Intra-Extracardiac Versus Extracardiac Fontan Modifications: Comparison of Early Outcomes

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Background. The intra-extracardiac (IE) Fontan modification has advantages over the lateral tunnel modification. A direct comparison of IE to the extracardiac (EC) modification so far has not been done. This study compared IE to EC Fontan with respect to early postoperative outcomes.

Methods. We retrospectively compared outcomes of the Fontan operation using the IE or EC conduit modification between January 2012 and December 2016. IE and EC groups were compared using univariate and multivariable regression analysis. To eliminate the confounding effects of fenestration, repeat intergroup comparison was performed after excluding nonfenestrated patients.

Results. There were 81 patients grouped according to Fontan modification into the IE group (n = 43) or EC group (n = 38). The Fontan was fenestrated in 100% of the IE group but in only 55% of the EC group ($p < 0.001$). Cardiopulmonary bypass time was shorter for the IE group (74 vs 103, $p < 0.001$) The IE patients had median cross-clamp time of 34 minutes, whereas only 2 patients in the EC group required cross-clamping (35 and 95 minutes; $p < 0.001$). The IE group had significantly shorter median duration of pleural effusion (8 days vs 11 days, $p = 0.007$) and hospital length of stay (9 days vs 13 days, $p = 0.001$) than the EC group. Multivariable linear regression analysis revealed that the IE modification was independently associated with reduced duration of pleural effusion ($p = 0.004$) and hospital length of stay ($p = 0.003$). Presence of any unfavorable hemodynamics on preoperative assessment was also associated with longer duration of pleural effusion and hospital length of stay for patients with fenestration.

Conclusions. The IE Fontan modification may be associated with reduced duration of postoperative pleural effusion and hospital length of stay compared with the EC modification.

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Fontan modifications have evolved over the last 4 decades, with each technique having its unique advantages and limitations [1]. The intra-extracardiac (IE) conduit modification combines the advantages of the extracardiac (EC) conduit and lateral tunnel techniques with regards to technical ease of fenestration, reproducibility, and reduced incidence of postoperative arrhythmias [1, 2]. A direct comparison between the IE and EC Fontan modifications, however, has so far not been done. We compared the IE Fontan modification to the EC modification with respect to early outcomes.

Patients and Methods

All patients who underwent the Fontan operation between January 2012 and December 2016 were retrospectively reviewed. The Children's National Medical Center Institutional Review Board approved the study, and waiver of informed consent was obtained.

Patients were divided into IE and EC groups according to the Fontan modification performed. Preoperative, operative, and early postoperative data were reviewed. The primary end points were duration of postoperative pleural effusion and hospital length of stay (LOS). Secondary outcomes included all other postoperative variables.

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Surgical Technique

The IE conduit Fontan modifications were performed as previously described on cardiopulmonary bypass (CPB), aortic cross-clamping, and cardioplegic arrest by using an oblique low right atriotomy to anastomose a beveled expanded polytetrafluoroethylene (ePTFE) conduit to the internal opening of the inferior vena cava (IVC) to the right atrium [1]. A 4-mm fenestration was created using an aortic punch in the intracardiac portion of the conduit before the right atriotomy was closed around the conduit. The conduit to cavopulmonary anastomosis was performed in a standard fashion.

The EC Fontan modifications were performed on CPB in a standard manner by an end-to-end anastomosis of an ePTFE conduit to the divided caudal end of the IVC. When performed, a fenestration was created using a 4-mm aortic punch along the left lateral aspect of the conduit just cranial to the IVC-conduit anastomosis, followed by anastomosis of the cardiac end of the divided IVC around the fenestration, as previously described [3]. Aortic cross-clamping and cardioplegic arrest was used only if concomitant intracardiac procedures were required. The conduit-to-cavopulmonary anastomosis was performed in a standard fashion. All patients had ring-supported ePTFE conduits of GORE-TEX (W. L. Gore & Associates, Flagstaff, AZ) or IMPRA (Bard Peripheral Vascular, Inc, Tempe, AZ), at the discretion of the operating surgeon.

