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Does repair of pectus excavatum improve cardiopulmonary function?

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Abstract

A best evidence topic was written according to a structured protocol. The question addressed was 'Does repair of pectus excavatum (PE) improve cardiopulmonary function?' One hundred and sixty-eight papers were found using the reported search, 19 level III evidence papers and three meta-analyses were relevant. Studies were divided into four groups based on the surgical technique applied and pulmonary and cardiac functions in these groups were analysed. The meta-analyses show conflicting results for improvements in pulmonary and cardiac functions when comparing surgical techniques, while four more recent studies show improved long-term results using the Nuss technique. The best evidence of papers studying the PE repair using the minimally invasive Nuss technique demonstrates a decrease in pulmonary function during the early postoperative period, however, there is a small but significant improvement during the late postoperative period and after bar removal. The best evidence for cardiac function in this group suggests an early improvement that is sustained during further follow-up. The best evidence of papers studying the PE repair using the Ravitch technique shows that pulmonary function decreased during the early postoperative period, however, there is a small but significant improvement during the late postoperative period. The best evidence for cardiac function in this group suggests an early improvement that is sustained during further follow-up. The best evidence of papers studying the PE repair using other techniques (modified Daniel's technique, modified Baronofsky's technique, sterno-costal turn-over technique and sterno-costal elevation technique) or where surgical techniques used were not described (preceding year 1985) suggests that there is no improvement in pulmonary function after surgery. There is some evidence that certain aspects of cardiac function improved after surgery in this group.

Keywords: Pectus excavatum • Nuss • Ravitch • Pectus repair • Cardiac function • Pulmonary function

INTRODUCTION

A best evidence topic was constructed according to a structured protocol as described in *ICVTS* [1].

THREE-PART QUESTION

Does [repair] of [pectus excavatum] improve [cardiopulmonary function]? Search strings were used as below.

[Pectus excavatum] OR [Pectus] and [repair] OR [Surgery] and [cardiopulmonary] OR [cardio respiratory] OR [cardiac function and pulmonary function].

CLINICAL SCENARIO

A 23-year old Caucasian man was referred by his general practitioner with a history of 'funnel chest' since birth. He describes symptoms of increasing breathlessness on exertion. How does pectus excavatum (PE) affect cardiopulmonary function? Does his symptom improve after surgery?

SEARCH STRATEGY

MEDLINE 1948 to present, OLD MEDLINE(R) 1946–1965, HMIC 1979-November 2011, EMBASE 1980–2012 Week 8 were searched via the OVID interface.

SEARCH OUTCOME

Of the 168 results found, studies with quantitative measures of, and including duration between, preoperative and postoperative cardiopulmonary function, published in the English language, indexed from January 1948 till February 2012 and describing the cardiopulmonary assessment procedures were considered. Pulmonary function including any of forced vital capacity, forced expiratory volume measured over 1 s (FEV_1), total lung capacity, vital capacity, residual volume (RV) or maximal oxygen uptake (VO_2 max) and cardiac function assessed using echocardiography, radionuclide assays, cardiac output and cardiac index studies were used as common criteria. Studies not matching all of the above criteria, narrative reviews and expert opinions not including statistical data analysis were excluded.

In total, 22 papers were found, of which three meta-analyses and their papers along with four recent papers were relevant; these are summarized in Table 1 [2–8].

RESULTS

Up to 40% of spirometric tests may change their clinical category (from normal to abnormal) simply by changing the equation used. Assuming values of <80% predicted values to be abnormal causes underdiagnosis in younger and taller individuals [9].

Pulmonary function: vital capacity [6, 10–14], inspiratory vital capacity [11, 15, 16], forced vital capacity [6, 8, 17–20], total lung capacity [10, 12–15, 21, 22], FEV_1 [6–8, 11, 13, 15–17, 19, 20] and $FEV_{25–75}$ [17, 19] are low in PE patients and correlate with severity of PE [10, 12, 14, 18].

Cardiac function: Work performance [6, 21], stroke volume [13] and RV [7, 14, 16, 23] indices were decreased. Mitral valve abnormality [5, 17, 24] was present in significantly larger proportion in PE patients but this did not correlate with the severity of PE [7, 16, 23].

