生命・愛心・卓越・創新

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Pulmonary function after surgical VSD closure

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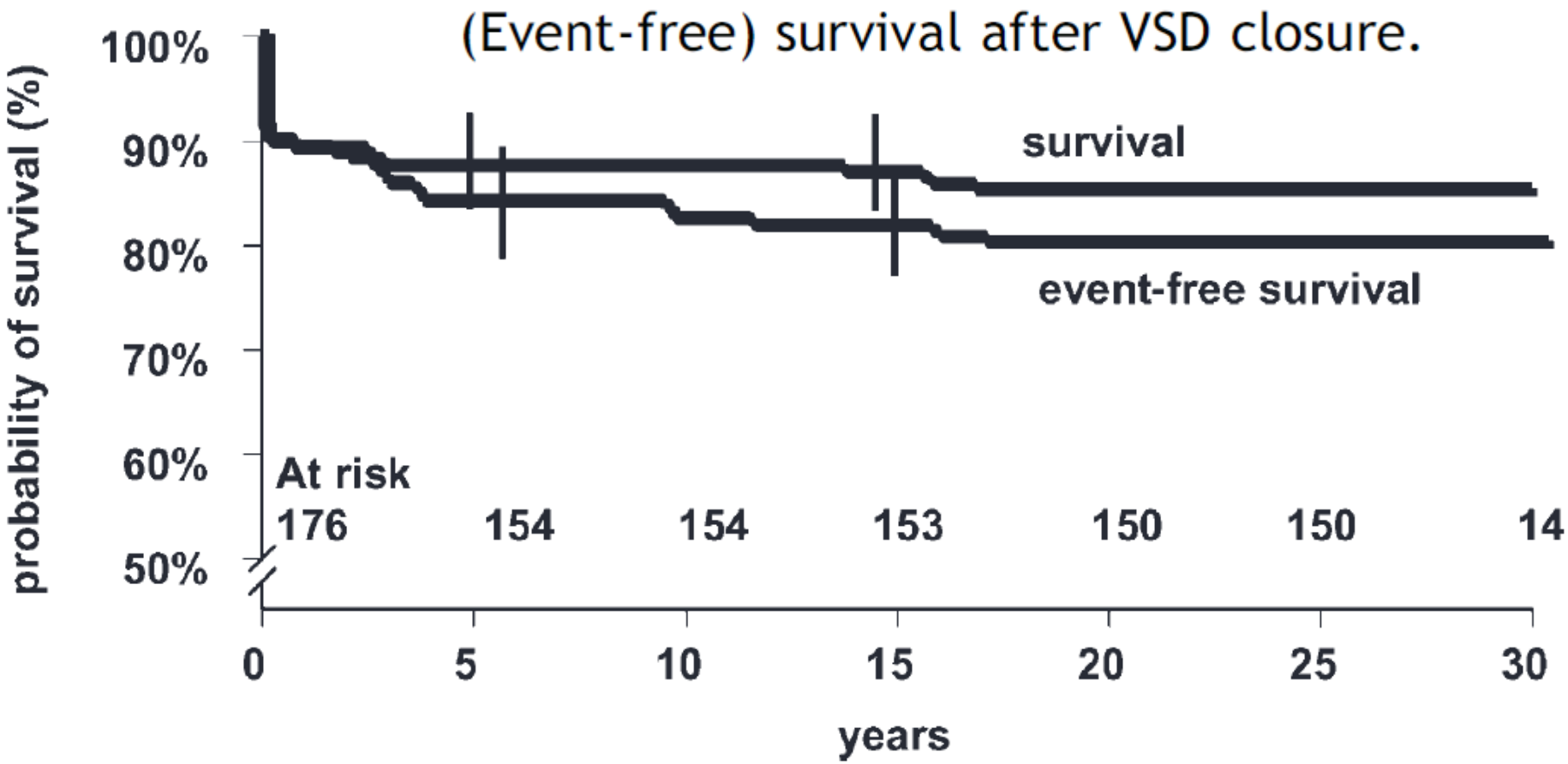
Current expectations for surgical repair of VSD