There were no changes in the preoperative, perioperative, perfusion, and postoperative management of patients, irrespective of the Fontan modification used. Patients underwent IE Fontan or EC Fontan at the discretion of the operating surgeon.

Vasopressin was used in 5 of 43 patients in the IE group and in 2 of 38 patients in the EC group ($p = 0.43$). No patients were treated with angiotensin-converting enzyme inhibitors in the early postoperative period. Postoperative diuretic use was standard throughout the study duration. All patients were treated with intravenous loop diuretics during the first 48 hours postoperatively, which was subsequently transitioned to oral loop diuretics. Chlorothiazide and spironolactone was added when indicated. There were no dietary restrictions or modifications in the postoperative period. Chest tubes were removed once the daily drainage was less than 10 mL/kg.

Statistical Analysis

Preoperative, intraoperative, and postoperative data were compared between the two groups using the χ^2 test for categorical variables and the Mann-Whitney *U* test for continuous variables. Continuous data are reported as median and interquartile range (IQR) or mean ± SD. Statistically significant univariate variables were adjusted for using multivariable linear regression analysis to determine independent predictors of increased duration of pleural effusion and hospital LOS [4]. In designing the study, we had conducted power calculations and determined that a comparison of the two study groups would require a minimum sample size of 37 patients per group to achieve 80% power for detecting a 30% difference between IC and EC groups in patients having a long duration of pleural effusion exceeding 12 days based on χ^2 analysis (nQuery Advisor 7.0 software; Statistical Solutions, Cork, Ireland).

Multivariable regression models using backward selection to adjust for possible confounding [5] were constructed to identify variables independently associated with longer duration of pleural effusions and hospital LOS for the entire study cohort and for duration of pleural effusion and hospital LOS. The χ^2 analysis indicated a significant association between the type of Fontan modification and year of operation ($\chi^2 = 17.56$, $p = 0.002$) with a higher percentage of patients undergoing IE modification in 2012 and 2013 compared with a higher percentage of EC modifications more recently in 2015 and 2016 (Supplemental Table 1). Therefore, year of operation was included in the multivariable analyses to adjust for this possible confounding factor and to account for any learning curve artifacts when comparing IE and EC groups.

The six covariates analyzed were Fontan modification, presence of fenestration, presence of any unfavorable hemodynamics on the preoperative assessment (ventricular end-diastolic pressure [VEDP] > 12 mm Hg, mean pulmonary artery pressure [MPAP] > 15 mm Hg, pulmonary vascular resistance [PVR] > 2 Wood U/m^2, presence of moderate or greater atrioventricular valve regurgitation and presence of moderate or greater systemic ventricular dysfunction), CPB time, cross-clamp time, and year of operation.

Multivariable logistic regression using backward selection to adjust for possible confounding [5] was also performed and to identify independent predictors associated with patients above the third quartile for each outcome, which was more than 12 days for pleural effusion and more than 18 days for hospital LOS. As with the continuous outcomes, we tested the same six variables, including type of Fontan modification, use of fenestration, presence of unfavorable hemodynamics on the preoperative assessment, CPB time, cross-clamp time, and year of operation.

To minimize the possibility of confounding due to the differences in the rate of fenestration between the two groups, another analysis was performed based on only fenestrated IE versus EC patients. Because fenestration patency at discharge was significantly higher for the IE group (41 of 43 [95%]) than for the EC group (14 of 21 [66%]; $p = 0.003$), the six candidate variables tested in this model were Fontan modification, patency of fenestration at discharge, presence of any unfavorable hemodynamics on the preoperative assessment (VEDP > 12 mm Hg, MPAP > 15 mm Hg, PVR > 2 Wood U/m^2, presence of moderate or greater atrioventricular valve regurgitation and presence of moderate or greater systemic ventricular dysfunction), CPB time, cross-clamp time, and year of operation.

The association between the two end points (ie, duration of pleural effusion and LOS) was analyzed using the Spearman ρ correlation.