A meta-analysis of pulmonary function by Malek *et al*. did not consider surgical techniques separately in the included studies [10–14, 16, 18, 19, 21, 22, 25] and reported that surgical repair does not significantly improve pulmonary function [2].

A similar meta-analysis by Malek *et al*. considering global cardiopulmonary function in the included studies [13, 14, 16, 18, 21–23, 25] showed significant improvement after surgery [3].

Another meta-analysis of studies [10–12, 15, 16, 19, 20, 22, 24, 25] reported that FEV_1 increased after Nuss bar removal, total lung capacity decreased after Ravitch repair, and exercise tolerance did not improve after either type of surgical repair [4].

Studies were divided into four groups based on the surgery type. Pulmonary function and cardiac function in these groups were analysed. Eight studies used Nuss, four used modified Ravitch repair, four used other techniques and three were undefined.

Nuss repairs

Studies measuring pulmonary function between 3 and 6 months postoperatively showed diminished values [14, 20, 24].

An early postoperative period study showed significantly reduced pulmonary function (forced vital capacity, FEV_1, total lung capacity) [14]. However, cardiac function (stroke volume) significantly improved postoperatively. Borowitz *et al*. [24] did not observe change in static or exercise pulmonary function, 6–12 months postoperatively.

A recent study showed that FEV_1 and cardiac index were lower in PE and were increased one year later when the bar was still *in situ* [7].

A late postoperative period study after removal of the Nuss bar showed postoperative sustained improvement in pulmonary function and cardiac function [8]. Lawson *et al*. [19] showed small (11%, 7%) but significant improvement in pulmonary function (FEV_1, forced vital capacity) in a sub-group of patients above 11 years of age after removal of the Nuss bar. Bawazir *et al*. [20] reported that pulmonary function and exercise tolerance were reduced postoperatively with significant increase during follow-up after bar removal but remained below normative values of similar age. Cardiac function increased at 3 months postoperatively and remained stable. Castellani *et al*. [6] found in their group that after bar removal, lung performance and exercise performance did not improve, but reported evidence of relief of cardiac compression. Coln *et al*. [5] demonstrated improvement of cardiac abnormalities after repair.

The majority of the studies performed post-bar removal demonstrated a small but significant improvement in pulmonary function [8, 19, 20].

Ravitch

Studies during 6–8 months postoperatively found reduced pulmonary function [18, 22].

An early postoperative period study showed no improvement in pulmonary function [26]. Increase in stroke volume was reported. Wynn *et al*. [22] showed total lung capacity and vital capacity decrease with RV increase suggestive of a restrictive deformity augmented by the procedure itself. VO_2 max, cardiac output and stroke volume increases were non-significant.

A late postoperative period study found a modest improvement (6.4%) in pulmonary function only in a subgroup with severely reduced pulmonary function ($FEV_1 < 75\%$ predicted) preoperatively [16]. Significant improvements in cardiac function including right ventricular diastolic volume indexes were noted. Hu *et al*. [13] reported a modest improvement (7%, 18%) in pulmonary function (total lung capacity, forced vital capacity), and cardiovascular function (ejection fraction %, EF%) improved significantly late postoperatively.

Other

Other studies consistently showed diminished pulmonary function [11, 12, 15, 25]. Derveaux *et al*. [11] showed that ventilatory restrictions worsen after surgery attributable to extensive surgery causing a restrictive defect.

Kaguraoka *et al*. [12] noticed no improvement in pulmonary function after repair. Morshuis *et al*. [25] noticed a significant reduction in pulmonary function and a significant increase in VO_2 max one year after operation. Long-term results by Morshuis *et al*. [15] showed a significant reduction in pulmonary function (inspiratory vital capacity, total lung capacity).

Unknown

A study at 3–9 months postoperatively demonstrated a small improvement in total lung capacity, VO_2 max and significant (22%) improvement in maximal voluntary ventilation [21]. Another study at 2–6 years found vital capacity, total lung capacity and maximal breathing capacity to be significantly low in PE patients, which significantly decreased postoperatively [10]. Peterson *et al*. [23] demonstrated no significant increase in right ventricular ejection fraction % (RVEF%) from rest to exercise after PE repair.

