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Impact of pectus excavatum on pulmonary function before and after repair with the Nuss procedure

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Abstract

Background/Purpose: Patient reports of preoperative exercise intolerance and improvement after surgical repair of pectus excavatum (Pex) have been documented but not substantiated in laboratory studies. This may be because no study has been large enough to determine if pulmonary function tests (PFTs) in the Pex population are significantly different from the normal population, and none has assessed improvement in pulmonary function after Nuss bar removal.

Methods: The authors studied PFT results in 408 Pex patients before repair and in a subset of 45 patients after Nuss procedure and bar removal. Significance of differences in percent predicted (using Knudson's equations) was tested using *t* tests (parametric) or sign tests (nonparametric). Normal was defined as 100% of predicted for forced vital capacity (FVC), forced expired volume in 1 second (FEV_1), and forced expiratory flow ($FEF_{25\%\text{-}75\%}$).

Results: Preoperatively, FVC and FEV_1 medians were lower than the normal by 13%, whereas the $FEF_{25\text{-}75}$ median was lower than normal by 20% (all $P < .01$). The postoperative group had statistically significant improvement after surgery for all parameters. Patients older than 11 years at the time of surgery had lower preoperative values and larger mean post–bar removal improvement than the younger patients. An older patient with a preoperative $FEF_{25\text{-}75}$ score of 80% of normal would be predicted by these data to have a postoperative $FEF_{25\text{-}75}$ of 97%, indicating almost complete normalization for this function.

Conclusions: These results demonstrate that preoperatively Pex patients as a group have decreased lung function relative to normal patients. After Nuss procedure and bar removal, we show a small but

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significant improvement in pulmonary function. These results are consistent with patient reports of clinical improvement and indicate the need for more in-depth tests of cardiopulmonary function under exercise conditions to elucidate the mechanism.

1. Introduction

Pectus excavatum (Pex) is a birth defect that results in a depression of the sternum and anterior chest. The size and shape of the depression range from mild concave depressions of a few millimeters to severe asymmetrical depressions of several centimeters. Most patients with more than mild Pex have displacement of the lungs and heart, and many report some degree of exercise intolerance or lack of endurance [1,2]. These patients tend to be round shouldered and have what physicians familiar with this disorder sometimes refer to as the *classic pectus posture*. In patients with severe depressions, there is clinical evidence that cardiorespiratory function may be impaired. This is usually manifested at the clinical level by mild to moderate exercise intolerance, chest pain with exertion, and recurrent respiratory tract infections [2] and at the laboratory level by decreased pulmonary function and stroke volume [3]. Nevertheless, questions remain about the impact of Pex on pulmonary function and the use of pulmonary function tests (PFTs) in assessing clinical outcomes in patients with Pex. Several factors may account for the apparently contradictory results in the literature including variability of the severity, the extent and nature of the surgical correction, and the age and small number of subjects studied.

After introduction of a minimally invasive procedure for Pex repair by the surgeons in our hospital, we have had a large influx of patients with Pex, many of whom have now had bar removal. We recently reported the results of a pre- and postsurgical survey of 19 patients in which patients and their parents reported significantly improved exercise tolerance after surgical repair of Pex with the Nuss procedure [4]. Patients further reported a decreased incidence of shortness of breath, chest pain, and tiredness. The purpose of the present investigation was to use more objective pulmonary function data from before and after treatment with the Nuss procedure to test the hypotheses that (1) patients with Pex who qualified for surgery (n = 408) have reduced PFTs relative to the normal population and (2) Pex repair results in significant improvement in PFTs after minimally invasive surgical intervention (Nuss procedure) and bar removal (n = 45).

2. Methods

2.1. Study population

We examined preoperative repair PFT results from 408 patients who were clinically approved for surgery at Children's Hospital of The King's Daughters (CHKD) in Norfolk, Va, between 1993 and 2003. The population was predominantly male (82%) and white (94%). The median age on the day of the PFT was 13.4 (interquartile range [IQR] 10.0,15.7). Marfanoid characteristics were noted by the surgeon in 24% of the patients, some degree of scoliosis was noted in 28%, and 39% self-reported frequent respiratory tract infections.