Roos-Hesselink JW, et al. Eur Heart J 2004

Mortality no longer the only "Outcome" of Interest

- Reduce Short/Long Term CardioPulmonary Morbidity
  - Short term post-operative critical care are widely studied
  - Long term subtle effects on cardiac function, pulmonary function and exercise performance are not widely appreciated
- Reduce Short/Long Term CNS Morbidity
  - Improve pre- & post-op care, cardiopulmoanry by-pass technique
- Shorten Length of Stay
  - Cost, Emotional Burden

Long-term cardio-respiratory consequences of CHD

- The dynamic interaction between the heart and lungs leads to a degree of respiratory co-morbidity including both restrictive and obstructive airway abnormalities, which may be overlooked in children with congenital heart disease.
- Many CHD Infants may not consider much beyond the immediate surgical mortality, and only later come to appreciate that many children will have significant cardio-respiratory limitations as well as neuro-cognitive abnormalities into their adult years.

Fitzgerald DA, et al. Paediatr Respir Rev 2007

How good is good enough?

- One of the reasons for physical limitations and decreases in functional capacity may be a disturbance in pulmonary function.
- 88% of children have significantly abnormal lung function (increased lung stiffness, restricted lung volumes, and hyperinflation) after TGA repair.
- Impairment of lung function related to disease itself or surgical procedure?

Samanek M, et al. Int J Cardiol 1989

Key questions of pulmonary function after surgical VSD closure

- Lung function before surgery
- Effects of surgical repair and cardiopulmonary bypass
- Long term cardiopulmonary function

Pathologic lung function in children with CHD

Left to Right shunt (high flow to lung)

- Pulmonary hyperinflation was more frequent in patients with VSD and coarctation of the aorta

Right to Left Shunt (Low flow to lung)

- Pulmonary restriction dominated in patients with TOF.
- Airways obstruction was observed most frequently in patients with TOF.