Adjusted odds ratios and 95% confidence intervals for significant independent predictors are reported. Statistical analyses were performed with Stata 15.0 software (StataCorp, College Station, TX). Statistical significance was set at two-sided p values of less than 0.05.

Results

A total of 81 patients underwent the Fontan operation (43 IE and 38 EC) during the study period. There were 2 operative deaths in the entire series, 1 in the IE group (multiorgan failure) and 1 in EC (postoperative low cardiac output requiring extracorporeal membrane oxygenation support and neurologic injury).

Univariate Analysis

COMPARISON OF ALL IE AND EC PATIENTS. The groups were comparable with respect to preoperative variables. All IE patients received a fenestration, whereas only 55% in the EC group were fenestrated ($p < 0.001$). CPB times were shorter for the IE group (median, 74 minutes; IQR, 65 to 90 minutes) than for the EC group (median, 103 minutes; IQR, 85 to 134 minutes; $p < 0.001$). The median cross-clamp time in IE patients was 34 minutes (IQR, 27 to 43 minutes), whereas only 2 patients in the EC group required cross-clamping of the aorta, for 35 and 95 minutes, respectively ($p < 0.001$). The conduit sizes were similar between the IE group (16.36 ± 0.97 mm) and the EC group (16.32 ± 0.93 mm; $p = 0.87$). The two groups were also comparable in fluid balance achieved within the first 24 hours after the operation (inclusive of intraoperative and postoperative fluid balance; $p = 0.103$), blood ($p = 0.371$) and blood product transfusion requirements. The postoperative ventilation time ($p = 0.38$) and intensive care unit (ICU) LOS ($p = 0.77$) were comparable. The IE group had significantly shorter median duration of pleural effusion of 8 days (IQR, 6 to 10 days) compared with 11 days (IQR, 7 to 20 days) in the EC group ($p = 0.007$) and shorter hospital LOS of 9 days (IQR, 7 to 12 days) compared with 13 days (IQR, 10 to 23 days) in the EC group ($p < 0.001$). Preoperative, perioperative, and early postoperative variables for all IE and EC patients are summarized in Table 1.

COMPARISON OF IE AND EC PATIENTS WITH FENESTRATION. To eliminate the confounding effect of fenestration on the duration of pleural effusion and hospital LOS, a repeat analysis was performed, comparing the EC and IE groups after excluding the patients who did not receive a fenestration.

Comparing 43 IE Fontan patients with 21 fenestrated EC patients revealed shorter median CPB time in the IE group (74 minutes; IQR, 65 to 90 minutes) than in the EC group (90 minutes; IQR, 84 to 115 minutes; $p < 0.001$). Fenestration patency at discharge was significantly higher for the IE group (41 [95%]) versus the EC group (14 [66%]; $p = 0.003$). The postoperative ventilation time was significantly shorter in the EC group (median, 12 hours; IQR, 9 to 30 hours) than in the EC group (median, 7 hours; IQR, 6 to 16 hours; $p = 0.04$). The IE group again had a significantly shorter duration of pleural effusion (median [IQR] IE group: 8 [6 to 10] days; EC group: 10 [8 to 20] days $p = 0.014$) and hospital LOS (median [IQR] IE group: 9 [7 to 12] days; EC group: 13 [9 to 24] days; $p = 0.011$). Results of the univariate analysis between IE and EC among patients with fenestration are summarized in Table 2.

Multivariable Analysis

DURATION OF PLEURAL EFFUSION: ALL PATIENTS. For the full cohort of 43 IE and 38 EC patients, we tested six candidate variables (Fontan modification, presence of fenestration, presence of any unfavorable hemodynamics on preoperative assessment [VEDP > 12 mm Hg, MPAP > 15 mm Hg, PVR > 2 Wood U/m^2, presence of moderate or greater atrioventricular valve regurgitation and presence of moderate or greater systemic ventricular dysfunction], cardiopulmonary bypass time, cross clamp time and year of surgery) based on duration of pleural effusion.