We compared preoperative and post–bar removal PFT results for a subset of 45 patients who had a PFT performed after bar removal. For this matched analysis of postoperative improvement, only preoperative results from the subset of 45 patients were included. The patients in this subset tended to be younger (median age 11.4 years, $P < .05$) and were more likely to report frequent upper respiratory tract infections (51.1%, difference not statistically significant), but were otherwise similar to the whole preoperative Pex population in terms of race, sex, scoliosis, and marfanoid characteristics. Sufficient time has not elapsed for the bar to be removed in the remaining patients, or they have not returned for post–bar removal PFTs.

Because patients presented from many different locations, PFTs were conducted by various licensed facilities and forwarded to the clinical staff at CHKD for inclusion in the medical record. The flow volume curves of all studies were examined to be certain there was no noise on the expiratory limb of the curve and that if there was premature termination of expiration, end expiration fell within 15% of the extrapolated residual volume. All data were recorded in an Access database. This study received exemption from review by the Institutional Review Board of Eastern Virginia Medical School.

Patients undergoing surgery were part of the series previously described [5]. The average Haller index was 4.8 (IQR 4.0, 6.2) for the preoperative population and 4.6 (IQR 4.0, 7.1) for the subset of 45 post–bar removal patients. Bar removal was usually performed as an outpatient procedure.

2.2. Statistical analysis

Statistical analyses were performed using the SAS System for Windows, Release 8.01 (SAS Institute, Cary, NC) and statistical significance was declared at an α level of .05. Distributions of continuous variables were evaluated for normality using the Shapiro-Wilk test and graphically using histograms and box plots. Data were described using the mean, median, and 25th and 75th percentiles (IQR, which is more appropriate for nonparametric data than the 95% confidence interval of the mean). All PFT scores were normalized using the Knudson values [6].

Table 1 Preoperative Pex patient population PFT percent of predicted values

Test[a]	Age (y)	N	Mean % of predicted	Median % of predicted	IQR [25th, 75th percentile]	P of difference from 100%[b]
FVC	All ages	408	87	87	[77, 97]	<.0001
	<11	119	90	89	[80, 100]	<.0001
	≥11	289	85	85	[76, 94]	<.0001
FEV_1	All ages	407	86	86	[76, 96]	<.0001
	<11	119	89	90	[80, 98]	<.0001
	≥11	288	84	84	[74, 94]	<.0001
FEF_{25-75}	All ages	402	81	80	[64, 98]	<.0001
	<11	116	86	85	[67, 102]	<.0001
	≥11	286	80	78	[62, 95]	<.0001

[a] All spirometry parameters normalized using Knudson normset [6]. A value of 100% indicates that the score is exactly what is expected for an individual based on their age and height.
[b] Independent samples t test.

Pulmonary function tests scores of forced vital capacity (FVC), forced expired volume in 1 second (FEV_1), and forced expiratory flow ($FEF_{25\%-75\%}$) were included in this analysis. To test the hypothesis that the preoperative PFT values were significantly different from the normal population, we assumed that the normal population would have a central value of 100% of predicted and used Student's sample t tests (normal data) or sign tests (asymmetric nonnormal data) to test if the Pex population score was different from a normal population score. To test the hypothesis that PFT scores would improve significantly after surgical repair, we used a paired t test or Wilcoxon's signed rank sum test (2-sided probability) as appropriate. Predicted values after repair based on preoperative values were estimated using a simple linear regression model. Regression curves were produced using observed preoperative PFT values as the predictors and postoperative PFT values as the outcomes (all as percent of normal for age, sex, and height). All PFT analysis results are presented for the whole group, and then stratified by the population median value of preoperative age, because of an interaction between preoperative age and PFT improvement in this population.

