Long-term Outcomes of the Fontan Procedure

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Fontan procedure

An ‘excellent palliative’ operation for complex CHD

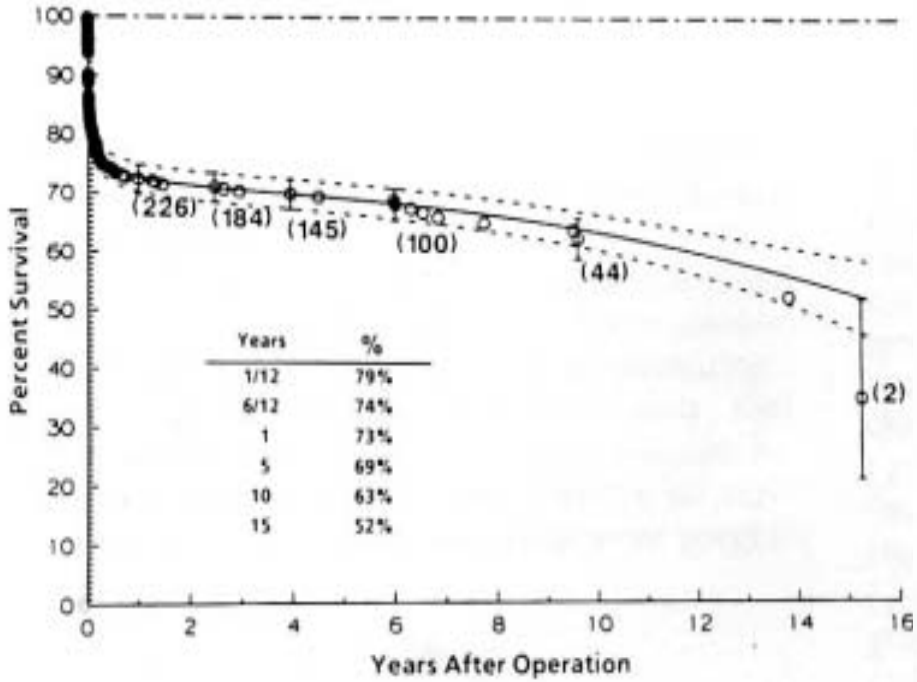
- Long term time-related survival
- Long term morbidity

Fontan procedure

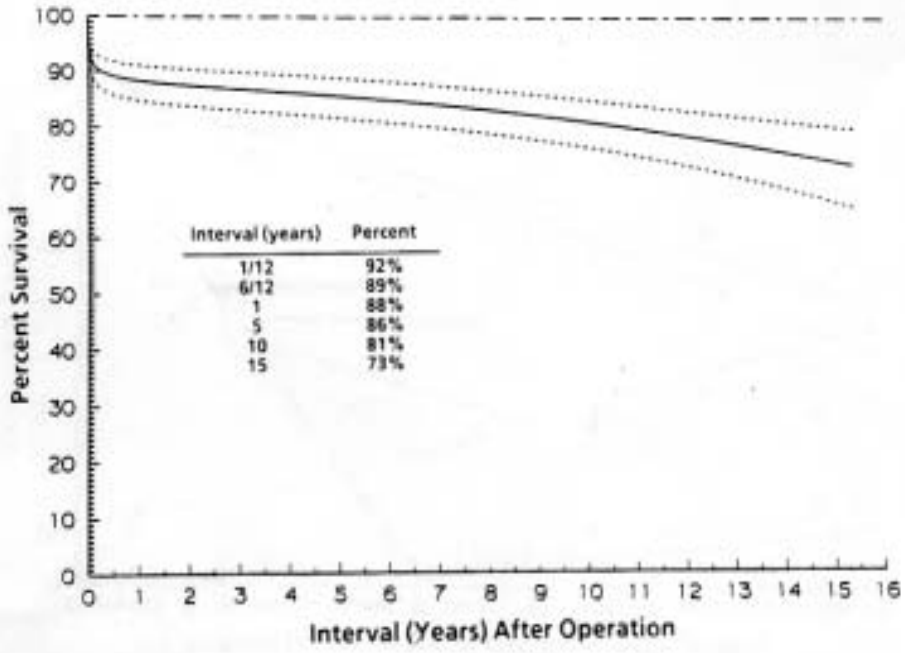
- Fontan ; Fontan F ; *Thorax.* 1971
- BCPS ; Hopkins RA ; *JTCS.* 1985
- Lateral-tunnel Fontan ; de Leval MR ; *JTCS.* 1988
- Baffle fenestration ; Bridges ND ; *Circulation.* 1990
- Extracardiac conduit Fontan ; Marcelletti C ; *JTCS.* 1990

Survival

Fontan et al. *Circulation* 1990



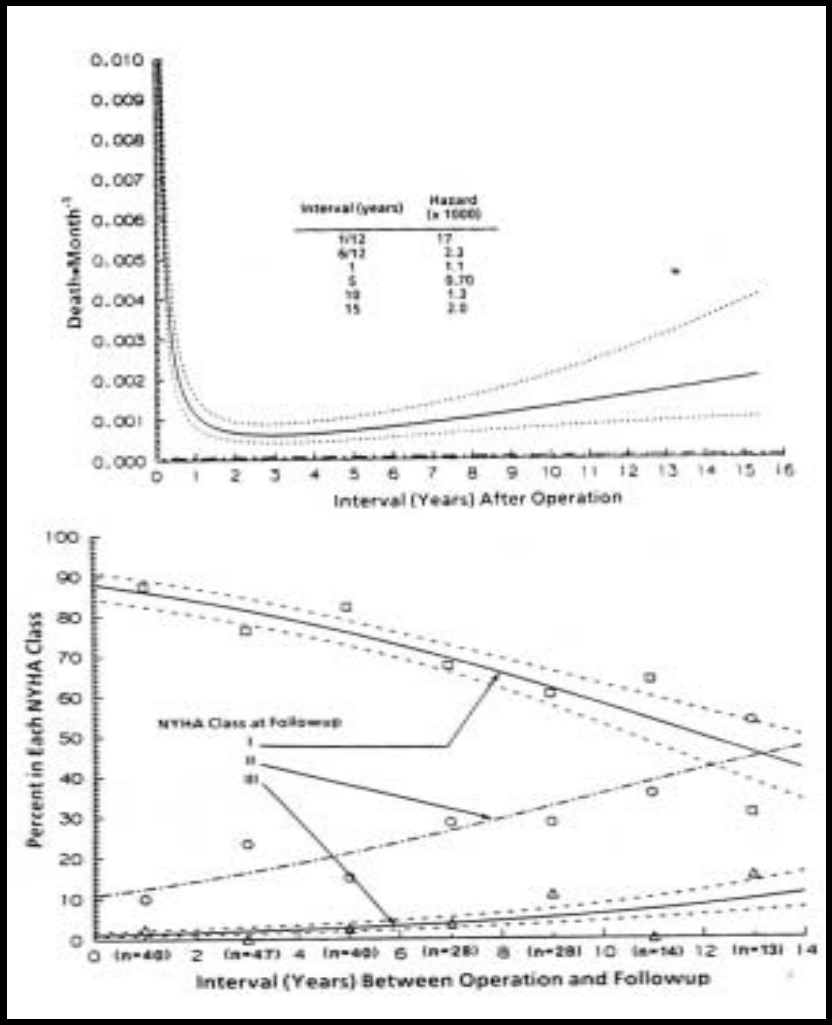
Overall survival

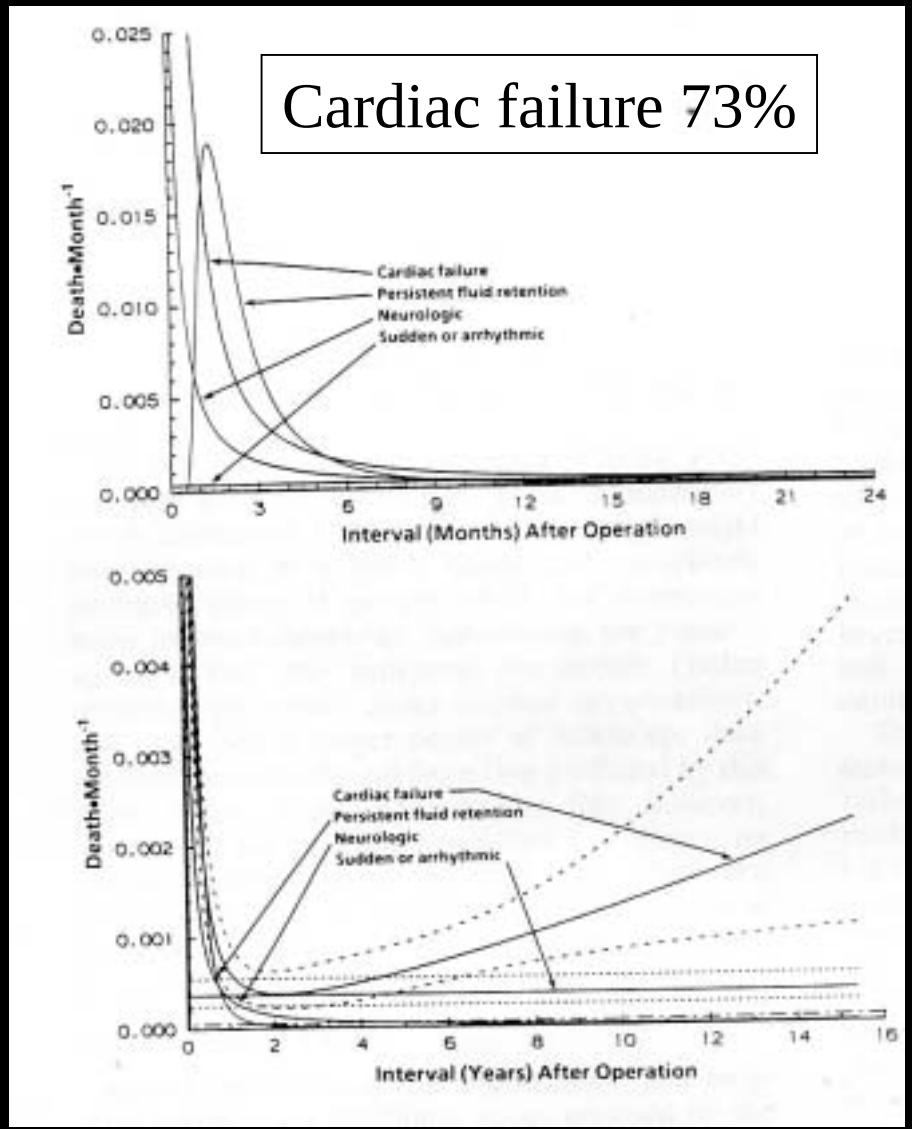


Survival after ‘perfect’ Fontan

Survival

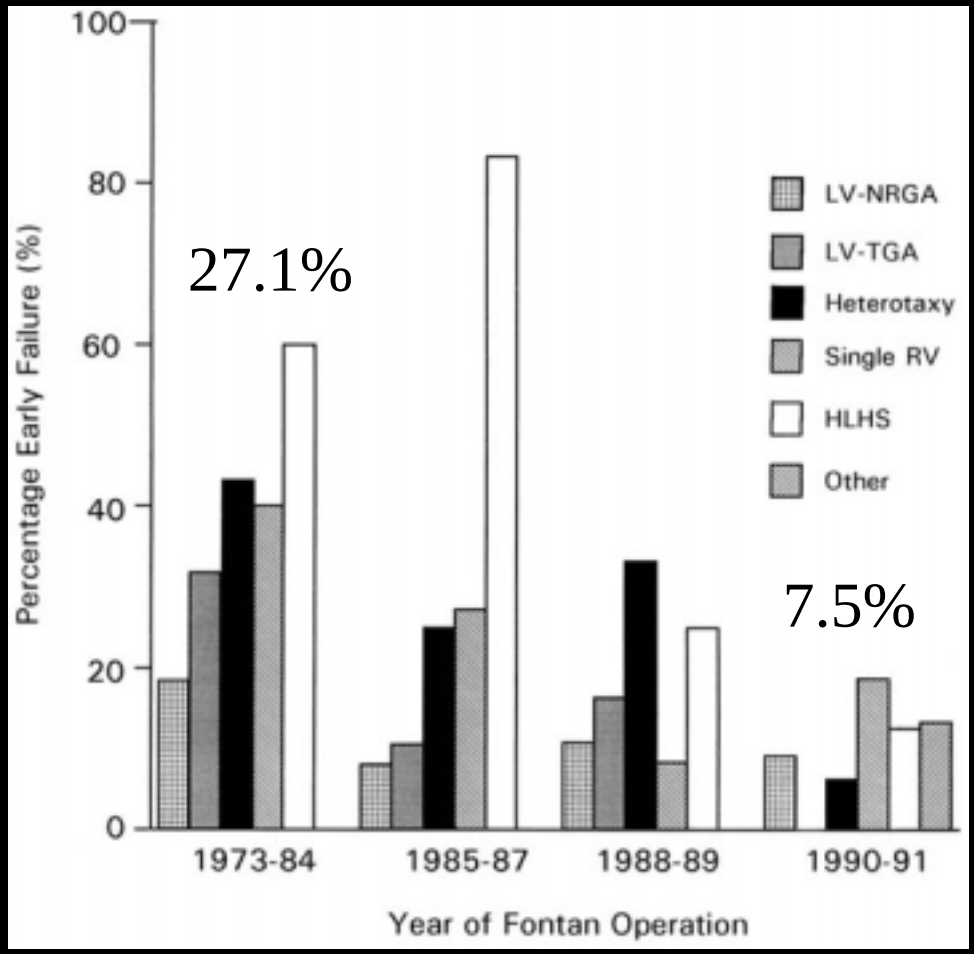
Fontan et al. *Circulation* 1990





Fontan operation in five hundred consecutive patients: Factors influencing early and late outcome