The multivariable linear regression analysis revealed that type of Fontan modification used was the only independent predictor of longer duration of pleural effusion ($p = 0.04$; Table 3). Multivariable linear modeling confirmed that patients undergoing EC modification are estimated to have prolonged pleural effusion by 4 days, independent of fenestration, length of CPB time, cross-clamp time, presence of any unfavorable hemodynamics on preoperative assessment, and year of operation (Fig 1).

The same six variables were analyzed by considering a cutoff for duration of pleural effusion at the upper quartile (>12 days) as a binary outcome, and the only significant independent predictor based on multivariable logistic regression was the Fontan modification, with the EC patients having an estimated odds of more than 12 days of pleural effusion, 5-times higher than IE patients (odds ratio, 5.0, 95% confidence interval, 1.8 to 15.5; $p = 0.003$; Fig 2). The other variables were not significantly related to duration of pleural effusion exceeding 12 days: presence of fenestration ($p = 0.847$), CPB time ($p = 0.847$), cross-clamp time ($p = 0.731$), presence of any unfavorable hemodynamics on preoperative assessment ($p = 0.584$), and year of operation ($p = 0.201$).

DURATION OF PLEURAL EFFUSION: PATIENTS WITH FENESTRATION. The multivariable linear regression analysis testing for the six covariates revealed that the independent predictors of longer duration of the pleural effusions were type of Fontan modification used (in favor of IE Fontan, $p = 0.011$) and presence of any unfavorable hemodynamics on preoperative assessment ($p = 0.044$; Table 3).

The multivariable linear modeling confirmed that among fenestrated patients, those undergoing EC modification are estimated to have prolonged pleural effusion by 4 days, independent of patency of the fenestration at discharge, CPB time, presence of any unfavorable

Table 1. Univariate Comparison Between Intra-Extracardiac and Extracardiac Fontan Patients

Variable[a]	Intra-Extracardiac (n = 43)	Extracardiac (n = 38)	*p* Value
Age, months	30 (24–37)	31 (26–39)	0.42
Weight, kg	11.9 (10.8–13.4)	11.8 (10.8–14.3)	0.81
Sex			
Male	27	23	0.83
Female	16	15	
Ventricular morphology			0.15
Right	24 (56)	15 (40)	
Left	7 (16)	13 (34)	
Indeterminate	12 (28)	10 (26)	
Ventricular end-diastolic pressure, mm Hg	11 (10–12)	10 (10–12)	0.52
Mean pulmonary artery pressure, mm Hg	14 (12–15)	14 (12–15)	0.91
Aortic saturation, %	86 (83–89)	84 (78–89)	0.22
Pulmonary vascular resistance, Wood U/m^2	1.6 (1.2–2.0)	1.3 (1.1–1.9)	0.34
Preoperative moderate or greater AVVR	2 (5)	1 (3)	1.00
Any unfavorable hemodynamics on preoperative assessment[b]	18 (42)	15 (40)	0.827
Cardiopulmonary bypass time, minutes	74 (65–90)	103 (85–134)	<0.001[b]
Cross-clamp time, minutes	34 (27–43)	0	<0.001[b]
Fenestration	43 (100)	21 (55)	<0.001[b]
Conduit size, mm	16.36 ± 0.97	16.32 ± 0.93	0.87
24-hour fluid balance, mL/kg	30 (2–58)	62 (10–103)	0.085
Vasopressin use	5 (12)	2 (5)	0.439
Pack red blood cells, mL/kg	10 (10–20)	10 (10–20)	0.507
Platelets, mL/kg	1.2 (1–1.5)	1.2 (1–1.5)	0.491
Cryoprecipitate, mL/kg	2.5 (1.8–3.2)	2.5 (2.0–3.3)	0.654
Fresh frozen plasma, mL/kg	8.1 (5.0–11.5)	10.0 (8.2–12.3)	0.156
Postoperative arrhythmias	15 (35)	18 (47)	0.26
Ventilation time, hours	12 (9–30)	11 (6–27)	0.38
Length of stay, days			
Intensive care unit, days	4 (3–6)	4 (2–8)	0.77
Postoperative hospital, days	9 (7–12)	13 (10–23)	<0.001[c]
Pleural effusion, days	8 (6–10)	11 (7–20)	0.007[c]
Mortality	1 (2)	1 (3)	1.00

