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Lung Function after the Minimal Invasive Pectus Excavatum Repair (Nuss Procedure)

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Abstract

Background The Nuss procedure was introduced at our center in 1999. The operation was mainly performed for cosmesis. Little information is available regarding the influence of this operation on lung function.

Methods The aim of this study, a prospective analysis, was to analyze the effect of the Nuss procedure on lung function variables. Between 1999 and 2007 a total of 203 patients with pectus excavatum were treated with the Nuss procedure, of whom 145 (104 male, 41 female) were located at Emma Children's Hospital. In the latter subset of consecutive patients, static lung function variables [total lung capacity (TLC), functional residual capacity (FRC), vital capacity (VC)] and dynamic lung function variables [forced expired volume in 1 s (FEV_1), maximum expiratory flow (MEF_{50})] were performed using spirometry and body box measurements at four time points: prior to operation (T0), 6 months after the Nuss procedure (T1, $n = 111$), prior to removal of the Nuss bar (T2, $n = 74$), and 6 months after removal (T3, $n = 53$). All values were expressed as a percent of normal values for sex, age, and height. Results were compared with a paired-samples *t*-test, with the level of significance at $p = 0.05$.

Results At 6 months after bar insertion the TLC, FRC, VC, FEV_1, and MEF_{50} showed a significant increase; and prior to bar removal the FRC and MEF_{50} showed significantly increased values. At 6 months after Nuss bar removal, none of the lung function variables showed any significant change compared to the preoperative values.

Conclusion After the Nuss procedure for pectus excavatum, there was no improvement of pulmonary function, but neither was the patient's pulmonary function harmed by resolving a largely cosmetic problem.

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Pectus excavatum (Pex) is the most common congenital chest wall deformity in children, occurring in approximately 1 in every 700 births [1]. Until 1998, the open, or classic, Ravitch or Welch repair was used as its surgical treatment.

A number of studies have documented the respiratory effects of this open pectus repair but with conflicting outcomes. Some studies showed that patients had a modest reduction in vital capacity (VC) and total lung capacity (TLC) preoperatively, which deteriorated after open repair [2–4]. This reduction in vital capacity and forced expiratory volume at 1 s (FEV_1) may be related to the timing of the assessment of pulmonary function after lung surgery. Quigley et al. suggested that a decrease in postoperative pulmonary function is related to an extensive open operation; their results with a less extensive technique showed no reduction in pulmonary function [5]. Cahill and coworkers demonstrated a small improvement in TLC

($p < 0.02$) and a significant improvement in maximal voluntary ventilation ($p < 0$ .001) postoperatively [6].

In 1998, Donald Nuss described a new procedure for Pex repair that rapidly achieved wide acceptance [7]. This Nuss procedure has now become the standard technique for pectus excavatum in children. Little (and conflicting) information is available regarding the influence of the minimally invasive Nuss procedure on pulmonary function variables.

Sigalet et al. documented a decline in pulmonary function after the Nuss procedure; this was significant for the FVC and VC, but the FEV_1 appeared not to be significantly reduced 3 months after the operative repair, with the bar still in situ. The total lung volume showed no significant change [8]. Borowitz et al. have shown no significant change in pulmonary function [FVC, FEV_1, forced expiratory flow at 25–75% forced vital capacity (FEF_{25-75}), TLC] 6 to 12 months after the first stage of the Nuss procedure, with the Nuss bar still in place [9]. Lawson et al. described a small but significant improvement in pulmonary function (FEF_{25-75}, FVC, FEV_1) after Nuss bar removal [10].

The aim of this study was to analyze the effect of the Nuss procedure on lung function before and after Nuss bar removal using preoperative lung function values as a baseline.