JTCS 1997, Boston

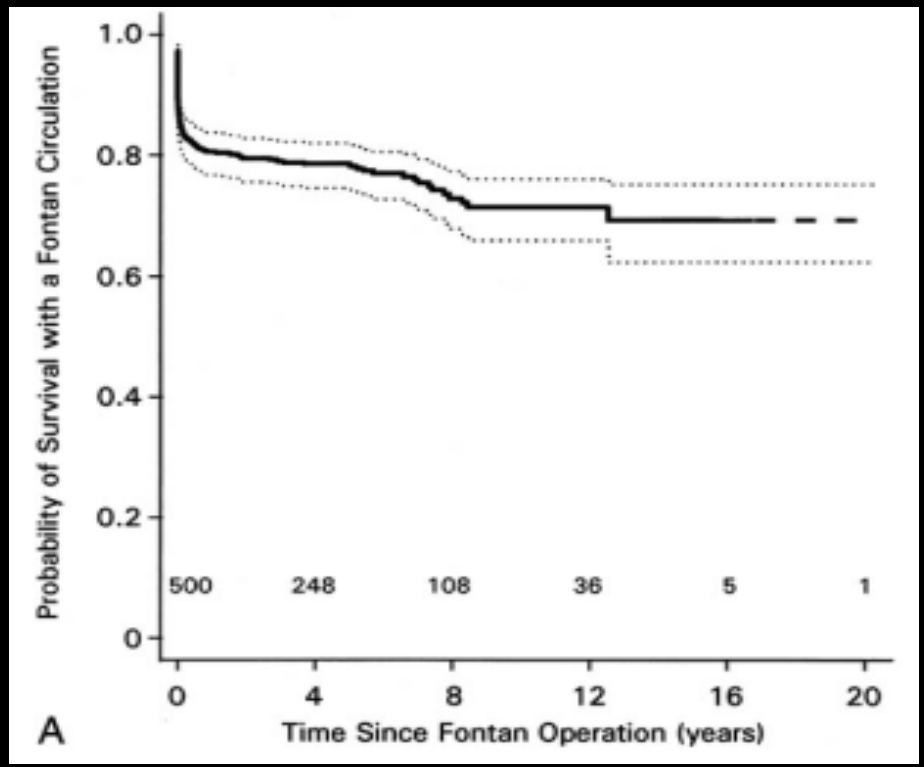


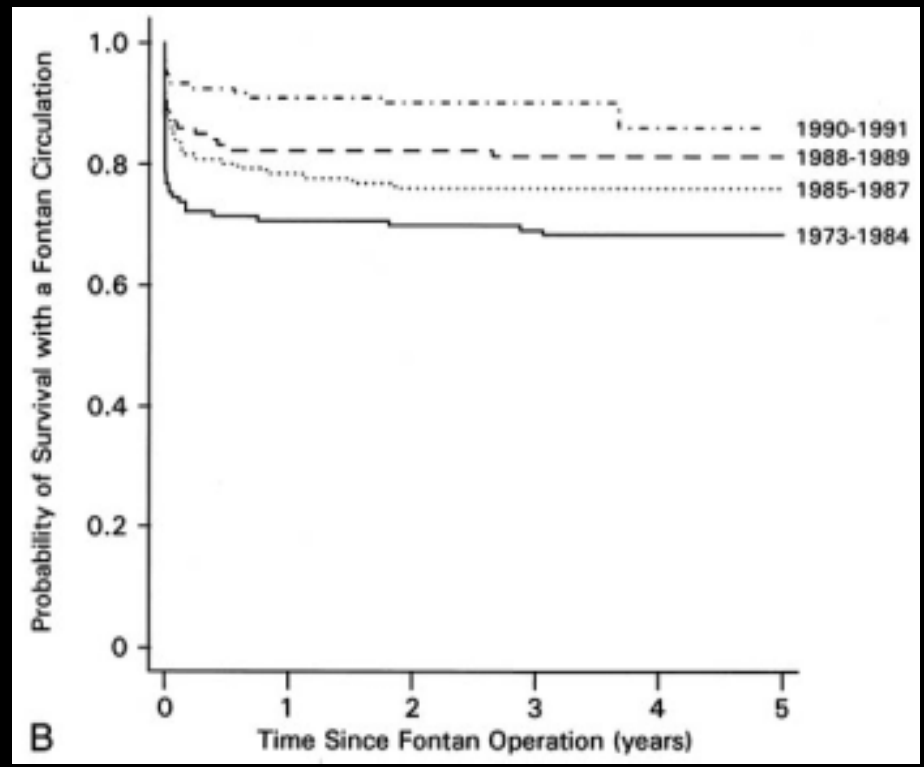
- **Risk factors**

- Preop PAP > 19 mm Hg
- Younger age at operation
- Heterotaxy syndrome
- Right-sided TV as the only systemic AV valve
- Pulmonary artery distortion
- Atriopulmonary connection
- Absence of a baffle fenestration
- Longer CPB

Fontan operation in five hundred consecutive patients: Factors influencing early and late outcome

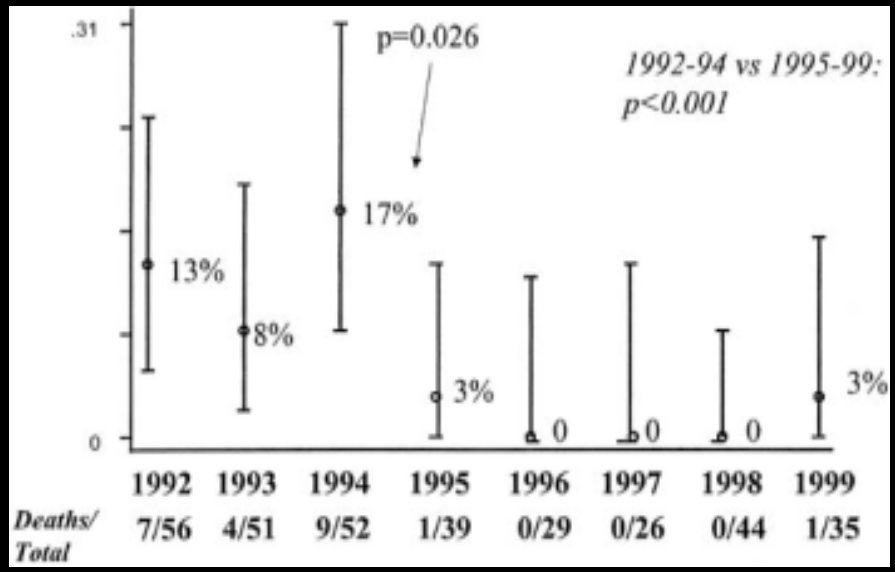
JTCS 1997, Boston

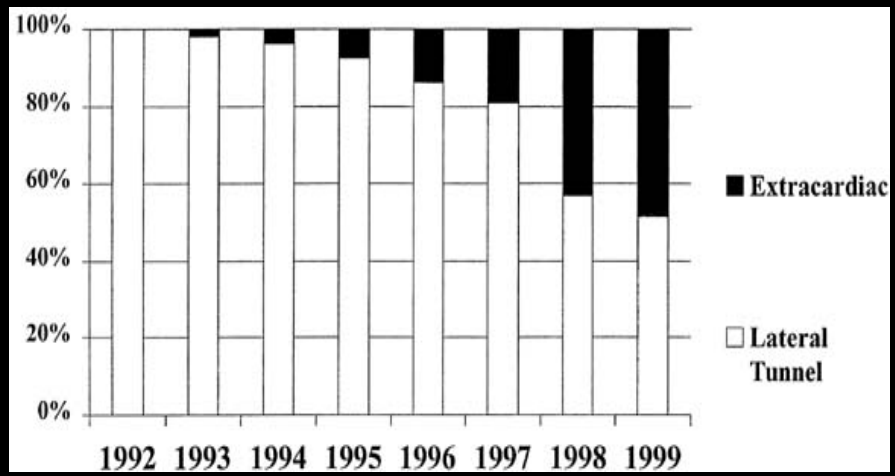




Survival

JTCS 2002





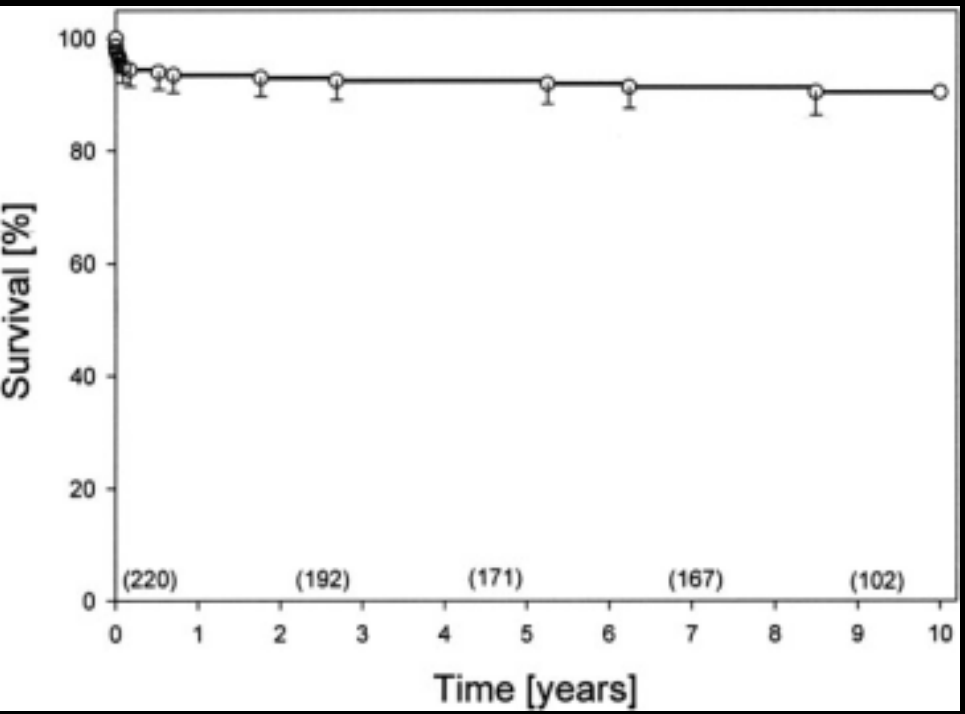
- Common AVV
- ↑ Preoperative PAP

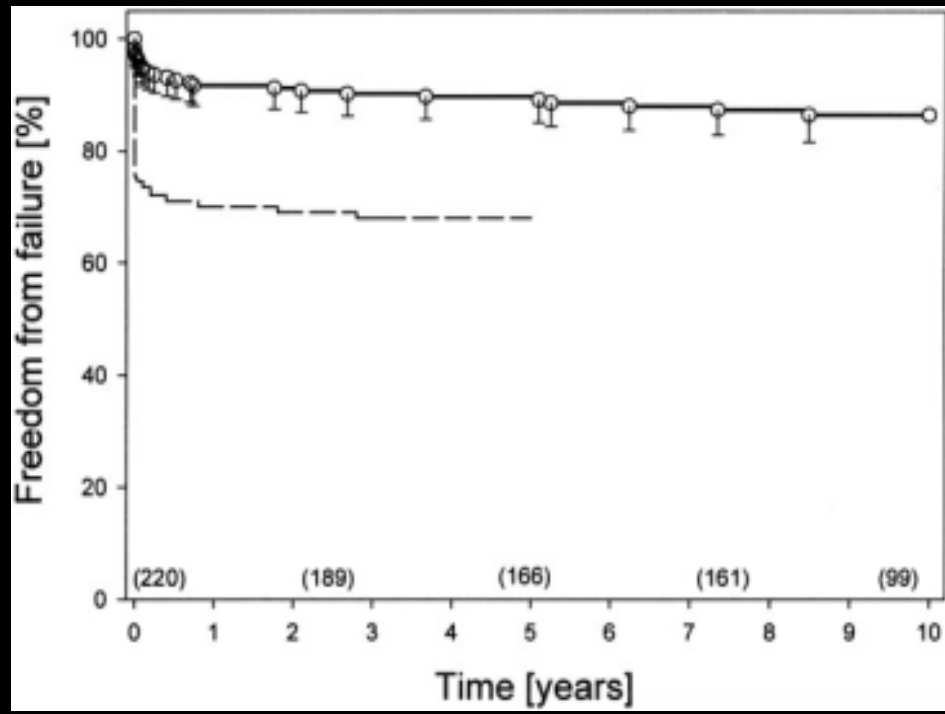
- Fenestration in a lateral-tunnel Fontan
- Modified ultrafiltration