Lubica H. Pediatr Cardiol 1996

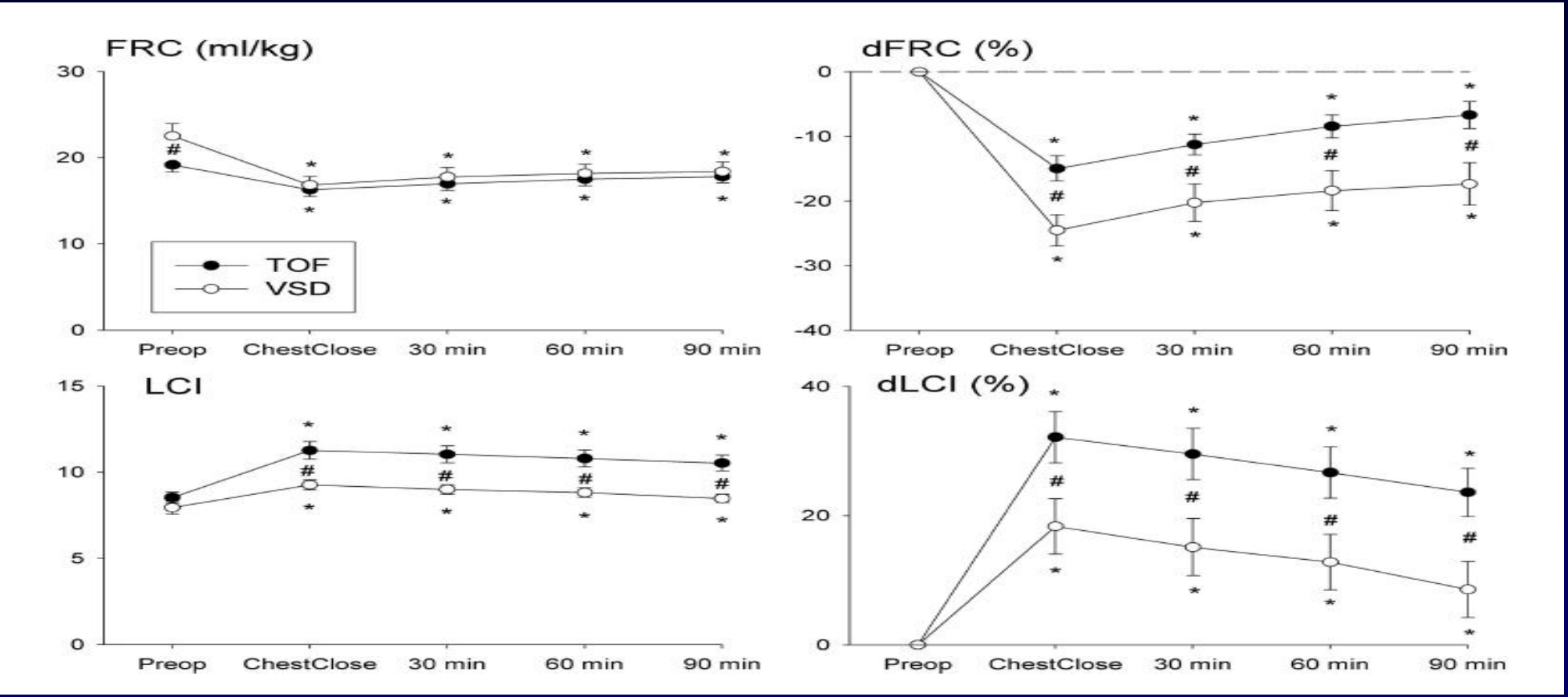
Immediate effects of cardiopulmonary bypass after surgical VSD closure

指标	CPB 前	CPB 后							
		3h	6h	9h	12h	15 h	18 h	21 h	24 h
OI									
肺动脉高压组	222±52##	240±49##	189±47	165±35*	170±54*	153±44**	191±52	195±66	201±61
无肺动脉高压组	424±73	318±42*	275±37*	251±35**	240±37**	245±44**	266±40*	275±89*	294±43*
A_aDO_2(mmHg)									
肺动脉高压组	442±52##	169±41##**	188±42**	200±45**	194±59**	208±53**	178±60**	182±55**	177±52**
无肺动脉高压组	246±74	119±23**	131±18**	150± 8**	151±19**	151± 7**	141±19**	138±38**	131±21**
$Pa_{O_2}/P_{A_{O_2}}$									
肺动脉高压组	0.3±0.1##	0.4±0.1	0.3±0.1	0.3±0.1	0.3±0.1	0.3±0.1*	0.4±0.1	0.4±0.1	0.4±0.1
无肺动脉高压组	0.6±0.1	0.5±0.1*	0.5±0.1*	0.4±0.1**	0.4±0.1**	0.4±0.1**	0.4±0.1*	0.5±0.2*	0.5±0.1*
RI									
肺动脉高压组	2.2±1.0##	1.6±0.6##	2.2±0.9	2.5±0.9*	2.5±1.3*	2.8±1.2*	2.0±1.0	2.1±1.0	2.0±1.1
无肺动脉高压组	0.6±0.3	0.9±0.2	1.1±0.3*	1.4±0.3**	1.6±0.3**	1.5±0.5**	1.3±0.3*	1.5±0.6	1.2±0.4
Cdyn(ml/cmH_2O)									
肺动脉高压组	4.1±0.6##	3.9±0.7##	3.8±0.8	3.7±0.7*	3.7±0.8*	3.6±0.9*	3.8±0.9	4.4±1.6	4.6±2.0
无肺动脉高压组	7.8±4.0	6.7±3.6	6.5±3.3*	6.5±3.9*	5.9±3.0*	6.4±3.6*	6.4±3.2*	6.8±4.0	5.9±3.7*
Cstat(ml/cmH_2O)									
肺动脉高压组	3.9±0.6##	3.8±0.7##	3.6±0.8	3.7±0.7	3.5±0.8*	3.6±0.8*	3.7±0.8	4.1±1.3	4.4±1.8
无肺动脉高压组	7.9±4.4	6.7±3.5	6.8±3.7	5.5±2.8*	5.7±2.9*	6.3±3.5*	6.1±3.1*	6.7±3.9	5.6±3.8*