[a] Continuous data are presented as the median (interquartile range) or mean ± SD. Categorical data are presented as number (%) of patients. [b] Includes the presence of one or more of the following: ventricular end diastolic pressure > 12 mm Hg, mean pulmonary artery pressure > 15 mm Hg, peripheral vascular resistance > 2 Wood U/m^2, presence of moderate or greater atrioventricular valve regurgitation (AVVR), and presence of moderate or greater systemic ventricular dysfunction [c] Statistically significant difference ($p < 0.05$) between intra-extracardiac and extracardiac groups.

hemodynamics on the preoperative assessment, and year of operation. In addition, those patients in whom any unfavorable hemodynamics are present on the preoperative assessment are expected to have 3 additional days of pleural effusion.

Analysis of the six candidate variables by considering a cutoff for duration of pleural effusion at the upper quartile (>12 days) as a binary outcome using multivariable logistic regression revealed that patients with the EC Fontan modification had an estimated odds of having duration of pleural effusion exceeding 12 days of almost 6-times higher than IE patients (odds ratio, 5.9, 95% confidence interval, 1.7 to 23.8; $p = 0.015$; Fig 2). Also, patients with presence of any unfavorable hemodynamics on the preoperative assessment are expected to have on average postoperative pleural effusion of 5 days longer compared with patients without unfavorable hemodynamics ($p = 0.022$). The other four variables were not significantly related to the duration of pleural effusion exceeding 12 days: patency of fenestration at discharge ($p = 0.450$), CPB time ($p = 0.990$), cross-clamp time ($p = 0.678$) and year of operation ($p = 0.444$).

POSTOPERATIVE HOSPITAL LOS: ALL PATIENTS. Multivariable linear regression analysis of factors associated with postoperative hospital LOS as a continuous variable indicated that only the type of Fontan (EC modification) was significantly associated with longer LOS ($p = 0.003$) independent of fenestration ($p = 0.441$), CPB time ($p = 0.840$), cross-clamp time ($p = 0.664$), presence of any unfavorable hemodynamics on preoperative assessment ($p = 0.786$), and the year of the operation ($p = 0.307$; Table 3).

Table 2. Univariate Comparison Between Intra-Extracardiac and Extracardiac Fontan Patients With Fenestration

Variable[a]	Intra-Extracardiac (n = 43)	Extracardiac (n = 21)	*p* Value
Age, months	30 (24–37)	32 (26–40)	0.26
Weight, kg	11.9 (10.8–13.4)	11.7 (10.1–14.2)	0.51
Sex			0.59
Male	27	11	
Female	16	10	
Ventricular morphology			0.15
Right	24 (56)	9 (43)	
Left	7 (16)	6 (29)	
Indeterminate	12 (28)	6 (29)	
Cardiopulmonary bypass time, minutes	74 (65–90)	90 (84–115)	<0.001[b]
Fenestration	43 (100)	21 (100)	1.00
Ventricular end-diastolic pressure, mm Hg	11 (10–12)	11 (10–12)	0.93
Mean pulmonary artery pressure, mm Hg	14 (12–15)	14 (12–16)	0.95
Aortic saturation, %	86 (83–89)	88 (84–90)	0.41
Peripheral vascular resistance, Wood U/m^2	1.6 (1.2–2.0)	1.3 (1.1–1.9)	0.24
Preoperative moderate or greater AVVR	2 (5)	0 (0)	1.00
Any unfavorable hemodynamics on preoperative assessment[c]	18 (42)	7 (33)	0.59
Cross-clamp time, minutes	34 (27–43)	0	<0.001[b]
Ventilation time, hours	12 (9–30)	7 (6–16)	0.04[b]
Length of stay, days			
Intensive care unit	4 (3–6)	3 (2–8)	0.30
Postoperative hospital	9 (7–12)	13 (9–24)	0.011[b]
Pleural effusion, days	8 (6–10)	10 (8–20)	0.014[b]
Fenestration patent at discharge	41 (95)	14 (66)	0.003[b]
Mortality	1 (2)	1 (5)	1.00