Children`s Hospital of Philadelphia

Lateral tunnel Fontan operation

JTCS 2001 Boston

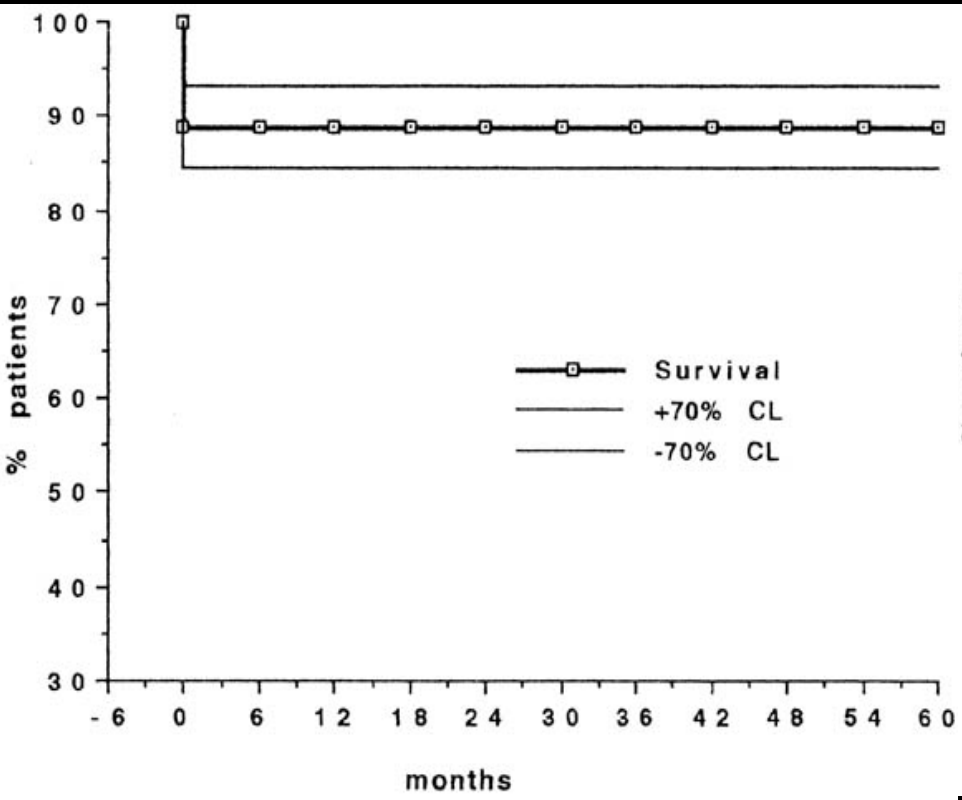


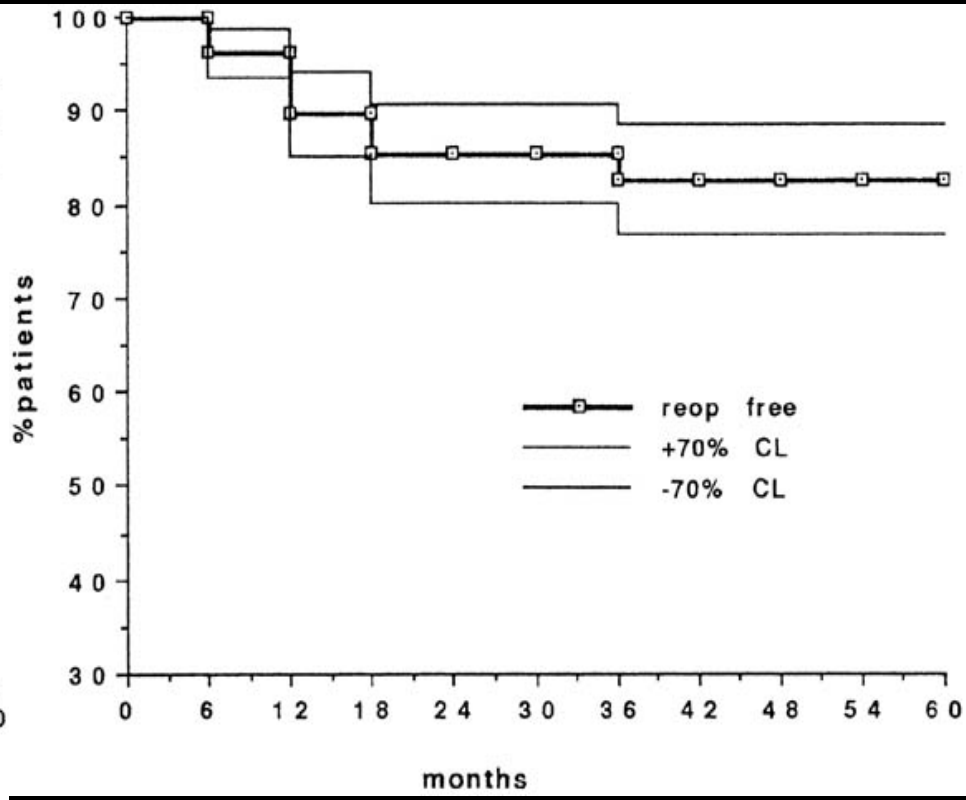


Early death; 5.4%

Extracardiac Fontan

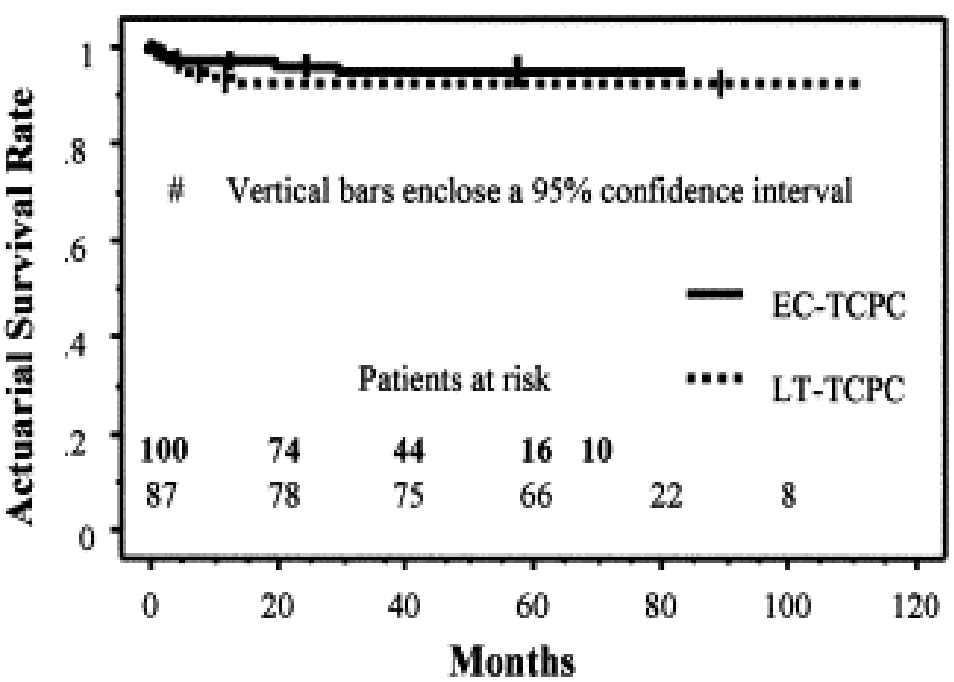
JTCS 1997, Italy

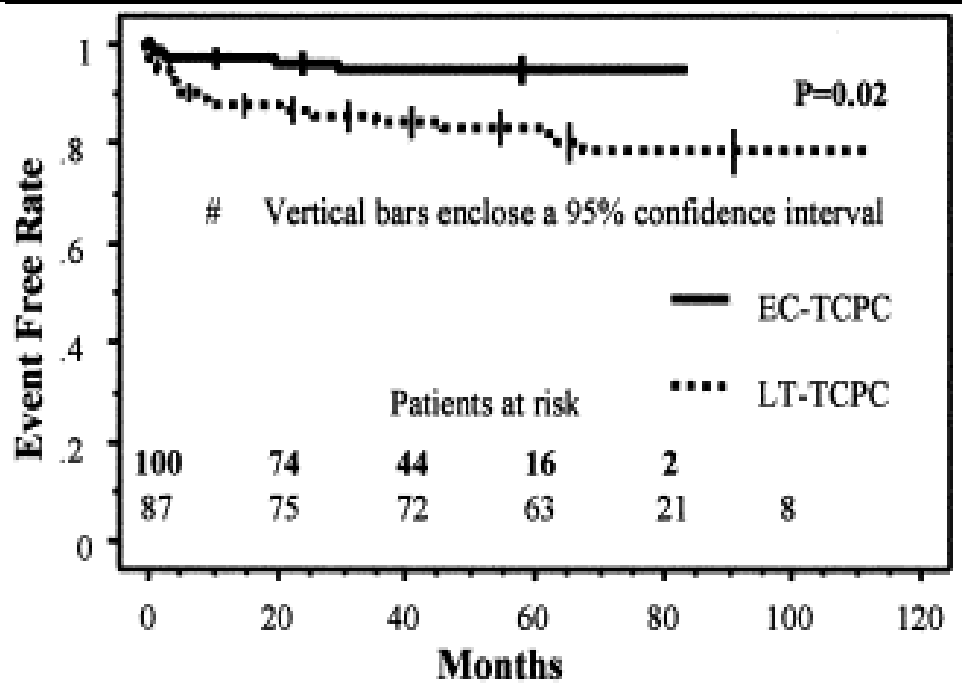




Extracardiac Fontan

ATS 2002, Japan



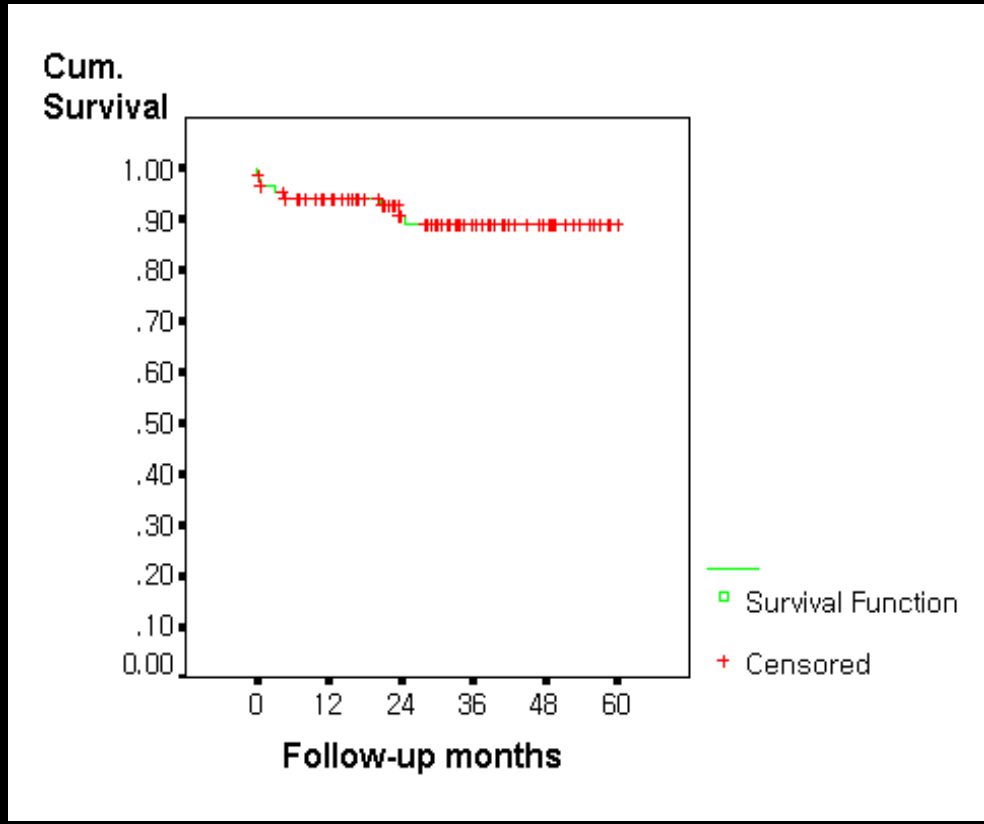


No early mortality

Extracardiac Fontan

Sejong General Hospital

- 1996 - 2001
- 89 patients
- 3 early death (3.4%)
- 5 late death

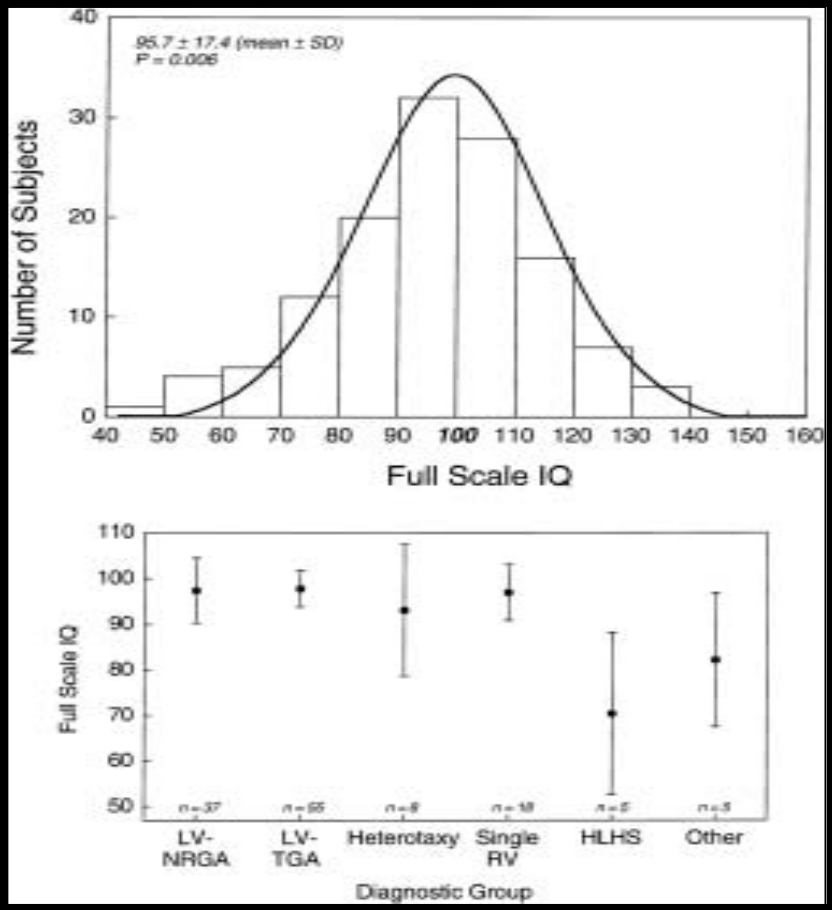


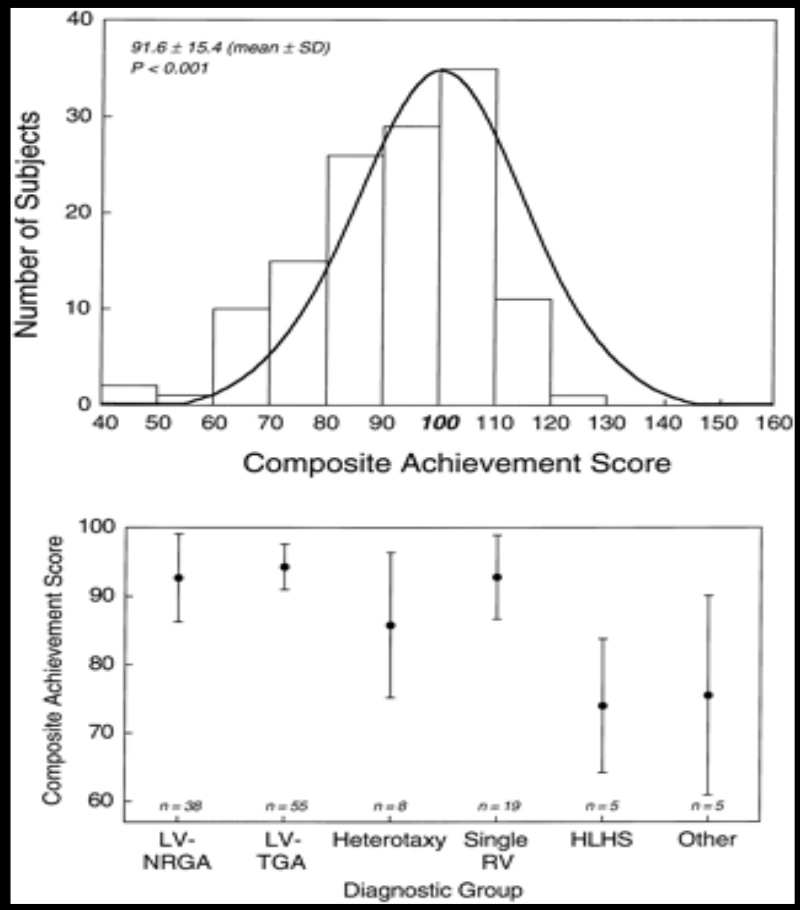
Survival rate	mean ± SD
1YSR	94.3% ± 2.5%
3YSR	89.2% ± 3.7%
5YSR	89.2% ± 3.7%

Late morbidity

- Neurodevelopmental outcome
- Somatic growth
- Exercise capacity
- Ventricular dysfunction
- Arrhythmia
- Thromboemboilsm
- Protein losing enteropathy
- Pregnancy issues