注：两组比较# $P<0.05$，## $P<0.01$；与本组 CPB 前比较 * $P<0.05$，** $P<0.01$

Jou YP, et al. Chin J Clin Thorac Cardiovasc Surg 2006

Changes in functional residual capacity and lung mechanics during surgical repair



Ungern-Sternberg BS, et al. Anesthesiology 2009

Pulmonary function after VSD repaired

- The size of the VSD, thus the degree of severity of the left to right shunt, and the influence of the timing of surgical procedures (primary closure versus pulmonary artery banding and subsequent VSD closure) may result in different pulmonary function outcomes.
- The age of intervention, and the follow up period are also important.

Fitzgerald DA, et al. Paediatr Respir Rev 2007

VSD with pulmonary hypertension after repair 6-16 years

Case No.	FEV_1 (s)	VC	$\frac{FEV_1\ s}{VC}$ (per cent)	TLC	TLCO
1	2·40	3·00	80	4·25	21·8
2	2·45	2·80	88	3·60	21·7
3	3·85	4·05	95	—	—
4	3·80	4·90	78	6·85	32·5
5	2·80	3·50	80	5·60	35·6
6	4·20	5·35	79	6·10	35·9
7	4·50	5·40	83	—	—
8	3·10	3·70	85	5·30	26·9
9	3·70	4·20	88	6·30	28·7
10	3·10	4·50	69	6·10	33·1
11	4·60	5·20	88	6·81	35·2
12	1·85	2·25	82	—	17·2
13	2·10	2·50	84	3·30	18·2
14	—	—	—	—	14·7
15	2·60	2·80	93	4·10	14·3
16	2·05	3·05	67	3·90	19·2
17	3·10	3·90	79	5·00	20·6
18	2·00	2·20	91	3·90	18·0
19	2·30	2·40	96	3·40	20·1
Mean ±SD	3·00 ±0·42	3·65 ±0·47	84 ±7	4·93 ±0·74	24·4 ±3·2
% Predicted mean ±SD	85·4 ±14	90·2 ±13		93·8 ±15	86·9 ±1·3
Norman range* % Predicted	80–120	80–120	> 75	80–120	> 75

FEV_{1S} forced expiratory volume in 1 second—litres/second; VC, vital capacity—litres; TLC, total lung capacity—litres; TLCO, carbon monoxide transfer factor—ml/mmHg per min.
*Normal data (Cotes, 1968).

Hallidie-Smith KA, et al. British Heart Journal, 1977

VSD with pulmonary hypertension after repair 6-16 years

Case No.	FEV_1 (s)	VC			TLCO
1					21·8
2					7
3					
4					
5					6
6					
7					
8					
9					
10					
11					
12					
13					18·2
14					14·7
15					14·3
16					19·2
17					20·6
18					18·0
19					20·1
Mean ±SD	3·00 ±0·42		±7	4·93 ±0·74	24·4 ±3·2
% Predicted mean ±SD	85·4 ±14	90·2 ±		93·8 ±15	86·9 ±1·3
Norman range* % Predicted	80–120	80–120	> 75	80–120	> 75

Lung function tests were normal for the group as a whole, only two patients showed mild restrictive ventilator defects !!

FEV_{1S} forced expiratory volume in 1 second—litres/second; VC, vital capacity—litres; TLC, total lung capacity—litres; TLCO, carbon monoxide transfer factor—ml/mmHg per min.
*Normal data (Cotes, 1968).