Patients and methods

Patients

From March 1999 to March 2007 a total of 203 patients with Pex were treated with the Nuss procedure at our bi-location center. The study group consisted of 145 patients at the Emma Children's Hospital AMC (ECH) and another 48 at the Vrije Universiteit Medical Center (VUmc). All ECH patients (104 male, 41 female), with a sex ratio of 2.5:1.0, underwent lung function measurements. The mean ± SD age of the patients was 14.9 ± 6.01 years (range 6.1–32.1 years). The data were collected prospectively. A second measurement was performed 6 months after bar insertion in 111 patients, in 74 of whom lung function was assessed prior to bar removal; and in 53 the final lung function measurements were performed 6 months after bar removal. The Nuss procedure was performed as described by Nuss et al. using thoracoscopic surveillance [7]. The risks and benefits of the Nuss repair were discussed with the patients and, if they were less 18 years of age, also with their parents. Informed consent was obtained from all.

Pulmonary function measurements

All pulmonary function tests were taken at four well defined time points. Measurements were performed in consecutive patients prior to the Nuss procedure (T0), 6 months after bar insertion (T1), prior to removal of the Nuss bar approximately 2 years after insertion of the bar (T2), and 6 months after bar removal (T3). The following static lung volumes and dynamic flow rates were measured: TLC, functional residual capacity (FRC), VC, expiratory flow rate (FEV_1), and maximum expiratory flow (MEF_{50}). Pulmonary function was measured with a pneumotachograph (Masterscreen I.O.S.; Jaeger, Würzburg, Germany). All pulmonary function parameters were measured until three reproducible recordings were obtained, with the best of three being used for analysis. All pulmonary function values were expressed as a percentage of the predicted value for sex, age, and height (mean percent of normal values ± SD) to exclude the effect of growth on lung volumes. Reference values used are those of Zapletal and coworkers [11].

Statistical analyses

To test the hypothesis that after the Nuss procedure and removal of the substernal bar pulmonary function improves significantly, we used a paired-samples t-test for all five lung function parameters as appropriate. A difference was regarded as significant at $p < 0.05$. Three paired-samples t-tests were performed on the various time pairs in the same patients—T0-T1 (n = 111), T0-T2 (n = 74), T0-T3 (n = 53)—and their t and df values were recorded. These pulmonary function tests scores of TLC, FRC, VC, FEV_1, and MEF_{50} were analyzed. All pulmonary function test results were determined for the whole group. Statistical analysis was performed using SPSS software (Statistical Package of the Social Sciences 12.0.1 for Windows; SPSS, Chicago, IL, USA). Descriptive statistics were used to express the mean or median values and ranges for all measurements.

Results

Demographic data are presented in Table 1. One patient had a mitral valve prolapse. Two patients required placement of two bars, and in six patients the Nuss procedure was a redo procedure after a Welch procedure earlier in life. A (small) pneumothorax occurred in 16 (14.4%) patients but did not require pleural drainage in any. In six (5.4%) patients a bar slip occurred, requiring replacement of the bar. Two patients required a second bar replacement after bar redislocation. Two (1.8%) patients had a superficial wound infection, for which antibiotic treatment was administered. In neither of these two patients did the bar have to be removed. The median hospital stay was 7 days (range 5–18 days). At follow-up, overcorrection oc-

Table 1 Overview of the demographics for boys and girls

Parameter	Boys (n = 78)	Girls (n = 33)
Age at surgery (years.months), median and range	15.0 (6.1–32.1)	12.0 (6.1–18.5)
Height (cm), median and range	175 (110–198)	158 (100–188)
Weight (kg), median and range	56 (18–89)	45 (17–87)

Lung function tests were given as percent of normal, relative to sex, age, and height

curred in one patient, whose bar was thus removed earlier (17 months) than the others.

Preoperatively, measures of static (TLC, FRC, VC) and dynamic (FEV_1, MEF_{50}) pulmonary function were all within the normal range of their predicted values (Table 2). Although there was a statistically significant, but clinically irrelevant, change in TLC, FRC, VC, FEV_1, and MEF_{50} six months after bar insertion and in FRC and MEF_{50} prior to bar removal; no significant changes could be shown in any of the lung function parameters measured 6 months after removal of the Nuss bar.