CLINICAL BOTTOMLINE

In patients with PE, both cardiac function and pulmonary function are reduced. Pectus repair using minimally invasive Nuss technique and Ravitch procedure cause an early decrease in the pulmonary function. However, a small, but significant, return of function does occur during the late postoperative period. Cardiac function increases during the early postoperative period, an improvement that is sustained. In contrast, pectus repair using other techniques has not shown similar improvements.

Table 1: Best evidence papers

Author, date, journal and country Study type (level of evidence)	Patient group	Outcomes	Key results	Comments
Sigalet *et al.*, 2007, Pediatr Surg Int, Canada [8] Cohort study (level III)	$n = 26$ Mean age = 13.2 ± 2.1 years Nuss	Preop and 3 months post-bar removal FVC FEV$_1$ TLC VC VO$_2$ max SV (ml) Cardiac output Cardiac index	Sustained improvement in PF and aerobic exercise tolerance (Mean ± SD) 90 ± 19 to 92 ± 21 (P = NS) 78 ± 16 to 84 ± 18 ($P < 0.05$) 95 ± 16 to 99 ± 14 ($P < 0.05$) 91 ± 19 to 93 ± 21 (P = NS) 71 ± 11 to 77 ± 11($P < 0.05$) 69 ± 21 to 84 ± 25 ($P < 0.05$) 4.7 ± 1.4 to 5.4 ± 1.5 ($P < 0.05$) 3.1 ± 0.8 to 3.3 ± 0.8 (P = NS)	Sex distribution not reported Patients not exercised up to anaerobic threshold were excluded Improvement in SV and CO and no change in CI maybe because of growth
Lawson *et al.*, 2005, J Pediatr Surg, USA [19] Cohort study (level III)	$n = 45$ (two groups, age < or >11 years) Median age = 11.4 years Male:female = 4:1 Nuss	Preop, postop and post-bar removal (mean = 2.9 years) Age <11 years $n = 20$ FEV$_1$ FVC Age >11 years $n = 25$ FEV$_1$ FVC	(Mean ± SEM) 86 (76–94 IQR) to 88 (79–97 IQR) ($P = 0.54$) 86 (75–94) to 89 (79–99) ($P = 0.1082$) 81 (74–90) to 90 (82–100) ($P = 0.0052$) 84 (76–92) to 90 (78–101) ($P = 0.0015$)	Small but definite improvement in patients over the age of 11 years, PF improvement after bar removal most prominent in FEF$_{25–75}$ = 15% No exercise testing performed
Bawazir *et al.*, 2005, J Pediatr Surg, Canada [20] Cohort study (level III)	$n = 22$ ($n = 10$ post-bar removal) Mean age = 13.5 ± 1.7 years Nuss	Preop, 3, 21–24 months postop and 3 months after bar removal FVC FEV$_1$ TLC VC VO$_2$ max SV Cardiac output Cardiac index	(Mean ± SEM) 89 ± 3 to 87 ± 4 79 ± 2 to 80 ± 4 ($P < 0.05$) 98 ± 3 to 98 ± 5 93 ± 3 to 87 ± 4 68 ± 2 to 71 ± 4 ($P < 0.05$) 70 ± 4 to 86 ± 7 4.8 ± 0.2 to 5.6 ± 0.3 ($P < 0.05$) 3.3 ± 0.1 to 3.5 ± 0.2 ($P < 0.05$)	Sex distribution not reported Decrease in early postoperative PF and exercise tolerance which improves above baseline *y* Early increase in CF which remains stable
Castellani *et al.*, 2010, Pediatr Surg Int, Austria [6] Prospective study (level III)	$n = 59$ Mean age = 15.7 + 4.5 years Male:female = 9:1 Nuss	Preop, 6–12 months and after bar removal within 3 years FVC VO$_2$ max	(Mean ± SEM) 91 ± 14 to 88 ± 13 (P = NS) 50 ± 6 to 50 ± 7 (P = NS)	PE repair does not improve PF and exercise performance, increase of body weight and de-conditioning cited
Tang *et al.*, 2011, Eur J Cardiothorac Surg, Denmark [7] Case–control study Prospective (level III)	$n = 49$ Mean age = 15.5 ± 1.7 years Modified (smaller bar) Nuss	Preop and 1 year postop (bar *in situ*) FVC FEV$_1$ Cardiac index	(Mean ± SEM) 96 ± 14 to 97 ± 13 (P = NS) 87 ± 13 to 91 ± 13 ($P < 0.01$) 6.6 ± 1.1 to 7.2 ± 1 ($P < 0.01$)	FEV$_1$, CI lower in PE preop significantly increased postop No exercise testing performed
Coln *et al.*, 2006, J Pediatr Surg, USA [5] Retrospective cohort study July 1998–Dec 2004 (level III)	$n = 107$ Mean age = 13 years Male:female = 4:1 Nuss	Preop and 2 years postop (bar *in situ*) Preop echo/ECG Postop echo/ECG	Cardiac compression in 117 (95%), MV abnormality in 54 (44%) Normal in 100 (93%)	Positive correlation attributed to Haller index. Known relationship between PE and MV prolapse-increases with age Showed complete relief of cardiac compression