Table 2 Pulmonary function before Nuss procedure and after bar removal

Test	Age at procedure	Timing	N	Mean % of predicted*	Median % of predicted*	IQR [25th, 75th percentile]	P of difference from 100%[a]	Mean difference in % of predicted	P of difference pre- to postoperatively[b]
FVC	All ages	Before	45	85	83	[77, 93]	<.0001	5	.0047
		After	45	90	90	[79, 101]	<.0001		
	<11	Before	20	86	85	[75, 94]	<.0001	4	.1082
		After	20	89	88	[79, 99]	.0017		
	≥11	Before	25	84	81	[76, 92]	<.0001	6	.0015[c]
		After	25	90	90	[78, 101]	.0081		
FEV_1	All ages	Before	45	84	85	[75, 93]	<.0001	6	.0093
		After	45	89	87	[80, 98]	<.0001		
	<11	Before	20	86	85	[76, 94]	.0006	2	.5359
		After	20	88	82	[79, 97]	.0004[d]		
	≥11	Before	25	81	80	[74, 90]	<.0001	9	.0052
		After	25	90	93	[82, 100]	.0018		
FEV_{25-75}	All ages	Before	45	81	79	[65, 94]	<.0001	8	.0350
		After	45	89	87	[76, 98]	.0014		
	<11	Before	20	86	82	[69, 102]	.0193	0	.9518
		After	20	86	83	[70, 93]	.0026[d]		
	≥11	Before	25	77	70	[63, 89]	<.0001	15	.0003
		After	25	91	91	[81, 103]	.0280		

*All spirometry parameters normalized using Knudson normset [6]. A value of 100% indicates that the score is exactly what is expected for an individual based on their age and height.
[a] Student's t test of difference from normal population score of 100%.
[b] Paired t test of difference from before operation to after bar removal.
[c] Sign test of difference from before operation to after bar removal.
[d] Sign test of difference from normal population score of 100%.

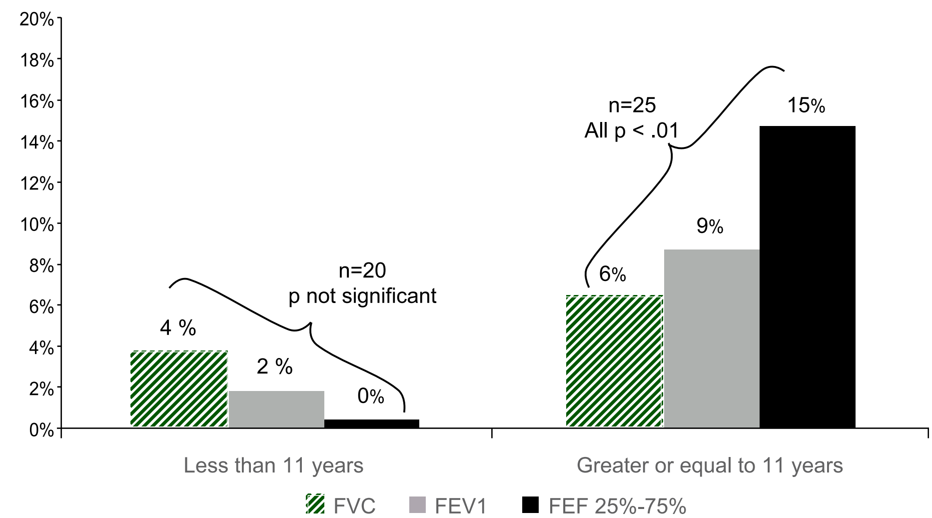

Fig. 1 Mean improvement in percent of predicted after bar removal.

The median value was selected to ensure adequate sample size in each age group.