Neurodevelopmental outcome





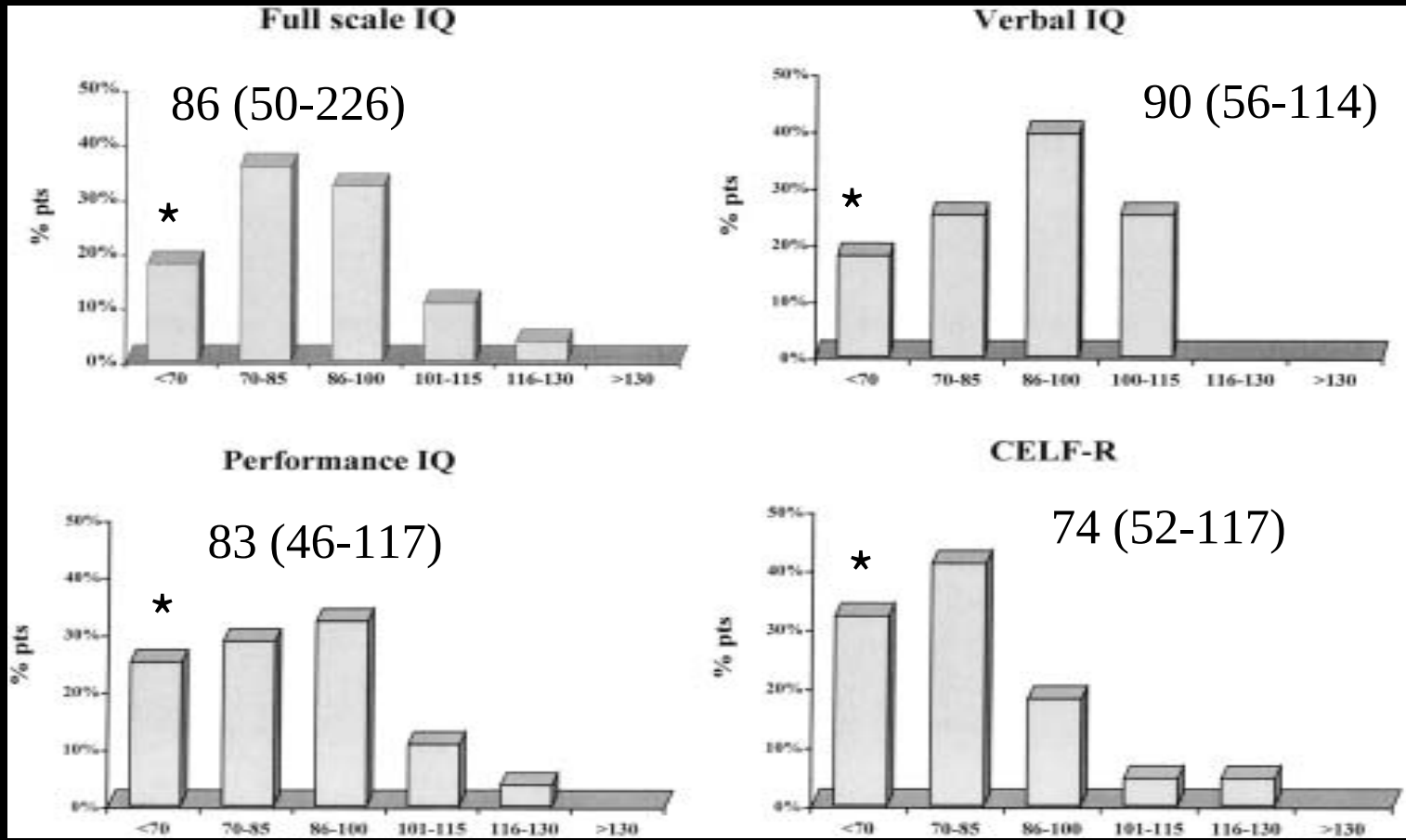
Risk factors

- Circulatory arrest, Prior PA band, HLHS
- Early major reoperation after Fontan

Circulation. 2000

Neurodevelopmental outcome

- 115 with HLHS; mean age: 9.0 ± 2.0 years



Pediatr 2000

Neurodevelopmental outcome

- Parental Assessment of Child's Health and Functional Status

Health	
Excellent	52 (45.2%)
Good	40 (34.8%)
Fair	14 (12.2%)
Poor	10 (8.7%)
Limitations to activity	
None	59 (51.3%)
Slight	43 (37.4%)
Significant	12 (10.4%)
Severe	2 (1.7%)

Pediatr 2000

Neurodevelopmental outcome

Circulation 2002

TABLE 4. Intellectual Outcome of Study Subjects

	Present Study Group*		Previous Fontan Study Group†		
Intelligence Measure‡	n	Mean (SD)	n	Mean (SD)	*P*
Full-scale IQ	26	92.5 (16.3)	128	95.6 (17.4)	0.41
Verbal IQ	26	95.4 (14.8)	128	96.6 (18.1)	0.74
Performance IQ	26	90.9 (16.5)	129	95.6 (16.4)	0.19

TABLE 3. Surgical Characteristics of Study Subjects

Procedure	Present Study Group (n=27)	Previous Fontan Study Group (n=133)	*P*	Contemporary Fontan Patients Not Evaluated (n=32)	*P*
Stage 1 Norwood	7 (26)	11 (8.3)	0.02	14 (44)	0.15
Bidirectional cavopulmonary anastomosis	14 (52)	22 (17)	<0.001	26 (81)	0.02
Lateral tunnel Fontan	25 (93)	68 (51)	<0.001	29 (91)	0.78
Fenestrated Fontan	26 (96)	37 (28)	0.001	31 (98)	0.90
Age at Fontan, y	2.4±0.96	7.3±6.5	0.0001	2.8±1.3	0.12

Values are n (%) except age, which is mean±SD. *P* values are vs Present Study Group.

Neurodevelopmental outcome

51 pts with mean age of 57.6 ± 4.7 months

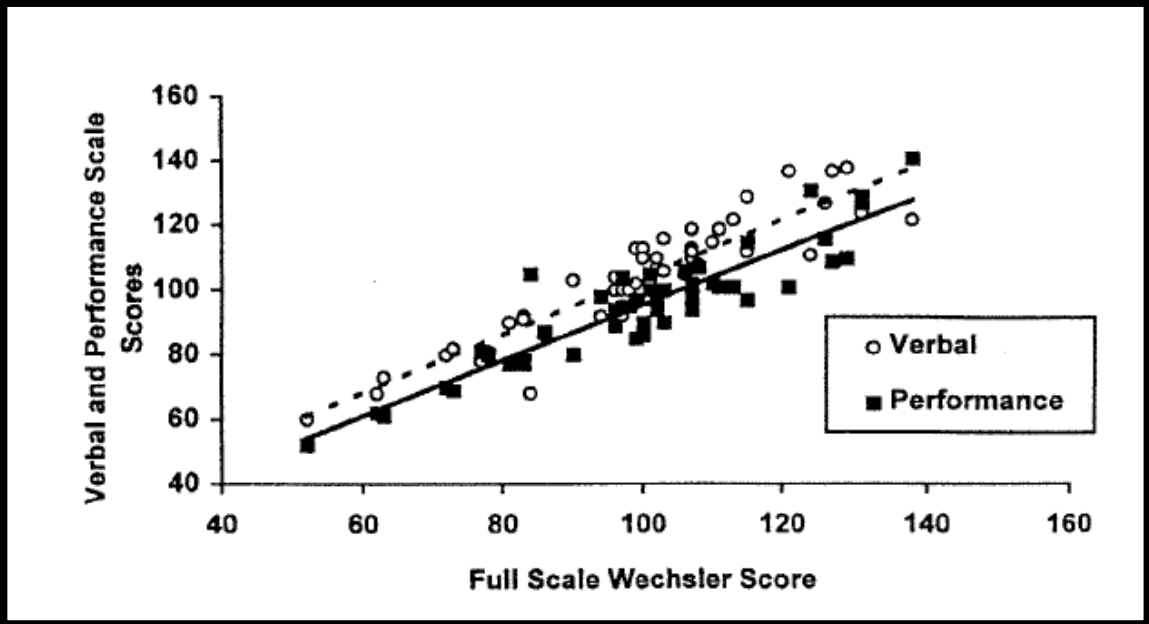
J Pediatr 2000;137:646-52

Table I. Wechsler and Vineland Test Scores for HLHS and non-HLHS subgroups

Instrument	Entire sample Mean + CI (n, range)	HLHS sub-group (n = 26) Mean + CI (n, range)	Non-HLHS sub-group (n = 25) Mean + CI (n, range)	*P* value *
Wechsler Tests				
Verbal	104.2 ± 5.3 (48, 60-138)	98.9 ± 7.6 (25, 60-129)	110.0 ± 6.7 (23, 80-138)	.04
Performance	95.5 ± 5.1 (48, 52-141)	89.7 ± 6.6 (25, 52-127)	101.9 ± 6.9 (23, 70-141)	.02
Overall	101.1 ± 5.4 (48, 52-138)	93.8 ± 7.3 (25, 52-131)	107.0 ± 7.0 (23, 72-138)	.01
Vineland Tests				
Communication	94.2 ± 4.0 (51, 52-120)	90.7 ± 5.8 (26, 52-116)	97.9 ± 5.4 (25, 74-120)	.08
Skills of Daily Living	91.7 ± 4.7 (51, 47-132)	90.3 ± 7.6 (26, 47-132)	93.2 ± 5.7 (25, 66-123)	.54
Socialization	93.1 ± 5.4 (51, 65-121)	89.5 ± 5.8 (26, 65-121)	96.8 ± 4.8 (25, 72-119)	.07
Motor	85.1 ± 6.9 (31, 42-124)	84.7 ± 9.1 (20, 42-124)	85.8 ± 10.6 (11, 53-114)	.88
Adaptive Behavior Composite	89.1 ± 4.4 (51, 53-126)	86.4 ± 6.8 (26, 53-126)	91.9 ± 5.5 (25, 72-123)	.22
Child Behavior Checklist				
Total	48.0 ± 2.7 (51, 26-73)	48.0 ± 3.5 (26, 30-63)	48.1 ± 4.1 (25, 26-73)	.98
Internal	47.4 ± 2.6 (51, 29-76)	48.0 ± 3.4 (26, 29-63)	46.0 ± 4.0 (25, 34-76)	.61
External	46.5 ± 2.4 (51, 30-62)	47.0 ± 3.3 (26, 31-64)	46.0 ± 3.4 (25, 30-60)	.96
Socioeconomic Status				
Hollingshead Four Factor Score	44.1 ± 3.5 (51, 17-66)	43.3 ± 5.1 (26, 17-66)	44.9 ± 4.9 (25, 23-66)	.67

**P* values apply to comparison testing between HLHS and non-HLHS subgroups.

Neurodevelopmental outcome

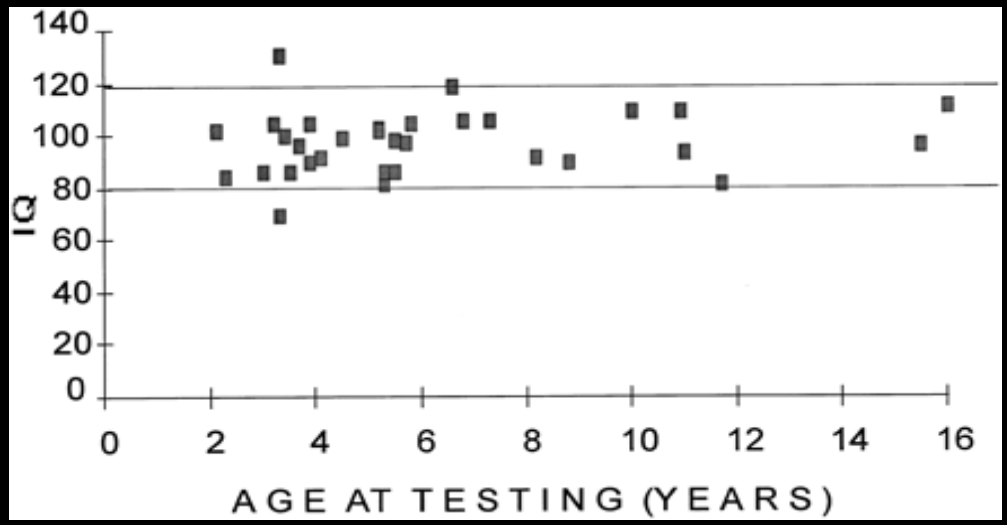


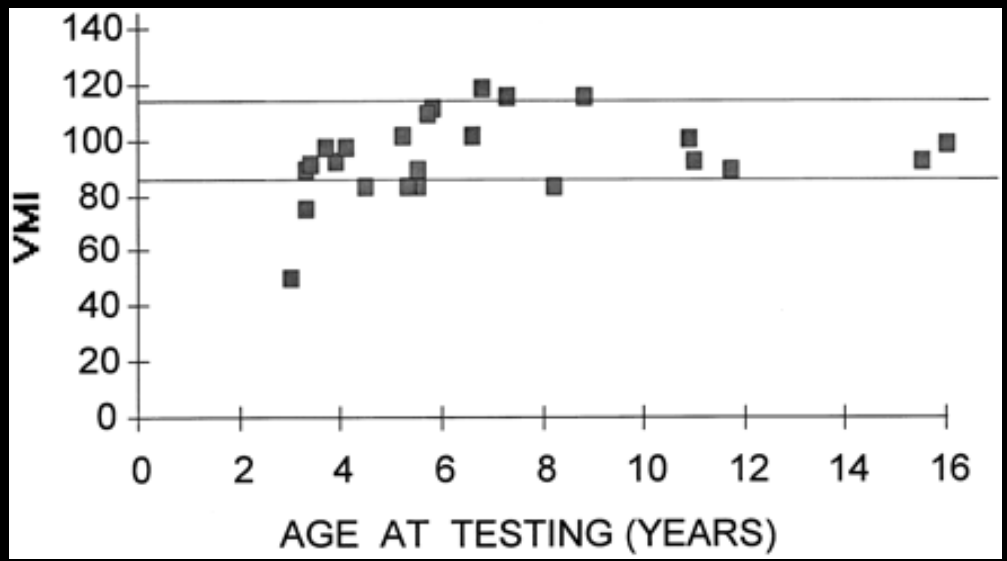
J Pediatr 2000;137:646-52

Risk factors

- Socioeconomic status
- circulatory arrest
- perioperative seizures

Neurodevelopmental outcome





Pediatr 1998

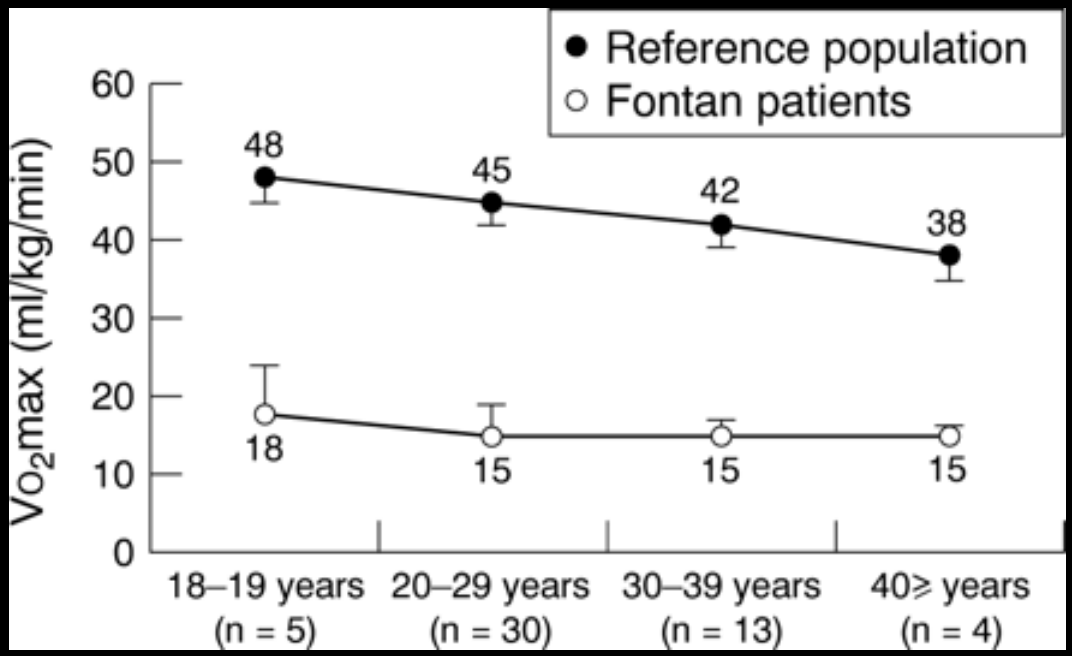
- Age at testing
  6.3 y (26 mo-16 y)
- Intelligence (IQ) scale
  97.5 (70 –131)
- Visual Motor Integration
  94.8 (50 –119)