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Table 1: (*Continued*)

Author, date, journal and country Study type (level of evidence)	Patient group	Outcomes	Key results	Comments
Sigalet *et al.*, 2003, J Pediatr Surg, Canada [14] Cohort Study (level III)	$n = 11$ Mean age = 13.5 + 3.1 years Male:female = 10:1 Nuss	Preop and 3 months postop FVC FEV_1 TLC VC VO_2 max SV (ml)	Severity of PE-Haller index CT/−4.1 + 0.9 (Mean ± SD) 92 ± 22 to 72 ± 15 ($P < 0.05$) 79 ± 22 to 68 ± 19 (P = NS) 108 ± 24 to 96 ± 16 (P = NS) 94 ± 21 to 75 ± 16 (P = NS) 69 ± 24 to 56 ± 25 ($P < 0.05$) 62 ± 24 to 78 ± 23 ($P < 0.05$)	All PF tests decreased in the early postoperative period
Borowitz *et al.*, 2003, J Pediatr Surg USA, [24] Cohort study (level III)	$n = 10$ Mean age = 13.4 ± 3 years Male:female = 10:0 Nuss	Preop and 6–12 months postop FVC FEV_1 TLC VO_2 max	P = NS for all measures, no restriction noticed after op Mean (range) 91 (*R*: 62–108) to 86 (*R*: 49–110) 91 (*R*: 65–112) to 88 (*R*: 57–116) 91 (*R*: 73–114) to 91 (*R*: 62–112) 85 (*R*: 52–106) to 88 (*R*: 52–108)	No results post-bar removal
Kowalewski *et al.*, 1998, Eur J Cardiothorac Surg, Poland [16] Cohort study (level III)	$n = 34$ Mean age = 13.4 (*R:* 4–35) Male:female = 12:5 Modified Ravitch repair	Preop and 5 years postop (echo done after 1 year) Group I-mod PE ($n = 24$) FEV_1 SVI_{LV} SVI_{RV} Group II-severity of PE ($n = 10$) FEV_1 SVI_{LV} SVI_{RV}	Mean ± SD 78 ± 17 to 83 ± 23 ($P < 0.082$) 36 ± 5 to 39 ± 8 (P = NS) 17 ± 3 to 25 ± 7 ($P < 0.001$) 65 ± 16 to 69 ± 15 ($P < 0.069$) 30 ± 10 to 42 ± 12 ($P < 0.05$) 10 ± 2 to 22 ± 5 ($P < 0.001$)	In a subgroup ($n = 22$) where preop FEV_1, IVC ($n = 18$) was <75% predicted, there was a statistically significant improvement postop Significant increase of RV diastolic and SV indexes No exercise testing performed
Hu *et al.*, 2000, Chin Med J, China [13] Case–control study (level III)	$n = 40$ Mean age = 4.6 years (*R*: 2.5–16 years) Male:female = 137:34 Modified Ravitch repair	Pre- and 4.2 years postop echo FVC FEV_1 TLC VC SV (ml) EF%	Cardiopulmonary function improved postoperatively whereas PF recovered slowly Mean ± SD 1.85 ± 0.26 to 2.18 ± 0.26 ($P < 0.005$) 1.49 ± 0.20 to 1.52 ± 0.23 ($P < 0.001$) 2.49 ± 0.28 to 2.67 ± 0.32 ($P < 0.05$) 1.74 ± 0.25 to 1.79 ± 0.31 (P = NS) 29.28 ± 7.95 to 35.91 ± 5.08 ($P < 0.01$) 59.40 ± 9.10 to 65.77 ± 4.6 ($P < 0.01$)	Control groups not defined CF below normal in PE SV increased postoperatively
Quigley *et al.*, 1996, J Pediatr, USA [18] Case–control study (level III)	$n = 15$ (inc. 6 mild asthmatics, 3 redo and 1 paralysed diaphragm plication) Mean age = 16 ± 3 years Ravitch repair	Preop and 8 months postop before bar removal FVC RV VO_2 max	PE vs control Mean ± SD 81 ± 17 to 80 ± 16 117 ± 33 to 109 ± 52 40 ± 8 to 40 ± 7	Sex distribution not reported, late postop not measured FVC did not decline postoperatively CT index correlated with severity of restrictive lung disease