[a] Continuous data are presented as the median (interquartile range). Categorical data are presented as number (%) of patients. [b] Statistically significant difference ($p < 0.05$) between intra-extracardiac and extracardiac and groups. [c] Includes presence of one or more of the following: ventricular end diastolic pressure > 12 mm Hg, mean pulmonary artery pressure >15 mm Hg, peripheral vascular resistance > 2 Wood U/m^2, presence of moderate or greater atrioventricular valve regurgitation (AVVR), and presence of moderate or greater systemic ventricular dysfunction

The regression model indicated that patients having EC modification are expected to have a postoperative hospital stay 8 days longer than patients with IE modification, irrespective of the other variables (Fig 1).

POSTOPERATIVE HOSPITAL LOS: PATIENTS WITH FENESTRATION. After excluding nonfenestrated patients, multivariable linear regression analysis of factors associated with postoperative hospital LOS as a continuous variable indicated that the same two variables were identified as contributing to a prolonged hospital stay: EC modification ($p = 0.014$) and presence of any unfavorable hemodynamics on preoperative assessment ($p = 0.048$; Table 3).

The regression model indicated that patients with fenestration having EC modification are expected to be in the hospital postoperatively for 7 days longer than those having IE modification, and patients with any unfavorable hemodynamics on the preoperative assessment are expected to have a postoperative stay 5 days longer. The other variables tested were not significant: CPB time ($p = 0.815$), cross-clamp time ($p = 0.753$), patency of fenestration at discharge ($p = 0.523$), and year of the operation ($p = 0.103$; Table 3).

A strong positive correlation was observed between duration of pleural effusion and postoperative hospital LOS (Spearman ρ correlation = 0.88, $p < 0.001$; Fig 3).

Comment

Despite a paradigm shift of Fontan operation over 4 decades, early outcome in terms of duration of pleural effusion and hospital LOS continues to be long for patients after the Fontan operation [1, 6]. Routine incorporation of fenestration leads to reduction in the duration of pleural effusion and hospital LOS [7–9]. Technical challenges of fenestrating an EC conduit, unreliable postoperative fenestration patency, and improved overall outcomes of the Fontan operation have led to a trend toward selective use of fenestration [10]. Other measures, such as use of vasopressin in the postoperative period [11] and modified postoperative protocols, including diet, diuretic, and angiotensin-converting enzyme inhibitors [12] use, may reduce the duration of pleural effusions.

We have previously reported the IE modification of the Fontan operation that combines the advantages of the EC and lateral tunnel modifications by use of a conduit avoiding exposure of the atrium to chronic high pressure, ease of reliable fenestration, technical simplicity, and reproducibility, and use of a standard short oblique right atriotomy, avoiding extensive atrial suture lines. The crista terminalis and the eustachian ridge are well preserved, thereby preserving the electrophysiological pathways [1, 2]. In a previous comparison between IE

Table 3. Results of Multivariable Linear Regression Analysis

Variable	Duration of Pleural Effusion: All Patients p Value	Duration of Pleural Effusion: Patients With Fenestration p Value	Hospital Length of Stay: All Patients p Value	Hospital Length of Stay: Patients With Fenestration p Value
Type of Fontan (IE vs EC)	0.004[a]	0.011[a]	0.003[a]	0.014[a]
Fenestration vs no fenestration	0.894	NA	0.441	NA
Fenestration at discharge (patent vs nonpatent)	NA	0.902	NA	0.523
Cardiopulmonary bypass time	0.187	0.689	0.840	0.815
Cross-clamp time	0.376	0.475	0.664	0.753
Unfavorable hemodynamics on preoperative assessment[b]	0.542	0.044[a]	0.786	0.048[a]
Year of operation	0.085	0.294	0.307	0.103