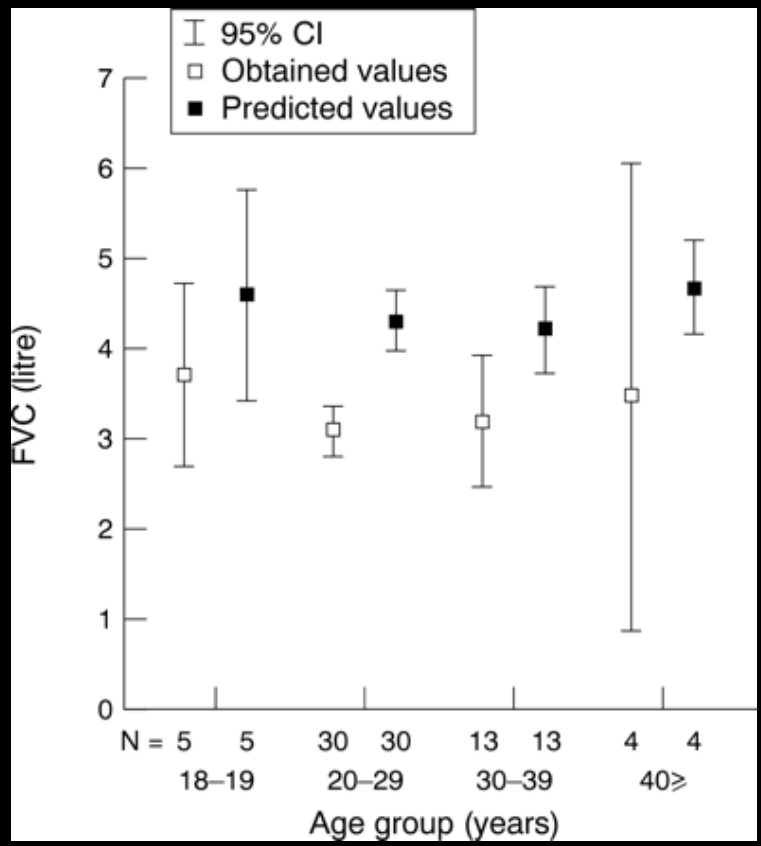
- Deep hypothermic circulatory arrest

Exercise capacity

Heart 2001

•52 adult patients with a Fontan circulation





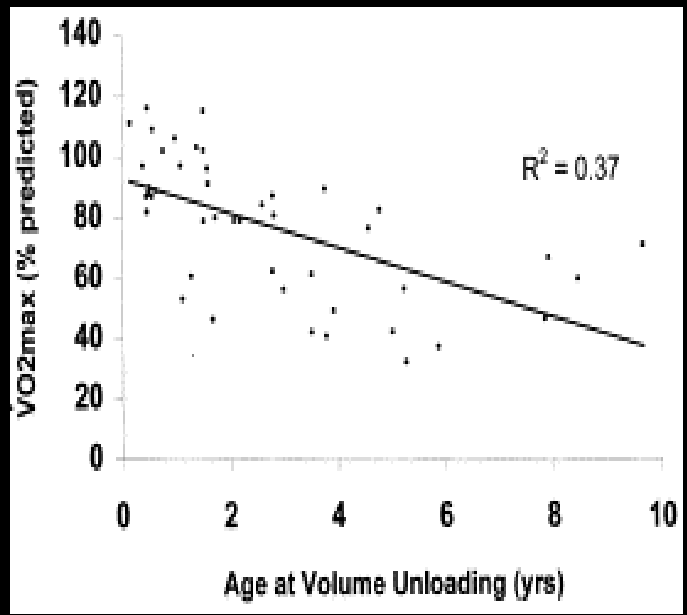
Exercise capacity

Table 3. Exercise Performance in the Study Population

	n	Rest Mean ± SD	Peak Exercise Mean ± SD
Heart rate (beats/min)	46	84.1 ± 13.6	155.9 ± 21.0
$\dot{V}O_2$ (ml/min/kg)	46		32.3 ± 8.9
$\dot{V}O_2$ (% predicted)	46		76.1 ± 21.1
Systolic BP (mm Hg)	46	103.1 ± 10.3	132.1 ± 14.8
Diastolic BP (mm Hg)	46	68.9 ± 9.9	71.5 ± 14.8
O_2 Saturation (%)	46	94.0 ± 2.9	92.2 ± 3.9
RER	46		1.05 ± 0.10
FVC (% predicted)	41	77.7 ± 16.9	
FEV_1 (% predicted)	41	78.8 ± 15.6	
MVV (% predicted)	40	70.6 ± 15.2	
Minute ventilation (% predicted)	46		78.7 ± 19.8
Breathing reserve (%)	40		19.2 ± 8.1

BP = blood pressure; FVC = functional vital capacity; FEV_1 = forced expiratory volume at 1 s; MVV = maximum voluntary ventilation; RER = respiratory exchange ratio; VO_2 = oxygen uptake.

JACC 1999



46 patients (8.7 ± 2 years)

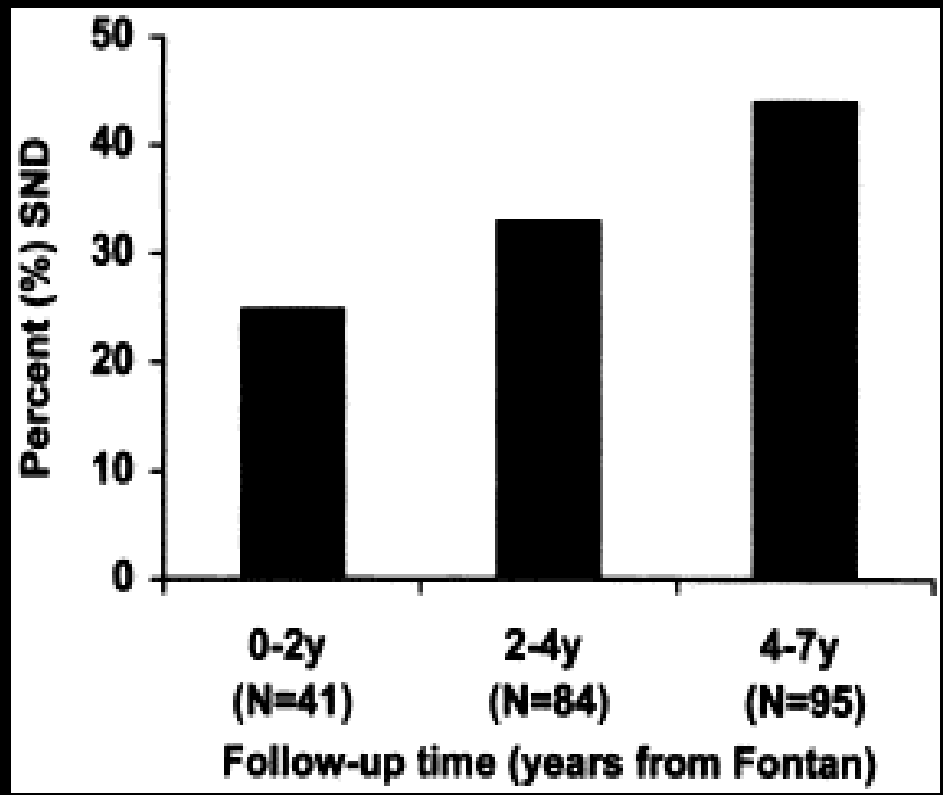
Arrhythmia

- Late brady- and tachyarrhythmia
  - SND
  - Atrial flutter or IART

Arrhythmia - SND

Circulation 1998

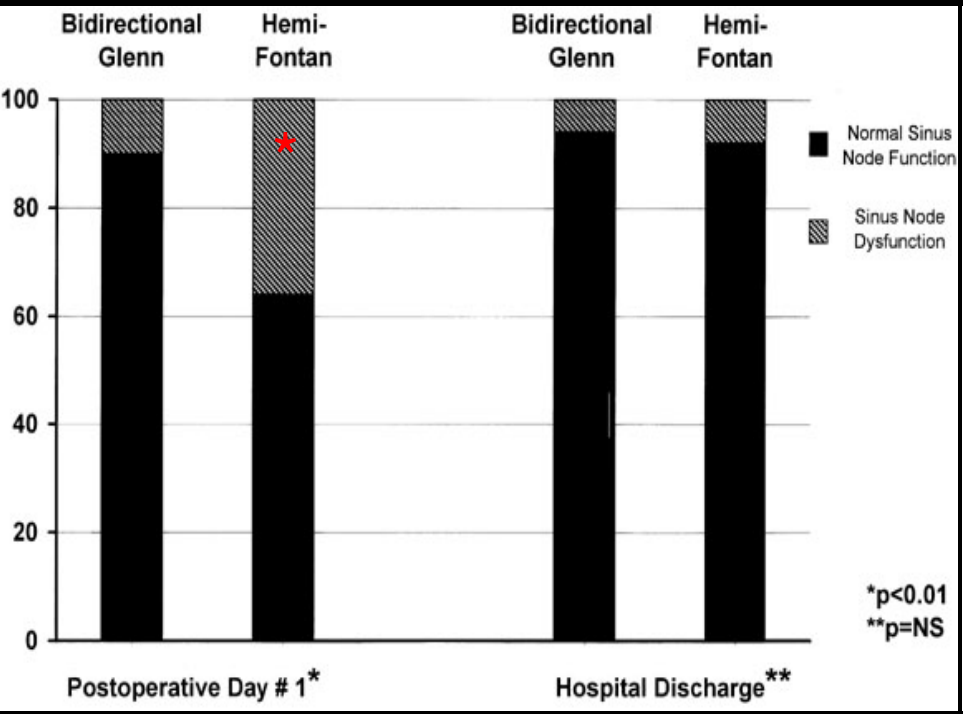
- 220 patients with staged Fontan (lateral tunnel)
- Follow-up; 3.5 +/- 1.7 years,
- 16 (6.7%); pacemaker
- 10 (4.1%) had atrial flutter

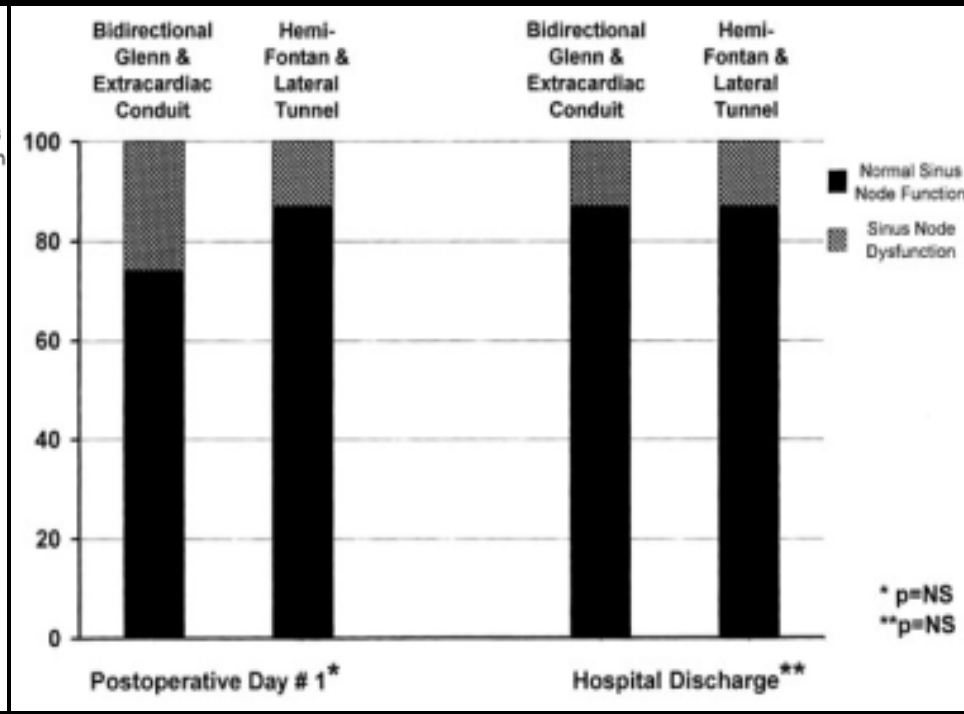


Arrhythmia - SND

- Lateral tunnel vs. Extracardiac conduit

JTCS 2000

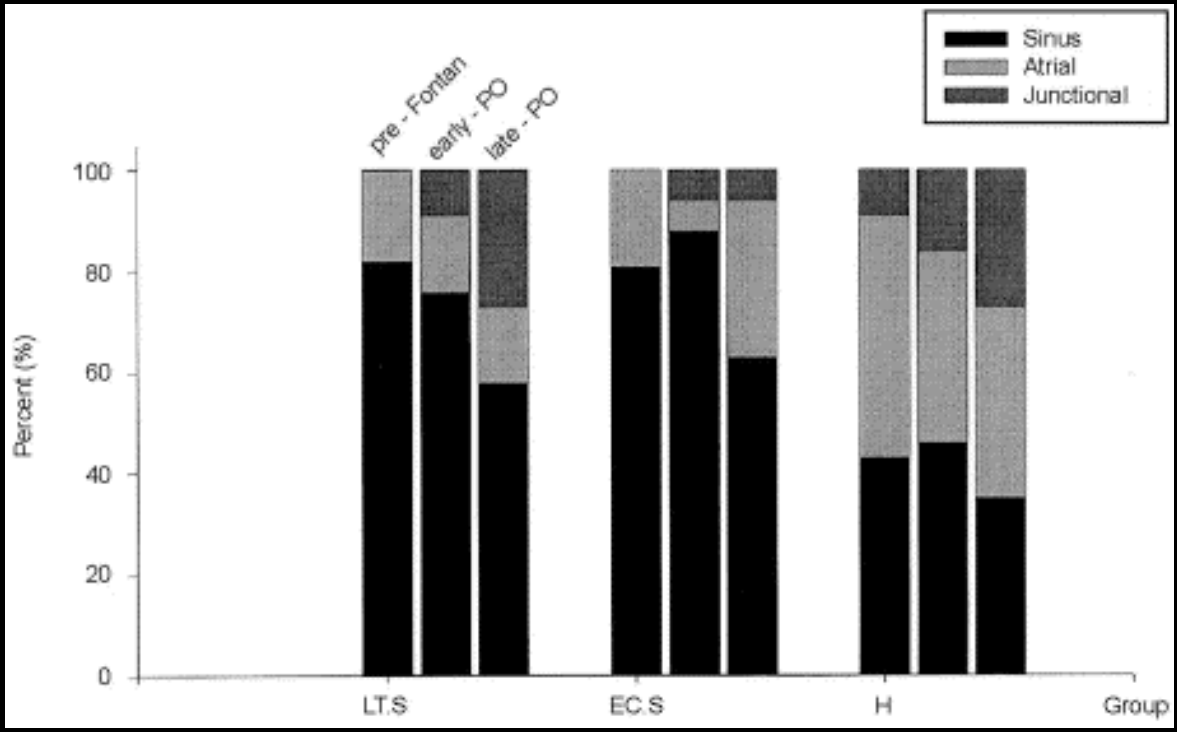




Arrhythmia - SND

	Early		Late		F/U
	LT	EC	LT	EC	
Cohen (2000)	13%	13%			
Ovroutski (2001)			48%	9%	4.5y vs. 2.4y
Azaki (2001)	45%	15%	25%	7%	2.5y
Bae (2003)			28%	9%	3.4y
Dilawar (2003)			21%	59%	1.6y vs. 3y
Kummar (2003)	0%	17%	15%	28%	3.6y