Continued

Table 1: (*Continued*)

Author, date, journal and country Study type (level of evidence)	Patient group	Outcomes	Key results	Comments
Wynn *et al.*, 1990, J Thorac Cardiovasc Surg, USA [22] Case–control study (level III)	*n* = 8 Mean age = 13.8 (*R*: 10–16) years Male:female = 11:2 Modified Ravitch repair	Preop and 6–21 months postop FVC FEV_1 TLC VO_2 max SV (ml) Cardiac output Cardiac index Minute ventilation Ve max	VC decreased postoperatively Mean ± SD 99 ± 18 to 89 ± 18 ($P < 0.008$) 99 ± 25 to 78 ± 38 (P = NS) 80 ± 7 to 73 ± 4 ($P < 0.01$) 36 ± 4 to 38 ± 8 (P = NS) 66 ± 23 to 70 ± 24 (P = NS) 12 ± 4 to 13 ± 5 (P = NS) 8 ± 1 to 8 ± 2 (P = NS) 67 ± 19 to 76 ± 28 (P = NS) 68 ± 12 to 79 ± 30 (P = NS)	Severity of PE not correlated with cardiopulmonary tests Small number Exercise CF and exercise ventilation showed no change Operative process itself restrictive
Derveaux *et al.*, 1988, Eur Respir J, Belgium [11] Cohort study (level III)	*n* = 17 Mean age = 11.9 ± 5.5 years Male:female = 3:1 Other: Baronofsky's technique	Preop and 12.2 ± 3.7 years postop FEV_1 VC	Restriction of lung function postoperatively Mean ± SD 88 ± 17 to 66 ± 1 ($P < 0.001$) 89 ± 10 to 64 ± 6 ($P < 0.001$)	Restriction attributed to extra pulmonary factors—the operation itself
Kaguraoka *et al.*, 1992, J Thorac Cardiovasc Surg, Japan [12] Case–control study (level III)	*n* = 22 Mean age = 21.5 ± 7.8 years Male:female = 17:5 Other: sternal turn-over, *n* = 11 and sterno-costal elevation, *n* = 11	Preop and 42 months postop FEV_1 TLC VC RV	Surgery did not affect respiratory function Mean ± SD 90 ± 5 to 89 ± 5 (P = NS) 98 ± 8 to 94 ± 9 (P = NS) 82 ± 12 to 85 ± 8 (P = NS) 129 ± 10 to 114 ± 16 (P = NS)	VC decreased 2 months postoperatively and recovered to preop levels in 6 months
Morshuis *et al.*, 1994, Chest, Netherlands [15] Retrospective analysis (level III)	*n* = 152 Mean age = 15.3 ± 5.5 years Male:female = 4:1 Other: modified Daniel's technique	Pre- and postop 8.1 ± 3.6 (*R*: 2.8–17.7) years FEV_1 TLC RV	Restrictive impairment of PF aggravated postoperatively Mean ± SD 79 ± 15 to 73 ± 16 ($P < 0.0001$) 84 ± 12 to 74 ± 12 ($P < 0.0001$) 105 ± 30 to 84 ± 20 ($P < 0.0001$)	Different numbers in postop measurements No exercise testing performed
Morshuis *et al.*, 1994, J Thorac Cardiovasc Surg, Netherlands [25] Cohort study (level III)	*n* = 35 Mean age = 17.9 ± 5.6 years Male:female = 4:1 Other: modified Daniel's technique	Pre- and 12 months postop FEV_1 TLC RV VO_2 max	Increase of restrictive lung function postoperatively Mean ± SD 84 ± 18 to 75 ± 10 ($P < 0.0001$) 86 ± 14 to 77 ± 5 ($P < 0.0001$) 103 ± 26 to 94 ± 7 ($P < 0.0104$) 31 ± 2 to 34 + 8 ($P < 0.0035$)	Increased SV response attributed to higher work of breathing Inconclusive study
Cahill *et al.*, 1984, J Pediatr Surg, USA [21] Prospective cohort study (level III)	*n* = 14 Mean age = 10.9 (*R*: 6–17) years Surgical technique not reported	Preop and 3–9 months postop TLC VC VO_2 max	TLC improved. Exercise performance improved Mean ± SD 3.2 ± 1.1 to 3.5 ± 1.1 ($P < 0.02$) 2.5 ± 1.0 to 2.6 ± 0.8 (P = NS) 1.3 ± 0.4 to 1.5 ± 0.4 ($P < 0.01$)	Sex distribution not reported, patient growth, technique of surgical repair not taken into account in analysis
Orzalesi and Cook, 1965, J Pediatr, USA [10] Case–control study (level III)	*n* = 5 *R*: 5–18 years Male:female = 1:1 Surgical technique not reported	Preop and 2–6 years (mean = 5 years) postop TLC VC RV	TLC and VC decreased significantly postop Mean ± SD 86 ± 7 to 78 ± 7 ($P < 0.001$) 72 ± 4 to 72 ± 9 ($P < 0.001$) 133 ± 29 to 102 ± 31 (P = NS)	Patient growth and technique of surgical repair not taken into account in analysis. No exercise testing