Hallidie-Smith KA, et al. British Heart Journal, 1977

Comparison of TOF, VSD, or ASD after correction (8-15 years)

TABLE II Functional Status for All Groups

	TF	VSD	ASD	Controls
Pulmonary function tests at rest				
Vital capacity (liters)	3.32 ± 1.1	3.26 ± 0.72	3.37 ± 0.70	4.16 ± 0.58
Forced expiratory volume (FEV_1) (liters)	3.00 ± 0.9	2.88 ± 0.6	3.21 ± 0.4	3.73 ± 0.52
Residual volume (liters)	1.1 ± 0.3	1.0 ± 0.1	1.0 ± 0.3	1.2 ± 0.2
Pulmonary diffusion capacity (D_LCO) (ml/min/mm Hg)	22.1 ± 6.7	23.2 ± 5.0	25.6 ± 5.5	28.1 ± 6.7
Maximal exercise evaluation				
$\dot{V}O_2$ max (ml/kg/min)	37.6 ± 10.0	34.0 ± 9.2	36.5 ± 7.0	41.3 ± 6.0
SaO_2 (%)	93.2 ± 4.1	92.7 ± 5.3	92.6 ± 4.9	96.1 ± 1.7
Maximal heart rate (beats/min)	178* ± 14	172* ± 17	179* ± 16	191 ± 12

All values are mean ± standard deviation.
* $p < 0.05$ vs controls.
SaO_2 = oxygen saturation; $\dot{V}O_2$ max = maximal oxygen uptake. Other abbreviations as in Table I.

Perrault H, et al. Am J Cardiol 1989

Lung function tests after primary repair of VSD

Lung function test	Test result (mean ± SD)	Percent of predicted value (mean ± SD)	*p*
VC (ml)	2913 ± 938	94 ± 14	NS
TLC (ml)	311 ± 1122	91 ± 11	NS
FRC (ml)	1850 ± 629	92 ± 14	NS
RV (ml)	868 ± 291	90 ± 24	NS
FRC/TLC (%)	48.4 ± 4.5	98 ± 10	NS
RV/TLC (%)	23.1 ± 5.7	94 ± 23	NS
Static recoil pressure (cm H_2O)			
At 100% TLC	46.1 ± 9.3	128 ± 26	<0.0001
At 90% TLC	22.9 ± 3.8	123 ± 20	<0.0001
At 60% TLC	11.5 ± 2.6	146 ± 29	<0.0001
Static lung compliance/TLC (ml cm H_2O^{-1} ml^{-1})	0.036 ± 0.010	95 ± 28	NS
Maximum expiratory flow rate (L s^{-1} L^{-1})			
25% VC/TLC	0.422 ± 0.150	93 ± 29	NS
50% VC/TLC	0.837 ± 0.206	96 ± 23	NS
60% TLC/TLC	0.820 ± 0.287	95 ± 32	NS
Peak expiratory flow rate (L s^{-1})	4.9 ± 1.5	86 ± 19	0.05
Specific airway conductance (L s^{-1} cm H_2O^{-1} L^{-1})	0.147 ± 0.125	75 ± 23	0.05

VC, vital capacity; TLC, total lung capacity; FRC, functional residual capacity; RV, residual volume.

Sulc J, et al. Pediatr Cardiol 1996

Lung function tests after primary repair of VSD

Lung function test	esult	*p*
VC (ml)		NS
TLC (ml)		NS
FRC (ml)		NS
RV (ml)		NS
FRC/TLC (%		NS
RV/TLC		S
Static re		
At 10		0001
At 90%		.0001
At 60% TL		0.0001
Static lung c		NS
Maximum		
25% VC/		NS
50% VC/T		NS
60% TLC/TL		NS
Peak expiratory flow rate (		0.05
Specific airway conductance (	23	0.05

VC, vital capacity; TLC, total lung capacity; FRC, functional r dual volume.