3. Results

Table 1 shows the FVC, FEV_1, and FEF_{25-75} results for the preoperative Pex population. For all 3 parameters, the population was significantly skewed away from normal, as illustrated by the *P* value in the last column. The 75th percentile for each parameter was below 100%, where in a normal population the 50th percentile would be expected to be near 100% and the 75th percentile would be expected to be above 100%. Tests of location confirm that the population average is significantly different from 100% on all parameters. In addition, patients younger than 11 years

Table 3 Expected change in FVC after surgical repair of Pex

Age at initial surgery	Preoperative % of normal[a]	Expected postoperative % of normal[b]	Expected postoperative % change[b]
All ages,	60	69	15
P = .0353	70	78	12
	80	87	8
	90	95	5
	100	102	2
	110	108	−2
Age <11,	60	69	15
P = .0694	70	78	11
	80	86	7
	90	93	3
	100	99	−1
	110	105	−5
Age ≥11,	60	69	15
P = .2296	70	78	12
	80	87	9
	90	96	6
	100	104	4
	110	111	1

[a] Raw scores normalized using Knudson formulas [6]. A value of 100% indicates that the score is exactly what is expected for individuals based on their age and height.

[b] Based on a linear regression model where percent change is predicted by preoperative normalized score.

Table 4 Expected change in FEV_1 after surgical repair of Pex

Age at initial surgery	Preoperative % of normal[a]	Expected postoperative % of normal[b]	Expected postoperative % change[b]
All ages,	60	76	27
P < .0001	70	84	19
	80	89	11
	90	93	3
	100	96	−4
	110	96	−12
Age <11,	60	73	22
P = .0027	70	81	15
	80	87	8
	90	91	1
	100	94	−6
	110	96	−13
Age ≥11,	60	78	30
P = .0032	70	85	22
	80	91	14
	90	95	5
	100	97	−3
	110	98	−11

[a] Raw scores normalized using Knudson formulas [6]. A value of 100% indicates that the score is exactly what is expected for an individual based on their age and height.

[b] Based on a linear regression model where percent change is predicted by preoperative normalized score.

tend to have PFT values closer to normal than the patients 11 years and older, as a percent of predicted, although there is substantial overlap between these 2 groups, as illustrated by the IQR.

Post–bar removal PFTs were available for a subset of 45 patients. Average time that the bar was in place was 2.9 years (range, 1.0-4.0 years), and average time between bar removal and the postoperative PFT used in this analysis was 1.2 years (range, 0.1-3.8 years). There was no difference between the 2 age groups (<11 or ≥11) in the time between bar removal and PFT testing. Table 2 shows the results of the comparison of preoperative and post–bar removal PFT values in this subset. As a group, these patients with Pex were significantly below normal before surgery and, although improved, remained significantly below normal after bar removal. The largest improvement was seen in patients that were at least 11 years old at the initial surgery (Fig. 1). Older patients showed a 6% improvement in FVC, a 9% improvement in FEV_1, and a 15% improvement in $FEF_{25\text{-}75}$ (as a percent of predicted, all $P < .05$). Younger patients showed smaller improvements, if any, none of which were statistically significant.

Tables 3-5 show the results of regression models in which the predictor was the preoperative percent predicted and the outcome was the postoperative percent predicted for FVC, FEV_1 and $FEF_{25\text{-}75}$. These data predict that a patient with 80% of predicted value for FVC, FEV_1, or $FEF_{25\text{-}75}$ would improve in percent predicted after surgery by 8%, 11%, and 17%, respectively. As shown, the largest predicted improvements are seen in older patients and patients with more severe restriction preoperatively. These data indicate that a younger patient would generally have lower PFT expressed as a percent predicted after bar removal than an older patient who had the same PFT percent predicted before surgery.

Table 5 Expected change in $FEF_{25\text{-}75}$ after surgical repair of Pex

Age at initial surgery	Preoperative % of normal[a]	Expected postoperative % of normal[b]	Expected postoperative % change[b]
All ages,	60	81	35
$P < .0001$	70	88	26
	80	94	17
	90	97	8
	100	99	−1
	110	99	−10
Age <11,	60	77	28
$P = .0062$	70	84	20
	80	89	11
	90	92	3
	100	94	−6
	110	94	−14
Age ≥11,	60	83	39
$P = .0003$	70	91	30
	80	97	21
	90	101	13
	100	104	4
	110	105	−5

[a] Raw scores normalized using Knudson formulas [6]. A value of 100% indicates that the score is exactly what is expected for an individual based on their age and height.