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BEST EVIDENCE TOPIC

Table 1: (*Continued*)

Author, date, journal and country Study type (level of evidence)	Patient group	Outcomes	Key results	Comments
Peterson *et al.*, 1985, Thorac Cardiovasc Surg, USA [23] Cohort study (level III)	n = 13 Age = 13 ± 4 (R: 6–19) years Surgical technique not reported	Preop and ≥6 (mean: 15 + 11) months postop	First-pass radionuclide angiocardiography Mean + SD	No limitation in exercise CF in PE. No correlation of symptoms or severity of deformity. EDVILV, SVI, estimated EDVRV increased at rest after repair with decrease in RVEF%
		LV EF%	0.76 + 0.05 to 0.75 + 0.08 (P = NS)	
		EDVILV	72 + 21 to 82 + 16 (P = NS)	
		SVILV	47 + 11 to 62 + 16 (P = NS)	
		Cardiac index	4.3 + 1.2 to 10.9 + 3.2 (P = NS)	
		RV EF%	0.55 + 0.08 to 0.51 + 0.09 ($P < 0.05$)	
		EDVIRV	87 + 26 to 125 + 33 (P = NS)	

VC: vital capacity; TLC: total lung capacity; FVC: forced vital capacity; FEV_1: forced expiratory volume measured over 1 s; IVC: inspiratory vital capacity; FRC: functional residual capacity; RV: residual volume; VO_2 max: maximal oxygen uptake; Ve max: maximum exercise ventilation; VO_2 max during exercise; SV: stroke volume; EF: ejection fraction; LVEF: left ventricular ejection fraction; RVEF: right ventricular ejection fraction; $EDVI_{LV}$: left ventricular end diastolic volume index; SVI: stroke volume index; SVI_{LV}: stroke volume index of left ventricle; SVI_{RV}: stroke volume index of right ventricle; $EDVI_{RV}$: right ventricular end diastolic volume index; PF: pulmonary function; CF: cardiac function; IQR: interquartile range; ECG: electrocardiogram; MV: mitral valve; CI: cardiac index; CO: cardiac output; CT: computer tomography.

Nuss and Ravitch procedures are established surgical techniques for the correction of PE, both conferring modest improvements in pulmonary function and cardiac function.

Conflict of interest: none declared.

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