Arrhythmia - SND



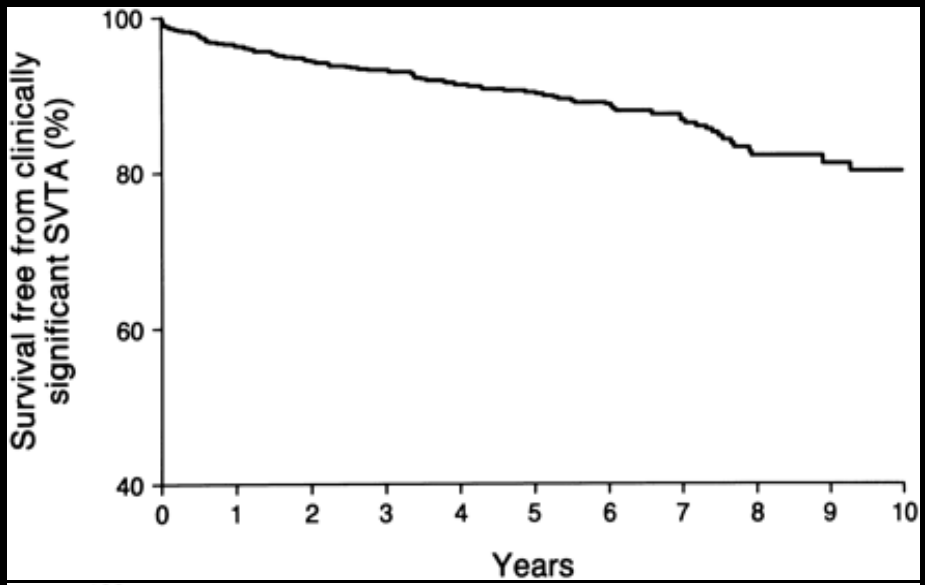
Bae et al.
Int J Cardiol 2003

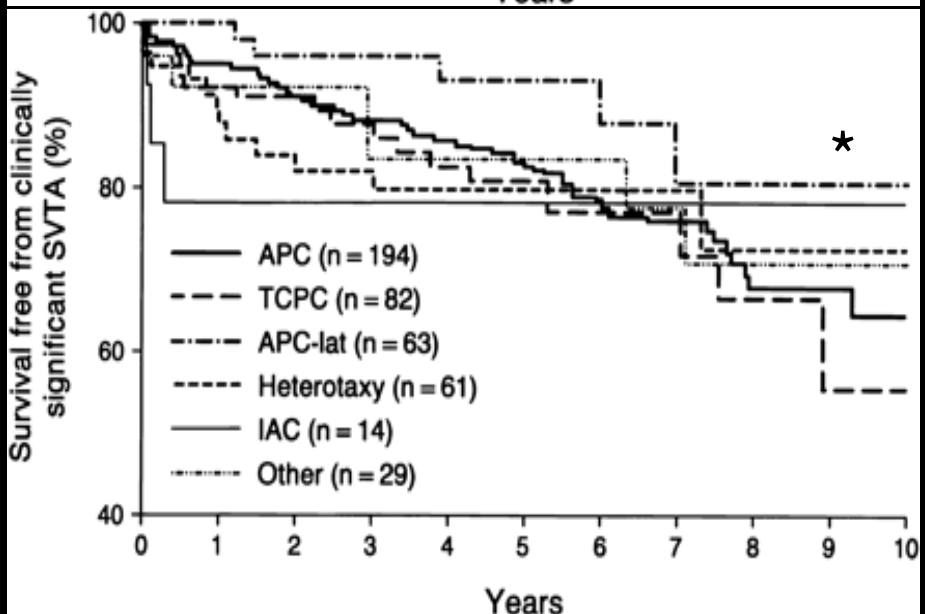
Sinus node dysfunction

	LT	EC	*P* value
Total	10/35	3/33	0.041
Solitus/inversus	8/26	0/16	0.013
Heterotaxy	2/9	3/17	ns
Pacemaker	1/35	0/33	ns

Arrhythmia - SVT

Circulation 1999



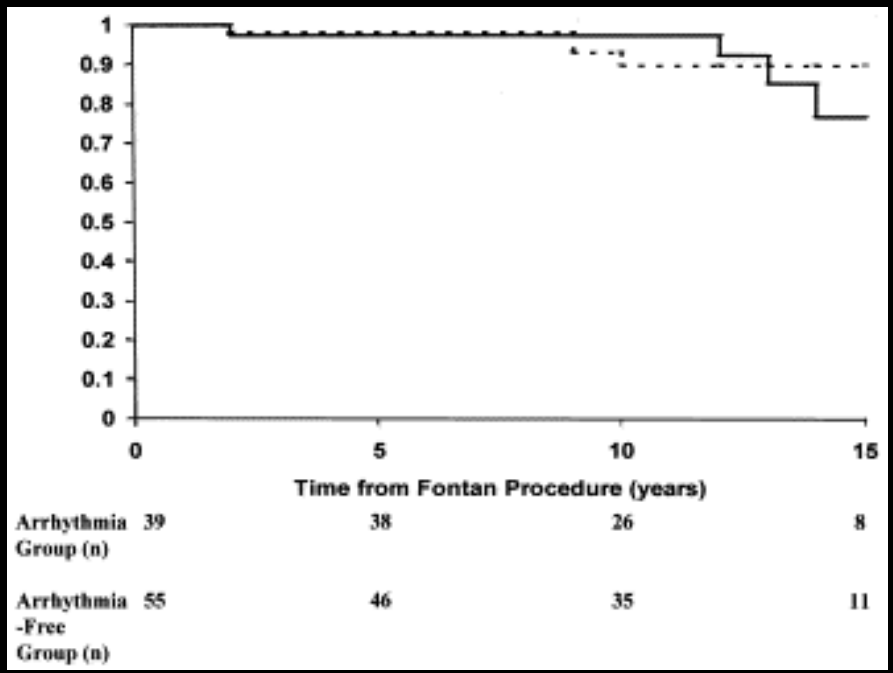


N=499 (1985-1993), Mayo

- Early SVT; 15%
  - AV valve regurgitation
  - Abnormal AV valve
  - Preoperative SVT
- Late SVT ; 17% at 5 yrs
  - Age at operation (<3 or >10 years)
  - Systemic AV valve replacement.

Arrhythmia - SVT

JACC 2001



survival

- 94 adults (1977-1994) at Toronto
- Late arrhythmia; 41 %
  - heart failure (46%)
  - right atrial thrombus (31%)
  - LAE, RAE
  - systemic AVVR (31%)

Arrhythmia - SVT

TABLE 5. Postoperative arrhythmias

Postoperative arrhythmias	EC	n	LT	n	*P* value
Temporary pacing	7 (12%)	59	15 (32%)	47	.01
Junctional	9 (15%)	60	21 (45%)	47	<.001
Supraventricular tachycardia		60		47	
None	55		31		
Atrial flutter	1		6		
Junctional ectopic tachycardia	3		10		
Atrial ectopic tachycardia	1		0		
Any supraventricular tachycardia	5 (8%)		16 (33%)		<.001

EC, Extracardiac conduit; *LT*, lateral tunnel.

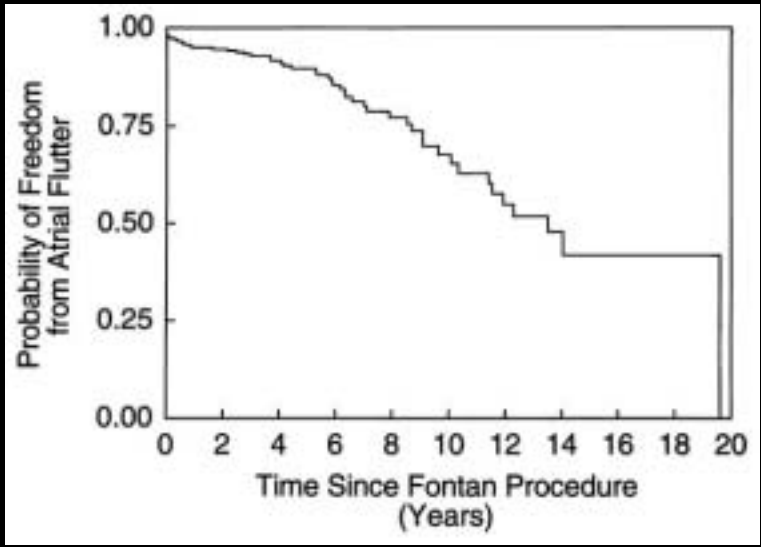
Late SVT 7% 25% f/u 2.5y

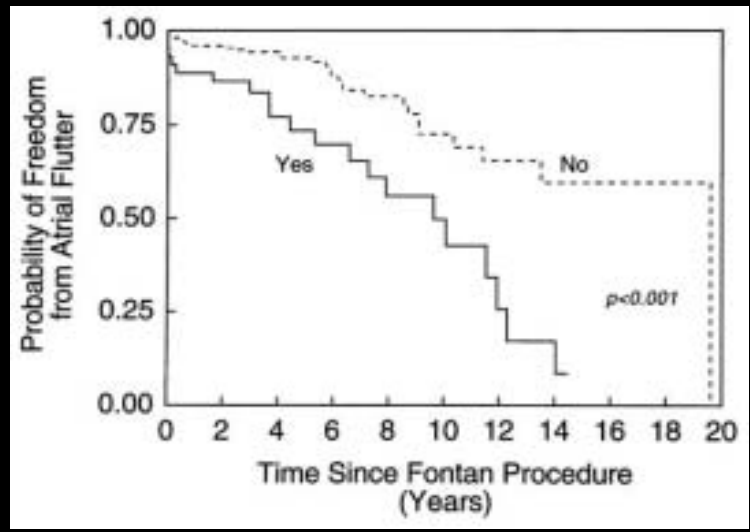
- Atrial arrhythmias before the Fontan procedure
- LT Fontan connection