Total 24/34 (71%) patients had significantly abnormal lung function.
The most frequently abnormal functional parameter, increased lung recoil pressure, decreased peak expiratory flow rate and specific airway conductance.

Sulc J, et al. Pediatr Cardiol 1996

Lung function tests after two-stage repair of VSD

Lung function test	Test result (mean ± SD)	Percent of predicted value (mean ± SD)	*p*
VC (ml)	2962 ± 887	87 ± 16	NS
TLC (ml)	4142 ± 1091	93 ± 11	NS
FRC (ml)	2257 ± 586	102 ± 13	NS
RV (ml)	1180 ± 319	111 ± 25	NS
FRC/TLC (%)	54.8 ± 5.1	111 ± 10	<0.001
RV/TLC (%)	29.2 ± 6.8	122 ± 26	<0.05
Static recoil pressure (cm H_2O)			
At 100% of TLC	43.1 ± 13.1	112 ± 35	NS
At 90% of TLC	20.8 ± 4.7	105 ± 22	NS
At 60% of TLC	9.9 ± 2.2	116 ± 25	NS
Static lung compliance/TLC (ml cm H_2O^{-1} ml^{-1})	0.038 ± 0.011	103 ± 30	NS
Maximum expiratory flow rate (L s^{-1} L^{-1})			
25% VC/TLC	0.351 ± 0.114	79 ± 26	<0.01
50% VC/TLC	0.726 ± 0.209	85 ± 21	<0.05
60% TLC/TLC	0.616 ± 0.249	74 ± 27	<0.01
Peak expiratory flow rate (L s^{-1})	5.1 ± 1.5	82 ± 15	<0.05
Specific airway conductance (L s^{-1} cm H_2O^{-1} L^{-1})	0.135 ± 0.061	69 ± 31	<0.01

Abbreviations as in Table 1.

[a] Defect closed after previous pulmonary artery banding.

Sulc J, et al. Pediatr Cardiol 1996

Lung function tests after two-stage repair of VSD

Lung function test								p
VC (ml)								NS
TLC (ml)								
FRC (ml)								
RV (ml)								
FRC/TLC (%)								001
RV/TLC (%								5
Static rec								
At 100								
At 90%								
At 60%								
Static lung com								
Maximum ex								
25% VC/								<0.01
50% VC/								<0.05
60% TLC/								<0.01
Peak expiratory								<0.05
Specific airway conductanc								<0.01

Abbreviations as in Table 1.
[a] Defect closed after previous pulmonary artery banding.

Total 10/13 (77%) patients had abnormal lung function.
Maximum expiratory flow rate and specific airway conductance were reduced.

Sulc J, et al. Pediatr Cardiol 1996

Lung function and cardiopulmonary exercise capacity in patients with corrected Tetralogy of Fallot

FEV1 (L)*	82.86 ± 16.46	3.31 ± 0.55
FVC (L)*	80.28 ± 16.21	3.78 ± 0.61
FEV1/FVC (%)	88.03 ± 9.99	
Dlco (ml/min/kg)*	85.93 ± 15.47	28.47 ± 4.41
TLC (L)*	91.37 ± 13.89	5.97 ± 0.83
SaO_2 (%)	96.84 ± 2.58	
6MWD (m)	601 ± 92	

* Expressed as percent of predicted value (second column) and absolute value (third column)

Work (watts)*	59.75 ± 20.15	122 ± 24.58
VO_2max (L/min)*	76.85 ± 21.46	2004 ± 430
VO_2@AT (L/min)**	50.6 ± 12.0	1319 ± 31.2
Heart rate (beats/min)*	78.16 ± 12.0	148 ± 18
VE (L/min)	46.68 ± 15.33	72 ± 11.04
O_2P*	96.73 ± 19.15	