Discussion

The aim of this study was to investigate whether the Nuss procedure influences lung function parameters. We found no significant differences in any of the investigated lung function parameters between the preoperative values compared to the lung function values 6 months after removal of the Nuss bar.

Over several decades, the debate has continued whether the Pex deformity results in true physiologically impaired exercise performance. This debate was induced by the clinical observation that some of these patients complained of a modest sensation of shortness of breath, with limited exercise tolerance. This complaint has been difficult to objectify at baseline, but it has also appeared difficult to show benefits of the pectus repair on the underlying mechanism that caused these complaints. So far, it has remained unclear whether the basic pathophysiologic problem was primarily ventilatory or cardiovascular (or both) caused by compression of the right ventricular outflow tract by the displaced sternum. Arguments seemed to be available for both of these possibilities, although conflicting evidence has been presented in the literature over the years.

A more recent study by Malek et al. has produced convincing data for a cardiovascular origin of these complaints in a group of Pex patients performing daily aerobic activity for 30 minutes to 2 hours an average of three times a week. As a group they showed no clinically meaningful pulmonary function abnormalities, with normal breathing patterns and normal gas exchange. However, on maximum exercise testing, the maximum oxygen uptake and oxygen pulse (an indicator of stroke volume) were significant lower than the reference values. This effect was more apparent in patients with a high Pectus Severity Index (PSI) [12]. This information suggests that in patients with severe Pex reduced exercise capacity is more likely to result from decreased cardiac output than from ventilatory limitations. The study has not been extended to patients with corrected Pex, so no data on the effects of surgical relief are available.

Limited data on cardiovascular parameters before and after the Nuss procedure have been published. Sigalet et al. showed that cardiac stroke volumes at rest had increased 3 months after bar insertion, but pulse rates were not shown to be influenced [8]. Whether baseline stroke volumes were decreased remained unknown owing to the absence of normal controls. Moreover, no measurements were taken during exercise. Recently, Coln et al. reported using noninvasive upright echocardiography/electrocardiogram with exercise in a group of 123 Pex patients, 106 of whom had symptoms with exertion. They showed cardiac compression in 95% of these patients. Repeated studies in 107 patients at 3 months to 2 years postoperatively with the bar still in place showed relief of symptoms in all symptomatic patients and cardiac compression in none [13]. Further studies of cardiopulmonary function during exercise are needed to clarify this aspect of Pex.

So far, three reports of lung function measurements after Nuss procedures have been published. In two of the three studies (n = 11, measured 3 months after bar insertion [8]; and n = 10, measured 6 to 12 months after bar insertion [9]), the Nuss bar was still in place at the time of the various measurements. Only in the study from Nuss's group were the measurements performed after bar removal (n = 45), but these patients formed a select subgroup of 408 patients who underwent the Nuss procedure [10]. Their article does not report why the postoperative lung function measurements were available for these patients and not for the others, which may reflect a selection bias based on possible deterioration in their condition regarding respiration and exercise.

The present study, however, reflects a consecutive series of unselected patients who were mainly operated on for cosmetic reasons. No cardiovascular parameters were included, however, nor were any measurements performed under exercise conditions. We found no changes in pulmonary function variables when baseline measurements were compared with measurements 6 months after bar removal. This is in contrast with the findings of Lawson et al., who noted a small but significant postoperative improvement in pulmonary function [10]. These observed differences may be explained by a difference in the

Table 2 Overview of the various lung function variables tested at four time intervals