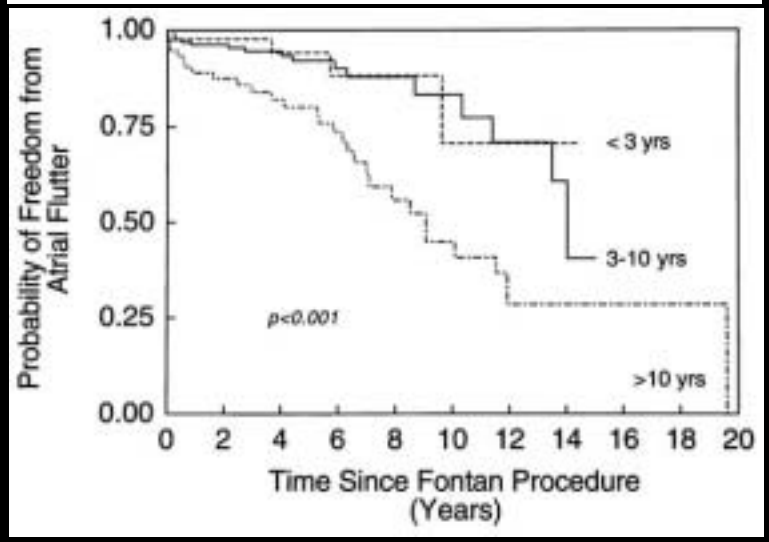
Arrhythmia – atrial flutter

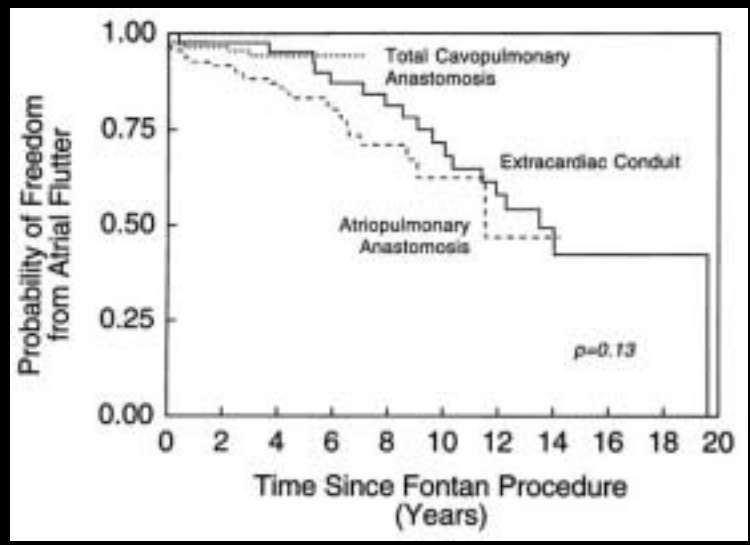
JTCS 1997, Boston

N=334

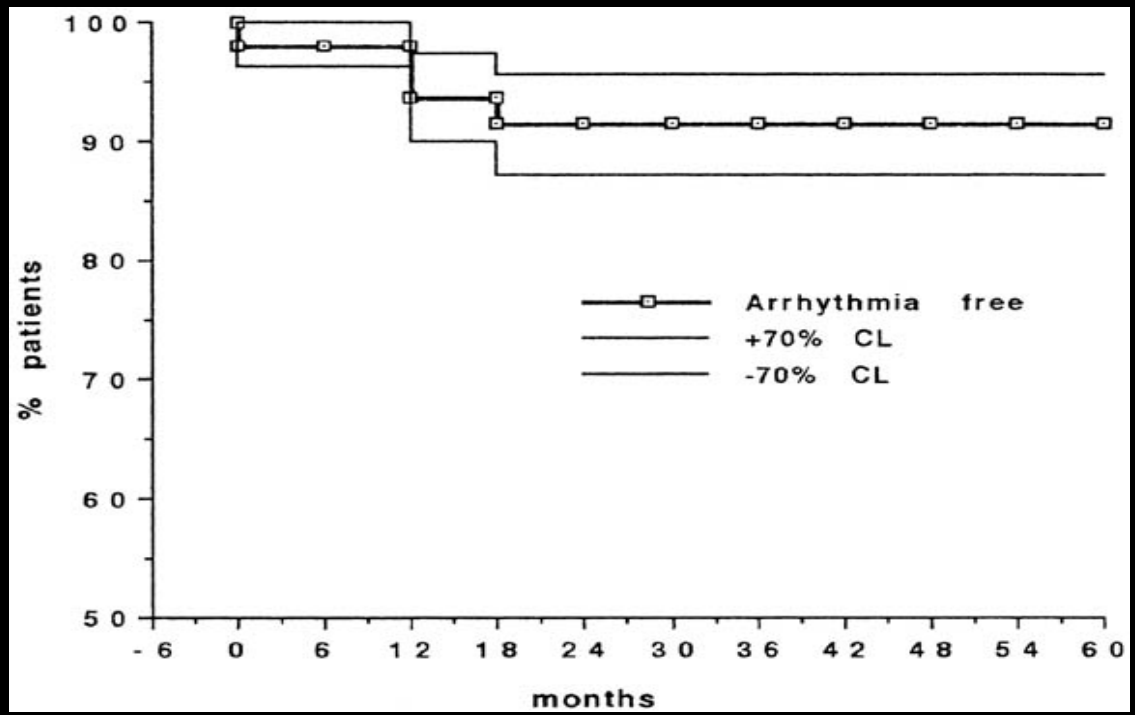








Arrhythmia – AF



Amodio et al
JTCS 1997, Italy

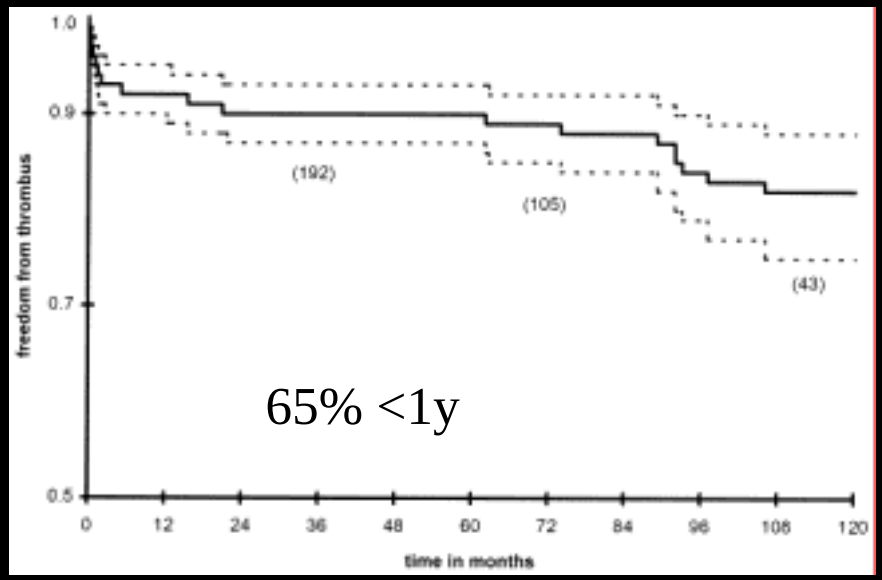
Amodio et al (1997)	ECC (n=60)	7.4 %	5 yr F/U
Cohen et al (1998)	LT (n=220)	4.1 %	3.5 yr F/U

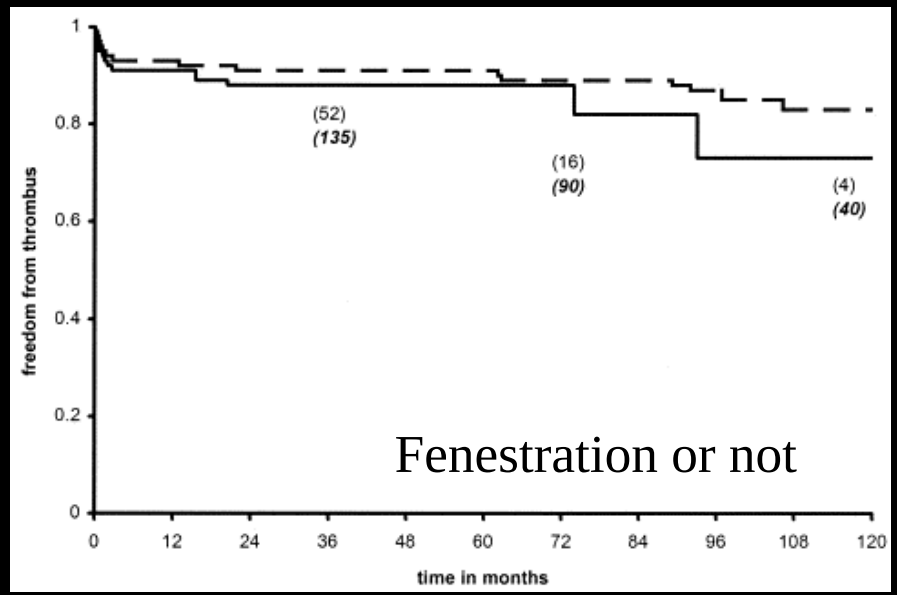
Thrombo-embolism

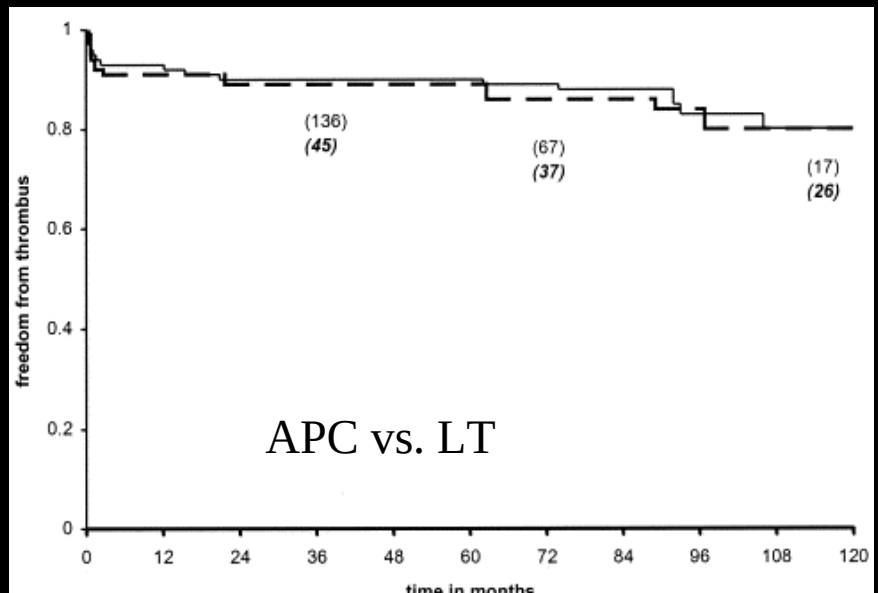
Study	year	F-U(y)	patients	Thrombosis (%)	Stroke/ atrial emboli
Cromme-Dijkhuis	1993	5	66	3 (5%)	NA
Jahangiri	1994	2	64	8 (14%)	3 (5%)
Danielson	1994	NA	449	18 (4%)	NA
du Plessis	1995	NA	645	NA	17 (2.6%)
Rosenthal	1995	5.2	70	11 (16%)	3 (4%)
Day	1995	4	68	NA	6 (9%)
Balling	2000	9.9	52	17 (33%)	NA (TEE in asymptomatic)
Coon	2001	2	592	52 (8.8%)	NA

Thrombo-embolism

ATS 2001



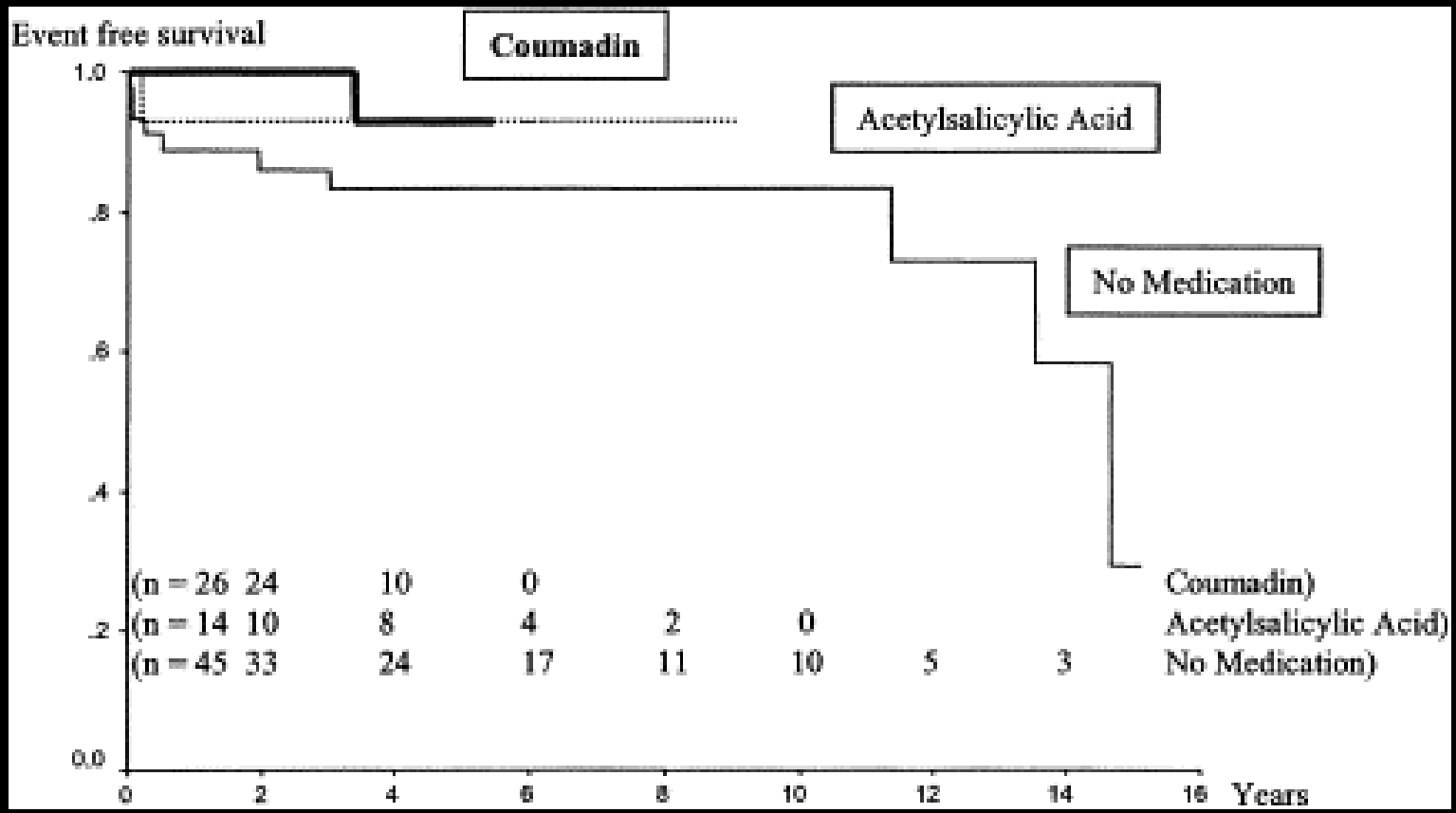




- 52 of 592 patients (8.8%)
  - Systemic venous 50%
  - Pulmonary venous 42%
  - Hypoplastic LV 4%
  - MPA 2%

Thrombo-embolism

- 85 patients with F/U 5.7 ± 3.5 years *ATS 2002*
- 15.3 % of TE



Thrombo-embolism

JACC 1998

Table IV. *Outcome of thromboembolic events after Fontan procedures according to antithrombotic treatment*

Treatment	Number treated	Outcome of treatment: Successful: Complete resolution	Outcome of treatment: Treatment failure: Death	Outcome of treatment: Treatment failure: Subsequent embolization, extension, or incomplete resolution	Outcome of treatment: Treatment failure: Subsequent takedown of Fontan
Surgery	4	1	2	1	—
Surgery + anticoagulation	14	7	6	—	1
Thrombolysis	6	3	1	3	—
Thrombolysis + anticoagulation	11	3	4	8	—
Heparin	5	3	1	1	—
Coumadin	23	14	2	7	1
Aspirin	2	—	—	2	—
Total	65	31	16	22	2