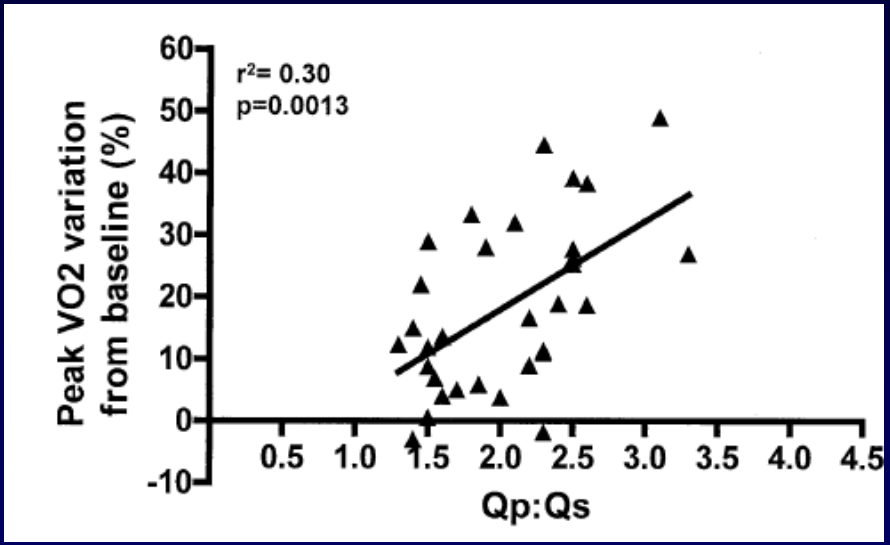
Izbicki G, et al. IMAJ 2008

Frequency of abnormal lung function before and after surgery for ASD

	Before (n = 26)		*After (n = 24)*		
	n	*%*	*n*	*%*	*p*
Lung volume restriction	2	7.7	3	8.3	NS
Hyperinflation	5	19.2	1	4.2	NS
Stiff lung	12	46.2	9	37.5	NS
Emphysematous lung	2	7.7	1	4.2	NS
Airway obstruction					NS
Central	4	15.4	0	0	< 0.05
Peripheral	4	15.4	4	16.7	NS
Total	18	69.2	12	50.0	NS

Sulc J, et al. Heart 1998

Cardiopulmonary functional improvement after transcatheter ASD closure in adults



	Baseline	6 Months	p Value*
VC (l)	3.44 ± 1.0	3.72 ± 0.9	0.0086
FEV_1 (l/s)	2.79 ± 0.83	2.98 ± 0.86	0.088
Peak V_{O_2} (ml O_2/kg/min)	21.9 ± 10.3	25.6 ± 9.9	<0.0001
Peak O_2 pulse (ml O_2/kg/beat)	8.9 ± 2.81	10.2 ± 3.7	0.0004
Peak heart rate (beats/min)	155.8 ± 21.7	157.4 ± 19.1	0.086
LVEDD (cm)	4.8 ± 0.4	5.1 ± 0.4	<0.0001
LVESD (cm)	3.0 ± 0.4	3.1 ± 0.4	0.19
LVEF (%)	73.8 ± 6.8	77.6 ± 5.3	<0.0001
LA diameter (mm)	28.9 ± 3.5	31.3 ± 3.8	<0.0001
RVLA dimension (mm)	75.5 ± 11.6	67.6 ± 9.6	<0.0001
RVSA dimension (mm)	36.2 ± 6.3	30.5 ± 6.0	<0.0001