[b] Based on a linear regression model where percent change is predicted by preoperative normalized score.

4. Discussion

Despite numerous studies of cardiac and pulmonary function in the laboratory over a 50-year period [3,7-17] there continues to be uncertainty as to whether the Pex anomaly results in cardiopulmonary abnormalities. Several authors have noted decreases in pulmonary function (primarily vital capacity and airflow rate) among patients with Pex, although the results often fall within the normal range [15-18]. These findings are consistent with ours, in which the population mean for pulmonary function is in the normal range, but the population as a whole is skewed below the distribution expected in a completely normal population. Similar data to ours were reported by Haller and Loughlin [14] and Zhao et al [15] for FVC and FEV_1, and by Mead et al [16] for FVC. Although the later group concludes no difference between the Pex patients and the normal controls, examination of the percent predicted vital capacity in the Pex patients shows that none of the Pex patients have a percent predicted above 100%, whereas more than half of the control patients have percent predicted values above 100%. This paper also confirms that a normal population would have a median value near 100% (see Mean, Table 1, mean FVC 103%, median 100%).

In the present study, we demonstrate that surgical repair of Pex using a minimally invasive technique can lead to significant improvement in pulmonary function after bar removal. This improvement, although small, is consistent with the subjective patient reports of improved exercise tolerance after surgical repair of the Pex defect we have previously reported [4]. Although others have not shown postrepair improvement in pulmonary function [17], it should be noted that they were studying pulmonary function after the surgically more extensive Ravitch procedure and not the minimally invasive Nuss procedure described here.

We observed that Pex repair has the largest impact on $FEF_{25\text{-}75}$, with average improvement of up to 12% and predicted improvement of more than 20% for an older child with 80% initial function. Reduction in $FEF_{25\text{-}75}$ is sometimes believed to result from increased airflow resistance in the smaller airways. Improvement in FVC was mild (highest average of 6%) but larger in FEV_1 (average up to 9%). The small increases in $FEF_{25\text{-}75}$ and FEV_1 percent predicted may result from an increase in lung volume post–Nuss procedure and bar removal. The FEV_1/FCV ratio was within normal limits (.85) for both the preoperative and post–bar removal populations, indicating that there was no appreciable change in large airway resistance.

Furthermore, we observed that younger patients started with a higher pulmonary function as a percent predicted than the older patients, but did not improve appreciably after surgery. The older patients showed significant improvement and thus ultimately had higher percent predicted than the younger patients after bar removal. Although we do not know why the older patients do better, we speculate that the stiffer chest cage of the older patients may remain more stable.

Patients who were observed by the surgeon to have marfanoid characteristics were included in this analysis. A report of a detailed analysis of these patients will be forthcoming. To answer any concerns that these patients might be driving our conclusions, we did a secondary analysis from which we excluded the marfanoid patients. Although removal of the marfanoid patients for this secondary analysis naturally reduced statistical power, the results of the study remained statistically significant and the study conclusions were identical to the main analysis presented in our Results section. Therefore, the patients with marfanoid characteristics did not drive the conclusions reported here. A similar post hoc analysis in which the patients with scoliosis were removed from the analysis had a similar lack of impact on the statistical significance or the results of the study, indicating that our conclusions are not a result of including patients with scoliosis in the analysis.

For the postsurgical candidates, there was a large variation in length of time between bar removal and PFT testing. To determine if this difference had any potential impact on our results, we tested the correlation between PFT results and length of time since bar removal for all 3 PFT parameters. There was a small (r = 0.3) but statistically significant correlation between FVC percent predicted and length of time since bar removal. Excluding from the analysis the patients who were less than 6 months from bar removal at the time of their PFTs (n = 5) had the expected slight impact on statistical power but no impact on study conclusions.

