocities were within normal limits for all groups.

To clarify the mechanism of these changes in diastolic function, we also examined the myocardial motion using tissue Doppler imaging. Septal and LV-free wall systolic TDI z-scores were substantially lower compared with reference values. This could reflect a suboptimal systolic function or possibly reduced LV preload. Because of increased mitral E-wave velocities in the TAPVD group, the E/e′ ratio z-scores were increased, further

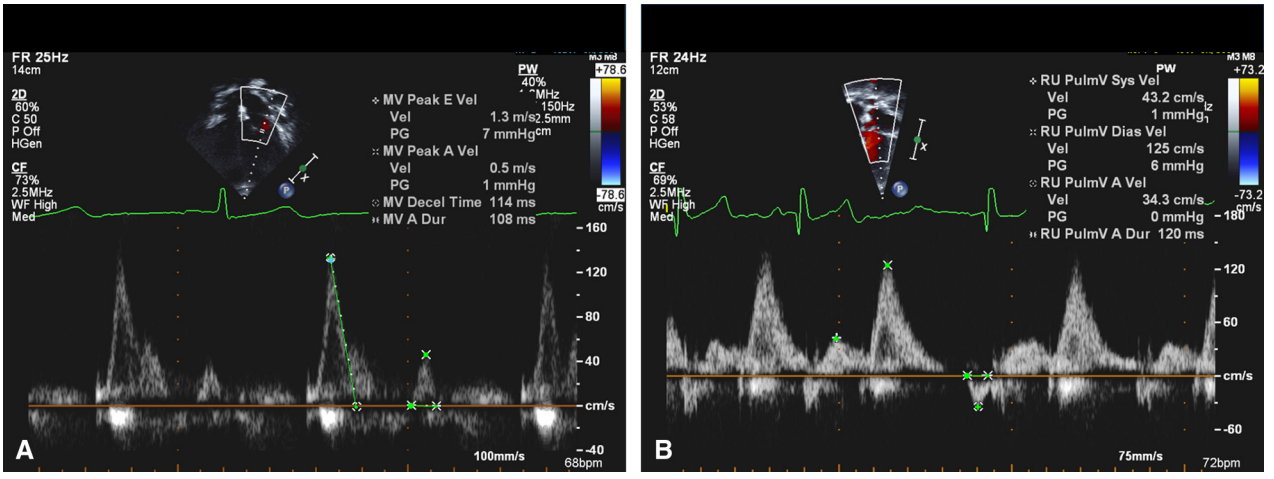


**FIGURE 2.** A, Typical mitral valve inflow pattern in a child with repaired total anomalous pulmonary venous drainage (TAPVD). Note rapid deceleration of early rapid filling. This patient also shows middiastolic mitral valve flow. B, Pulmonary venous flow pattern in a child after TAPVD repair, showing low-velocity systolic pulmonary venous flow (S wave) and increased diastolic flow velocity (D wave).

corroborating the evidence of diastolic impairment in the TAPVD group.

As for the right ventricle, subjective analysis of the systolic function was normal in all the patients, but both systolic and diastolic TDI z-scores were significantly lower in the TAPVD group. We are uncertain of the cause of this finding. Previous studies of the effect of device closure of atrial septal defects (ASDs) on right ventricular tissue Doppler velocities in children have observed higher systolic velocities, but normal diastolic velocities, preoperatively demonstrating the effect of long-term increased right ventricular preload; these velocities all normalize after transcatheter intervention.[21] It is possible that the effects we have observed are due to bypass-induced injury. There are several studies documenting reduced myocardial velocities for the right ventricular free wall after surgical ASD closure in the early postoperative period,[22,23] but these are generally thought to be transient changes.

### Altered Ventricular Preload in Utero

It is well recognized that alteration of fetal cardiac blood flow can have important implications for cardiac development.[24] For example, clipping of the right atrium in fetal chicks increases LV preload,[25] and left atrial reduction induces LV hypoplasia.[26] In addition to changing ventricular volumes, these studies also showed alteration of cardiomyocyte proliferation and expression of myosin. Interestingly, in our study, the mitral valve annulus size did not differ between the TAPVD group and controls. Although the use of the size of one cardiac structure, such as the mitral valve, may be a guide to adequacy of the left ventricle, it is not uncommon, however, to see disproportionate alterations in cardiac structures in congenital heart disease. Indeed, in the setting of hypoplastic left heart syndrome, not all of the left structures are symmetrically or uniformly reduced.[27] Indeed, in the echocardiographic scoring system for determining adequacy of the left ventricle, described by Rhodes and colleagues,[28] multiple LV structures are measured and used in the scoring algorithm.

Although in utero interventions to correct blood flow patterns are being explored in an attempt to ameliorate these changes, our findings may have important implications in considering the therapeutic options for hypoplastic ventricles; they undergo postnatal procedures, such as myocardial resection or stripping of endocardial fibroelastosis, with a goal of increasing the size of the ventricular cavity. Within our population of infants with relatively mild preoperative LV hypoplasia due to TAPVD, there is evidence of LV diastolic dysfunction at late follow-up. These findings are relevant to the decision-making process when the management of patients with significantly more hypoplastic ventricles is considered. We would hypothesize that the degree of diastolic dysfunction might be even greater in ventricles that are more significantly hypoplastic to start with and then subsequently undergo staged ventricular rehabilitation. Furthermore, although the diastolic impairment observed at this early age in our study would not be likely to cause clinical symptoms, these findings have important implications for adult life, with the potential for earlier development of heart failure with normal ejection fraction.

### Limitations

The retrospective aspects of this study did not allow us to perform a more complete assessment of diastolic function of the other subgroups. Although this may have provided additional mechanistic information, it does not negate the findings of abnormal diastolic function using standard and well-established Doppler measurements.

In both the TGA and normal groups, many patients had inadequate 2-chamber views to permit assessment of LV volume using the biplane Simpson method, mostly because of poorly visualized myocardium at end diastole or poor delineation of the blood-endocardium interface. Therefore, we chose to use the area-length method for calculation and comparison of the LV volumes between the groups, because all the patients had adequate short-axis basal and 4-chamber views.

The mean age at surgery for the TAPVD and TGA patients was different. We chose the TGA patients to allow a uniform population to control for the effect of bypass. The differences in diastolic function are evident, even though the arterial switch patients underwent operations that were performed at an earlier and more vulnerable stage of myocardial development. Despite this increased vulnerability, these patients did not display reduced diastolic function.

Our sample size of patients with repaired TAPVD is relatively small. However, we restricted our cohort to local patients who had neither postoperative complications nor more complex cardiac conditions in association with TAPVD. Despite these limitations, this remains one of the largest studies of repaired TAPVD and the only study assessing diastolic function.

## CONCLUSIONS

Patients with repaired TAPVD are usually regarded as having excellent outcomes after surgery, with many of them even being discharged from long-term follow-up. Our findings of left ventricular diastolic dysfunction in asymptomatic patients warrant a more careful approach. We postulate that the diastolic impairment in these patients is the result of altered ventricular loading in utero and in the early postnatal period. These findings may have important implications in considering postnatal management of hypoplastic ventricles and attempts to achieve biventricular repair.

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