Giardini A, et al. JACC 2004

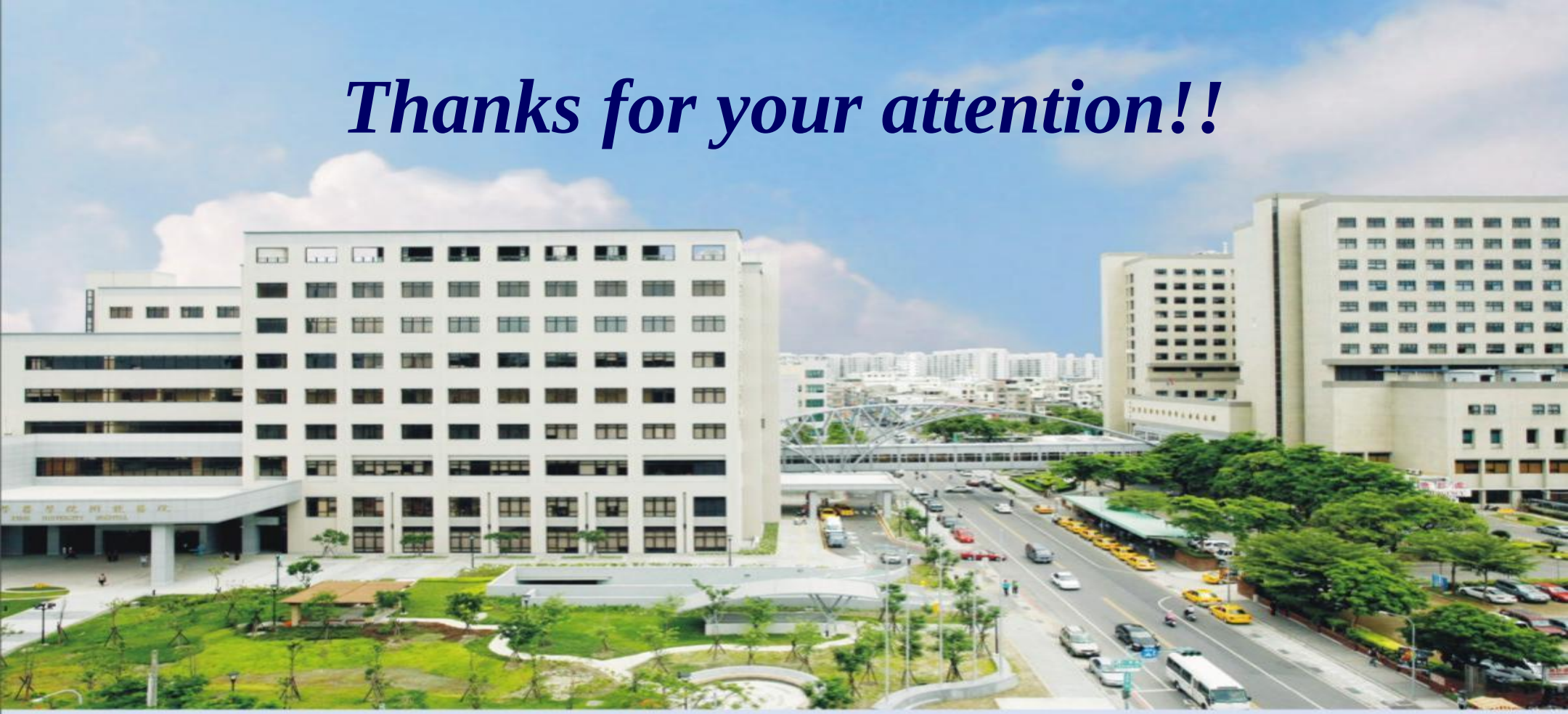
Conclusion (I)

- According to the limited data, there is a discrepancy between their good clinical condition and abnormal lung function tests after VSD surgical closure.
- Lung function test data need not correlate in some cases with pulmonary hemodynamics. The beneficial postoperative changes in children with VSD are consequences of the reversal of the pulmonary vascular engorgement after surgical repair.

Conclusion (II)

- We therefore believe that a lower frequency of lung function test abnormalities is possible in patients after early open-heart surgery for VSD.
- Further studies on pulmonary function after trans-catheter closure of VSD are needed.

Thanks for your attention!!



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