Ventricular function

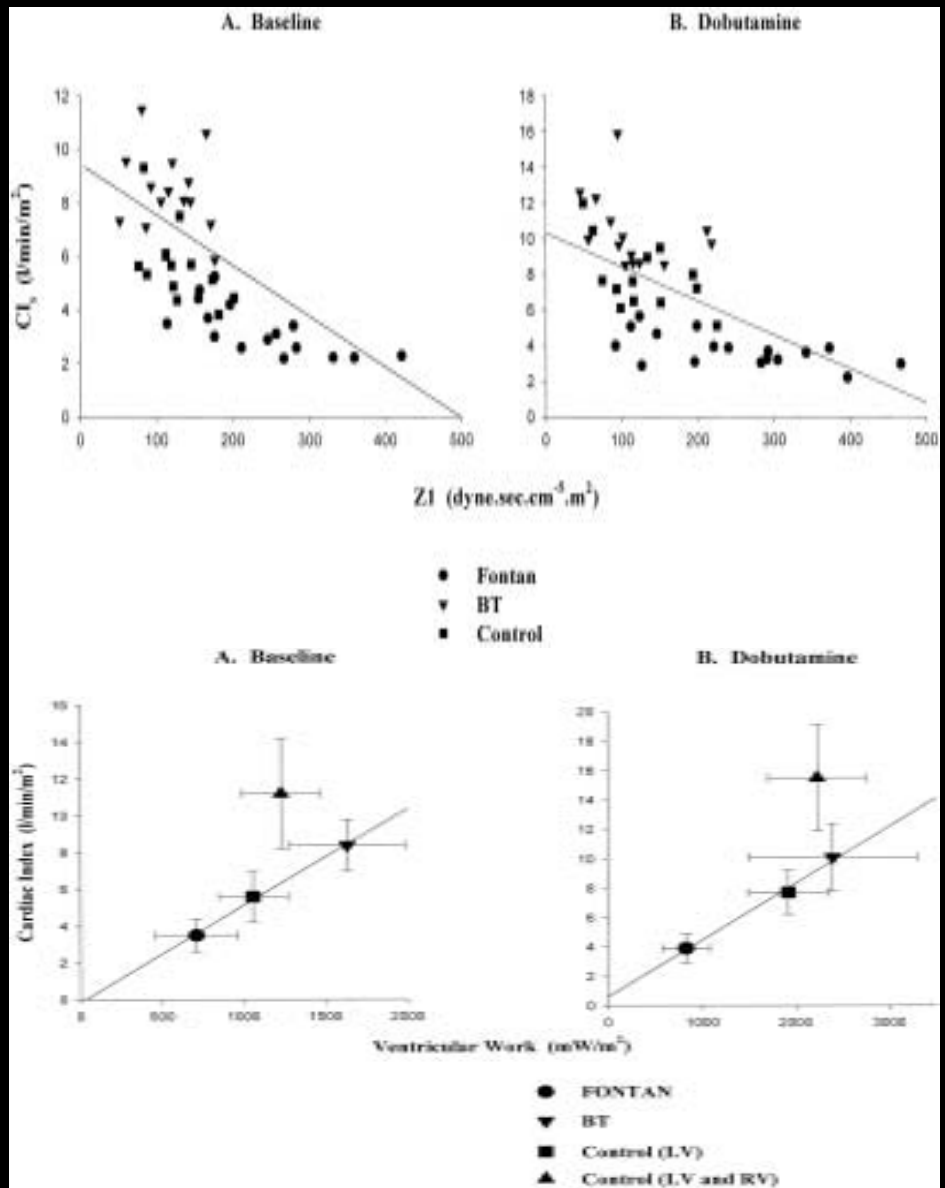
Heart 2000

- Diastolic dysfunction
  - ↑ IVRT
  - ↓ E wave deceleration time
  - ↓ E and A wave velocities
  - ↓ E:A velocity ratio

- Reduction of left ventricular compliance.
- Ppersisting abnormalities of relaxation.

- This may be one of the mechanisms underlying the functional deterioration late after the Fontan procedure

Ventricular Afterload and Ventricular Work in Fontan Circulation



Circulation 2002

- ↑ vascular resistance
- ↑ ventricular afterload
- ↓ ventricular hydraulic power cost per unit
- ↓ ß-adrenergic reserve

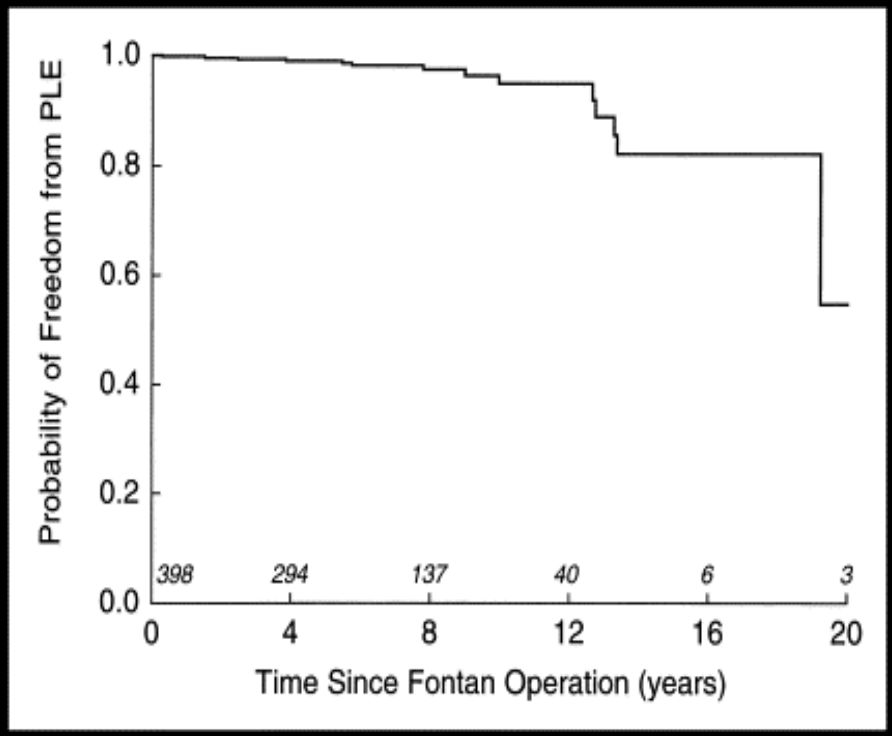
Abnormal myocardial-peripheral vascular coupling

Ventricular function

- Enalapril in Patients After Fontan Procedure (*Circulation.* 1997)
- 18 subjects (14.5±6.2 years of age, 4 to 19 years after Fontan procedure)
- Enalapril for 10 weeks.
- No change in abnormal systemic vascular resistance, resting cardiac index, diastolic function, or exercise capacity

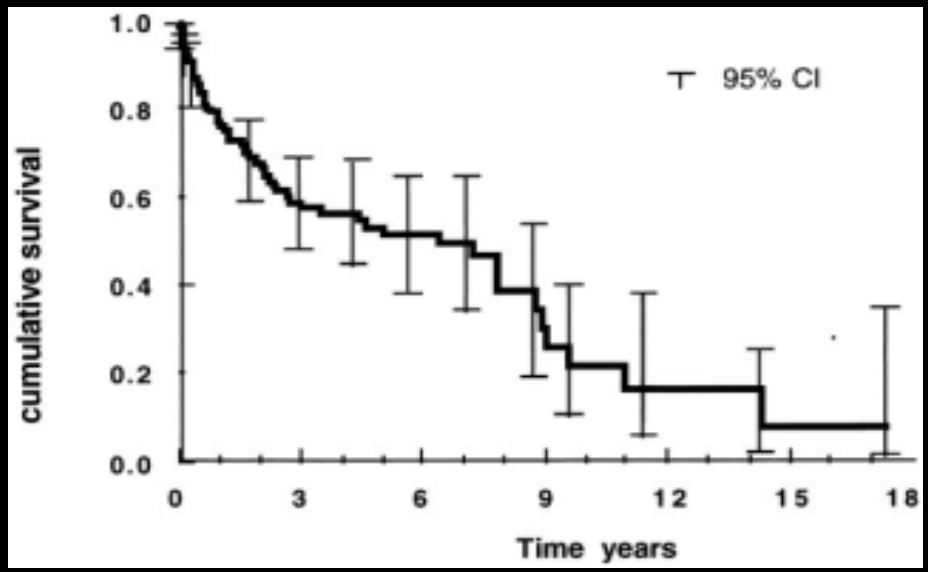
Protein losing enteropathy

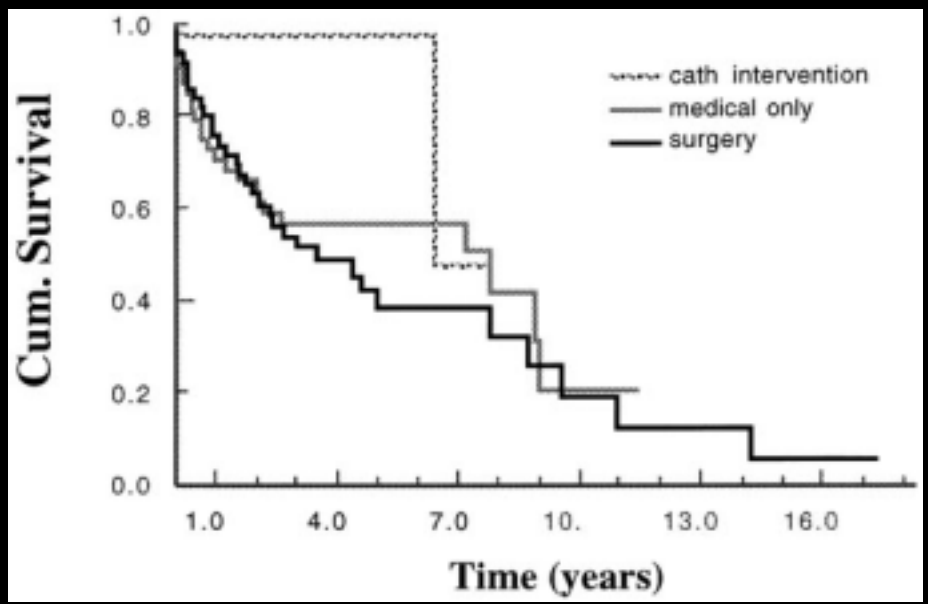
AJC 2001



- 15/398 patients (3.8%)
- at a median of 9.0 years (range 0.3 to 21.2) after Fontan
- Freedom from PLE
  - 99.8% at 1 year
  - 98.9% at 5 years
  - 94.8% at 10 years
- Risk factors
  - **longer CPB time**
  - **single RV anatomy**

Protein losing enteropathy





JTCS 1998

- Multicenter study
- 3029 Fontan operations
- 3.7% of incidence
- Median 2.7 years after op. (0.1 -16.4 years).

Pregnancy

JACC 1996

- 33 pregnancies in 14 mothers with Fontan
- 15 (45%) live births

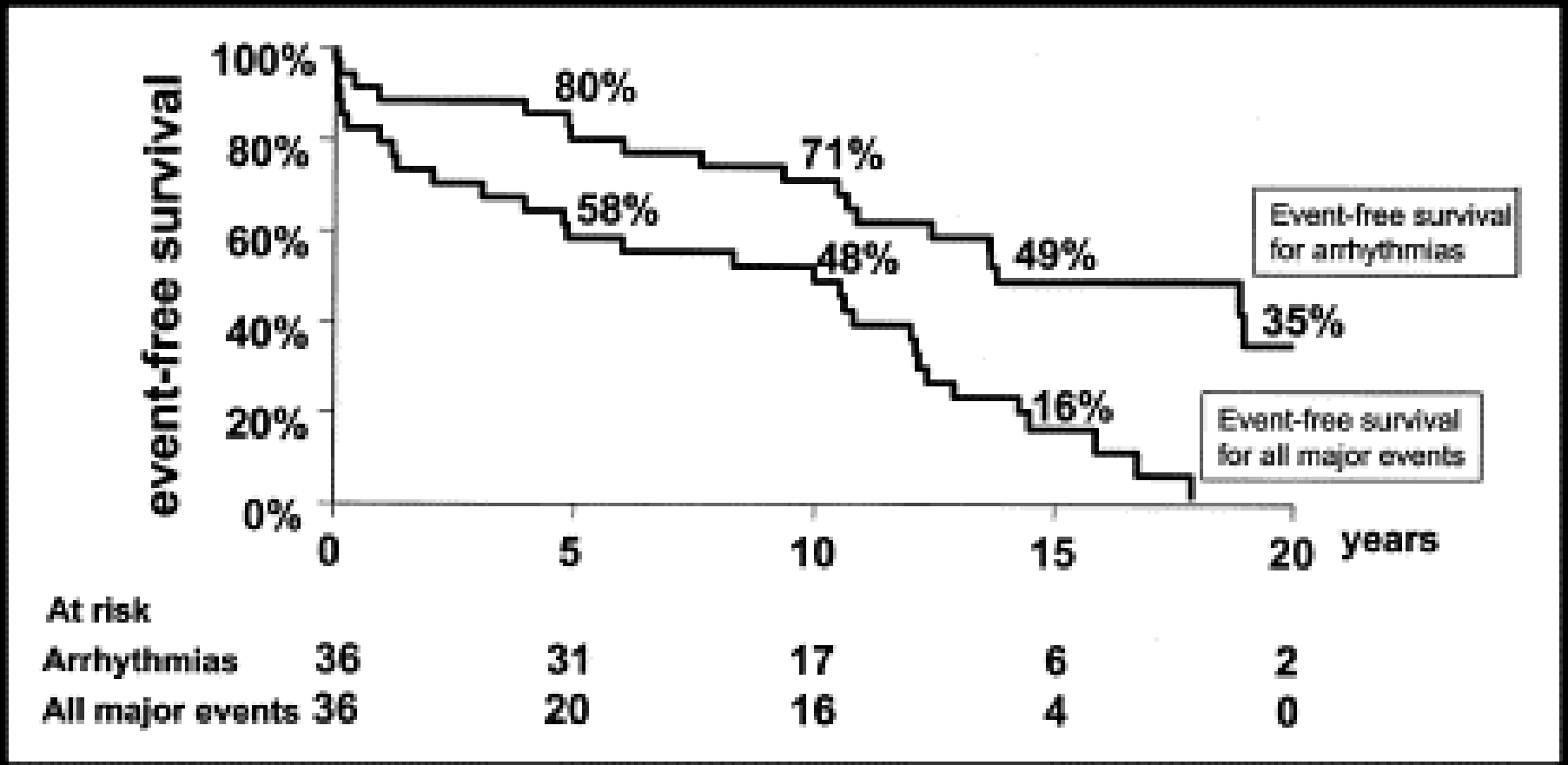
  13 spontaneous abortions

  5 elective terminations
- Reported prepregnancy problems
  - Atrial flutter
  - Ventricular dysfunction
  - AR, AVVR
  - Supraventricular tachycardia
- No maternal cardiac complications during labor

Long-term outcome and quality of life in adult patients after the Fontan operation

•36 adult Fontan patients

Netherlands AJC 2004



Long-term outcome and quality of life in adult patients after the Fontan operation

•36 adult Fontan patients

Netherlands AJC 2004

TABLE 3 Quality of Life Based on the Short Form 36 Results Compared With Population Normative Data

	Fontan Patients (n = 22)	General Population	p Value
1. Physical functioning	80.2 ± 14.5	93.1 ± 11.8	<0.0001
2. Role — physical	61.9 ± 40.0	86.4 ± 27.6	<0.0001
3. Role — emotional	79.4 ± 34	85.4 ± 30.0	0.4
4. Social functioning	77.6 ± 26.7	87.8 ± 19.1	0.02
5. Mental health	54.5 ± 22.6	78.7 ± 15.2	<0.0001
6. Energy/vitality	68.8 ± 21.2	70.7 ± 16.4	0.6
7. Pain	79.1 ± 23.8	80.9 ± 19.4	0.9
8. General health perception	56.7 ± 21.6	78.2 ± 17.3	<0.0001

Values are mean ± SD.

Conclusions

- Fontan procedure is a ‘good palliative’ operation for complex CHD.
- Despite improved survival, significant morbidity remains after the Fontan completion, including ventricular dysfunction, arrhythmia, thrombo-embolism, protein-losing enteropathy, somatic growth retardation, decreased exercise capacity, and below average cognitive function.