[a] Variables independently associated with increased duration of pleural effusion. [b] Includes presence of one or more of the following: ventricular end diastolic pressure > 12 mm Hg, mean pulmonary artery pressure > 15 mm Hg, peripheral vascular resistance > 2 Wood U/m^2, presence of moderate or greater atrioventricular valve regurgitation, and presence of moderate or greater systemic ventricular dysfunction.

EC = extracardiac; IE = intra-extracardiac; NA = not applicable.

Fontan and lateral tunnel Fontan, the IE modification was superior in intermediate-term freedom from arrhythmias, comparable to the lateral tunnel modification [2]. This is a first study directly comparing IE to the EC modification.

The IE modification is a technically simple and reproducible procedure. It is also easy to fenestrate by a simple punch hole in the intracardiac portion of the conduit, leading to 100% use of the fenestration in this method.

Our study shows a significant effect of the use of IE modification on the duration of pleural effusion and hospital LOS. Although the presence of a fenestration may have a contributory effect upon the outcomes, our analysis shows that the IE Fontan modification independently led to shorter duration of pleural effusion and hospital LOS. This benefit was seen in both the overall analysis and the subgroup analysis of patients who received a fenestration.

A significant difference was noted in the patency of the fenestration at discharge between the IE and the EC groups: only 66% of fenestrations were patent at discharge with the EC modifications, whereas 95% of the fenestrations with the IE modifications were patent at discharge. Although this may account for some of the differences noted, multivariable analysis showed that the Fontan modification and not patency of the fenestration was independently associated with shorter duration of pleural effusion pointing. This indicates toward advantages of the IE modification beyond a higher patency rate of the fenestration.

Univariate analysis showed the CPB times were also shorter for the IE modification; however, multivariable analysis showed longer CPB times were not associated with longer duration of pleural effusions or hospital LOS. Shorter CPB times required for the IE modification are

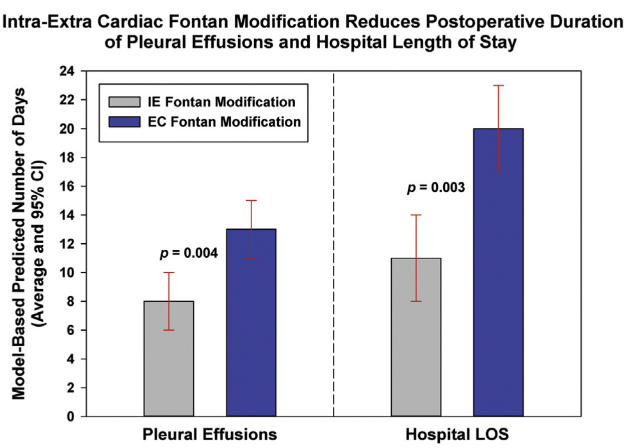

Fig 1. Multivariable linear regression model–based prediction shows reduced duration of pleural effusion and hospital length of stay (LOS) with the intra-extracardiac (IE) Fontan compared with the extracardiac (EC) Fontan modification. (CI = confidence interval.)