Parameter and no.	Time[a]	Mean (%)	SD	t	df	p
TLC						
$n = 111$	T0	90.86	11.28	2.844	110	0.005*
	T1	88.74	11.79			
$n = 74$	T0	90.32	8.655	0.611	73	0.543
	T2	89.58	10.71			
$n = 53$	T0	90.13	8.773	0.673	52	0.504
	T3	89.19	10.62			
FRC						
$n = 111$	T0	93.09	16.39	–2.340	110	0.021*
	T1	96.05	14.90			
$n = 61$	T0	93.07	13.67	–3.326	73	0.001*
	T2	98.50	15.66			
$n = 53$	T0	93.55	14.04	–1.368	52	0.177
	T3	96.40	16.64			
VC						
$n = 111$	T0	89.87	12.87	4.413	110	0.000*
	T1	85.76	14.79			
$n = 74$	T0	89.46	11.48	1.419	73	0.160
	T2	87.42	14.30			
$n = 53$	T0	89.40	11.53	0.098	52	0.922
	T3	89.26	12.41			
FEV_1						
$n = 111$	T0	94.63	13.87	2.304	110	0.023*
	T1	92.61	15.48			
$n = 74$	T0	94.65	13.39	–.516	73	0.607
	T2	95.43	15.89			
$n = 53$	T0	94.91	13.00	–.183	52	0.856
	T3	95.19	14.18			
MEF_{50}						
$n = 111$	T0	86.56	21.74	–3.228	110	0.002*
	T1	90.91	21.00			
$n = 74$	T0	88.82	23.37	–3.119	73	0.003*
	T2	95.62	25.65			
$n = 53$	T0	88.45	22.37	–0.891	52	0.377
	T3	91.04	22.79			

T0: prior to bar insertion; T1: 6 months after bar insertion ($n = 111$); T2: prior to bar removal ($n = 74$), T3: 6 months after bar removal ($n = 53$)

TLC: total lung capacity; FRC: functional residual capacity; VC: vital capacity; FEV_1: forced expired volume in 1 s; MEF_{50}: maximum expiratory flow

Function tests at T0–T1, T0–T2, and T0–T3 were compared using paired t-tests

*Significant differences; $p < 0.05$ versus preoperative by paired-samples t-test

indications for their operative procedure. Could there be other selection biases?

The decision for surgery in Pex patients in the United States seems primarily to depend on physical complaints (i.e., shortness of breath, reduced exercise tolerance, mitral valve prolapse) rather than on cosmetic complaints (i.e., shame, despair about not being able to participate in peer activities). It remains unclear if the decision to perform the Pex surgery is based on the fact that some insurance policies require medical reasons to justify the surgery or if there are alternative reasons Pex patients with physical complaints are selected to undergo reconstructive surgery and others are not [12]. If in the above-mentioned earlier studies only Pex patients with physical symptoms were included, it could explain the observed differences with our results, as our series reflects a consecutive group of Pex patients who were not selected based on physical complaints.

In The Netherlands, as most likely occurs in other European countries, most of the Pex patients undergoing reconstructive repair are presented to the pediatric surgeon to be considered for operation because of severe cosmetic problems with their Pex. Especially children in their puberty and adolescence, shame about their body appearance keeps them from swimming and participating in other sports with their peers. Whether this lack of sporting activity or the physiologically impaired exercise performance as a consequence of the Pex causes them to have a baseline general condition that is slightly lower than normal remains a question. What became clear during the follow-up of our study is that after their reconstruction most of the patients started to become more involved in sporting activities, and their exercise tolerance may be positively influenced by this circumstance—something not measurable by spirometry.

Of course, it is necessary to collect data of cardiopulmonary function under exercise conditions before and after completion of the Nuss procedure to really comprehend the probable influence of restored outflow from the right ventricle [14–16]. On the other hand, it may be important to randomize Pex patients pre- and postoperatively to a training program of increased sports activities to determine if lung function at baseline and after the Nuss procedure becomes normal, independent of the surgery applied.

Conclusions

The Nuss procedure for pectus excavatum does not produce improved pulmonary function. However, it is comforting to know that resolving this congenital chest deformity, which may have a significant cosmetic impact on the patient, does not harm the patient's pulmonary function.

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