Post–bar removal PFT results were available on a small proportion of our patients. We used all post–bar removal PFT results that were in our records. The nature of our population, which is primarily out of state, precludes many of the patients from returning for a PFT after bar removal and sufficient time for healing. In our study population, there were 175 patients who were post–bar removal but for whom we did not have post–bar removal PFT values. We compared the preoperative characteristics of these post–bar removal patients to the 45 patients in our subsample to determine the likelihood of our sample's being biased. The 45 patients in our subsample were virtually identical to the 175 post–bar removal patients who did not contribute postremoval PFT results, except that they were twice as likely to be less than 11 at the time of the procedure. Our stratification by age controls for any potential bias resulting from this difference. Uncontrolled bias is unlikely given the similarity of the groups on all other factors.

Our study is limited by the inclusion of only surgical candidates, who are by definition more likely to have at least moderately restricted chest wall function. Thus, our results are not generalizable to the total Pex population at large. This is offset by the fact that this population does represent the population of surgical candidates about whom clinical decisions must be made. A further limitation is the absence of measurements of maximum voluntary ventilation. Finally, we did not assess cardiopulmonary function under exercise conditions. Beiser et al [3], Haller and Loughlin [14] and others have proposed that improvement in symptoms after Pex repair relate to enhanced venous return to the heart and increased stroke volume because the anterior chest and sternum are no longer pressing on the heart and decreasing end-diastolic filling of the right side of the heart. This has prompted us to initiate a study of cardiopulmonary function under exercise conditions in Pex before and after surgical correction.

This is the first large series of patients studied for pulmonary function after the Nuss procedure for repair of Pex. In this study, we observed small but potentially clinically relevant improvement in pulmonary function after bar removal. This is consistent with the improved exercise tolerance after surgical repair we have previously reported.

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Discussion

J.A. Haller (Baltimore, MD): Thank you, Mr Chairman, for allowing me to rise again so soon, but I wanted not only to congratulate Dr Goretsky on a nice presentation but also to suggest that he may be barking up the wrong tree. I have also felt that this was going to be primarily a pulmonary problem over the years in the management of patients with Pex and we have been able to show similar kinds of changes that you have reported to us, and there is no question that there is a breathing abnormality in these patients. I think the recent studies on the cardiovascular function of these patients from Polish colleagues using echocardiographic studies with very nice videos have shown that it is more likely that the dysfunction that these children and young adults have is due to compression of the outflow tract of the right ventricle by the displaced sternum. As we all know, as you watch children grow with uncorrected pectus abnormalities, such as pectus excavatum, the heart does shift into the left chest and that causes that ectopy that we see so often, the ectopic position, in those patients. That pressure on the outflow tract to the right ventricle acts as a constriction and their studies indicate that after repair this is relieved, so that the implication, I think, is a correct one, that the primary problem is the inability to increase cardiac output with exercise and that over time this becomes more and more obvious. Thus, the teenager is unable to continue to participate in active sports, particularly those requiring considerable stamina. I believe those studies are likely to yield more information that would be convincing to our critics than the pulmonary function studies, and I would be interested in your thoughts about that.

M.J. Goretsky (response): We agree fully. We are presently hoping to do similar tests. It is just more of a function in our institution of having the cardiology support to run the tests that you read in the Polish literature.

J.M. Laberge (response): With a severe pectus you would think PFTs should show a restrictive disease, and yet most of the time what you see is a more obstructive pattern and quite often in fact reversible with bronchodilators. So were any of these patients treated with bronchodilators at the time of reassessment or chronically on bronchodilators?

M.J. Goretsky: A lot of our patient population comes from outside the area. Specifically, there are some patients who are being treated for asthma and have bronchodilators. We specifically did not count that variable in looking at the data though.