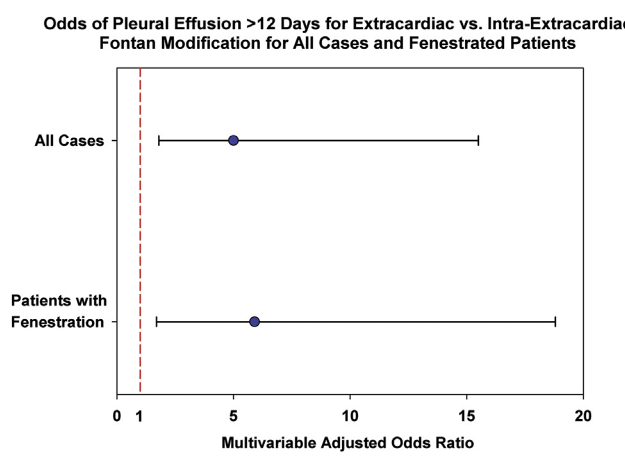

Fig 2. Dot-and-whisker plot of the multivariable logistic regression analysis depicting odds ratios (blue dots) and confidence intervals (whiskers) of pleural effusion exceeding 12 days for extracardiac versus intra-extracardiac Fontan modification for all patients (p = 0.003) and patients with fenestration (p = 0.015).

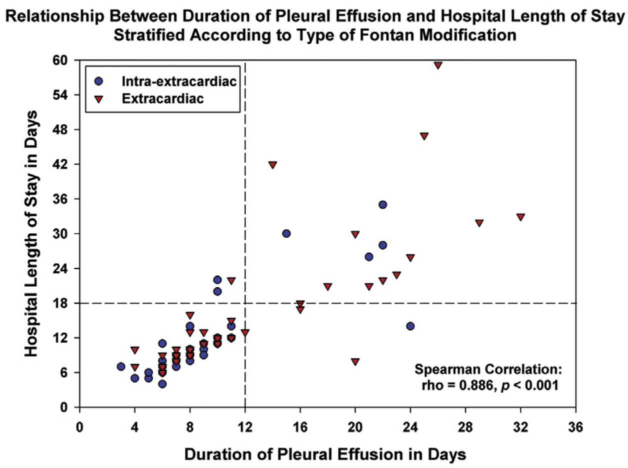

Fig 3. Positive correlation is shown between duration of pleural effusion (x-axis) and hospital length of stay (y-axis). The horizontal and vertical dotted lines represent third quartile for hospital length of stay (18 days) and duration of pleural effusion (12 days), respectively.

indicative of the ease of anastomosis, simplicity, and reproducibility of this technique.

One speculation for the better performance of the IE modification could be due to an overall lower energy loss across a much wider intraatrial inferior caval anastomosis to a beveled ePTFE conduit, compared with the end-to-end IVC-to-conduit anastomosis in the EC modification, leads to an overall more efficient Fontan circulation. Computation fluid dynamic studies comparing energy loss between the two modifications may provide further answers.

Our study also revealed longer duration of pleural effusion and hospital LOS in the patients with fenestration and presence of any preoperative unfavorable Fontan hemodynamics (VEDP $>$ 12 mm Hg, MPAP $>$ 15 mm Hg, PVR $>$ 2 Wood U/m^2, presence of moderate or greater atrioventricular valve regurgitation, and presence of moderate or greater systemic ventricular dysfunction). Poor hemodynamics is a risk factor known to be significant since the inception of the Fontan operation [13] and, although somewhat mitigated, is still relevant [14]. Our data show that in the presence any unfavorable hemodynamics on preoperative evaluation, especially when considering a fenestrated Fontan, adopting the IE modification may lead to significant effect on reducing the duration of pleural effusions and hospital LOS.

Our study has the drawback of being a retrospective analysis of a single-center's practice. The patients were not randomized to the IE or EC Fontan modification, which was chosen at the discretion of the operating surgeon. This study only looks at immediate postoperative outcomes, and long-term follow up is needed to compare the two techniques. With limited patient numbers, we carefully selected covariates for the multivariable regression model based on the outcomes of the univariate analysis and clinical relevance; however, overfitting the model remains a risk. A randomized controlled trial with good statistical power is needed to validate the results of this single-center retrospective study.

This is a first report of a direct comparison between IE and EC modifications, which shows a reduction in the duration of pleural effusion and hospital LOS with use of the IE modification. Longer-term outcomes of the IE and EC modification need to be compared in future studies.

Conclusion

The IE Fontan modification may be associated with reduced duration of postoperative pleural effusion and hospital LOS compared with the EC modification. Longer-term outcome studies are needed to determine the optimal Fontan modification.

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