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Functional and Aesthetic Outcomes of Patients Underwent Modified Ravitch Technique for Repair of Pectus Excavatum

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Abstract

Background: Pectus excavatum is the most frequent congenital defect of the chest wall. Surgical treatment with modified Ravitch-type repair is recommended in patients with cosmetic dissatisfaction or considerable cardiopulmonary symptoms. We aimed to analyze the surgical, aesthetic, cardiopulmonary functions and patient satisfaction outcomes of modified Ravitch repair pre and postoperatively.

Methods: This was a prospective analysis of 13 pectus excavatum patients undergoing repair by modified Ravitch using a permanent titanium plate fixed with a screw from September 2021 to August 2023. Patients were included to relieve pressure on the heart and lungs if complaining of exercise intolerance, cosmetic impairment, shortness of breathing, chest pain, or psychological disturbance with an age range from 10 years to 30 years old. While patients who had received conservative or surgical treatment previously or patients with scoliosis, Marfan syndrome or bronchial asthma were excluded. At the 6-month postoperative visit, a postoperative satisfaction survey was conducted.

Results: The means of the age of patients (16.4 ± 2.36 years); operative duration (120 minutes); blood loss (200± 15.47 mL) and Haller index was (3.8± 0.35) preoperatively compared with less than 3.0 (2.7± 0.08 postoperatively; hospital stay (7 days). The most frequent complications were seroma in one patient (7.69%), postoperative bleeding in one patient (7.69%) and skin infection in one patient (7.69%) of patients. No recorded infection of the sternal plate or required operative re-exploration for infection. All patients were subjectively satisfied with the excellent surgical results. Exercise intolerance despite increased exercise performance was observed following surgery, including less sensation of dyspnea.

Conclusion: Modified Ravitch-type repair is a secure and reliable method for treating pectus excavatum with better relief of preoperative symptoms.

Keywords: Pectus excavatum, Modified Ravitch, Aesthetic, Cardiopulmonary, Outcomes

Conflicts of Interest: *None declared*
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Introduction

Pectus excavatum (PE) is the most frequent chest wall deformity in children and adolescents, with prevalence

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↑What is "already known" in this topic:
Pectus excavatum is the most frequent congenital defect of the chest wall. Surgical treatment with modified Ravitch-type repair is recommended in patients with cosmetic dissatisfaction or considerable cardiopulmonary symptoms.

→What this article adds:
This study reports that Modified Ravitch-type repair is a secure and reliable method for treating pectus excavatum with better relief of preoperative symptoms.

rates from 1:400 and 1:1000. Males are 3–5 times more affected than females (1). The anterior chest wall of most patients has an impression on it that either exists at birth or appears throughout early childhood. It results from a deformity of a rib cartilage that affects the sternum. When growth stops, the deformity remains and gets worse (2).

Patients with pectus excavatum present with a range of complaints that don't match the actual extent of the deformity. Common symptoms include early fatigue relative to peers their age, early exhaustion upon effort, early weakness, inappropriate tachycardia, retrosternal tightness, back discomfort, and a poorer sense of self-esteem, and a lower quality of life (3).

The Haller index (HI), the correction index (CI), or the pectus severity index (PI), are the most frequently used thoracic indicators for evaluating the severity of pectus excavatum with cross-sectional imaging (1). Little is known about the movement of the chest wall in patients with funnel chests when free breathing is not required for conventional CT and MRI exams. Up to now, the degree of disease has been assessed by static axial cross-sections of the thorax at the funnel's lowest point. Although there is evidence that HI and CI fluctuate during breathing, the phase of the breathing cycle utilized to calculate the indices is not standardized (4).

Several treatment modalities of PE were used, including conservative therapy using a suction cup and physiotherapy to enhance posture, fitness, and muscular strength in addition to many surgical procedures, which have advanced over time (2). The first surgical treatment of pectus excavatum was done in 1899 by Tietze through partial sternal excision. Ravitch turned this procedure into an open repair method with significant subperichondrial cartilage removal and non-metallic stabilization (5). Temporary internal stabilization devices have been modified to stabilize the chest wall and stop paradoxical respiratory motion (6).

Surgery is considered the best treatment procedure for patients with chest abnormalities. According to the literature, patients are most frequently motivated to have surgery to address a chest wall abnormality for improvement of pulmonary and cardiac functions as well as cosmetic reasons (7). However, there are considerable debates over the cardiopulmonary advantages of pectus excavatum treatment due to limited underpowered studies and the timing of postoperative testing (8-10).

In the present study, we aimed to evaluate the functional and aesthetic outcomes of patients who underwent the modified Ravitch technique for the repair of pectus excavatum.

Methods

This is a prospective study performed on patients with pectus excavatum corrected by modified Ravitch technique during cardiac surgery at our university hospital with the aid of Cardiothoracic surgery, Orthopaedic surgery, Chest, Radiology, and Plastic surgery departments between 2021-2023.

Inclusion and exclusion criteria

All patients with Pectus excavatum indicated for surgery to relieve pressure on the heart and lungs as they were complaining of exercise intolerance, cosmetic impairment, shortness of breathing, chest pain, and psychological disturbance with age range from 10 years to 30 years old were included in this study. While patients who had received conservative or surgical treatment previously or patients with scoliosis, Marfan syndrome or bronchial asthma were excluded.

Preoperative evaluations

All patients underwent evaluation by standardized medical history, laboratory investigations, chest x-ray (CXR) Posteroanterior, and lateral views, Electrocardiography (ECG), Chest three-dimensional computed tomography (3D-CT) examinations, Pulmonary function tests (PFT), Echocardiography, Exercise tolerance test (ETT).

Chest computed tomography (CT) & Haller index (HI)

Chest computed tomography (CT) was performed for all patients, and indexing of chest wall deformities by Haller index (HI) to ensure the standardization of the treatment plan and the timing of the operation. the Haller index (HI) is calculated by dividing the transverse diameter of the chest CT by the distance between the deepest point of the vertebra's anterior and posterior surfaces (11) Haller index was 3.8 (3.2-4.5) considered as a severe deformity and a higher CT ratio indicates more severity of the pectus deformity (Figure 1).

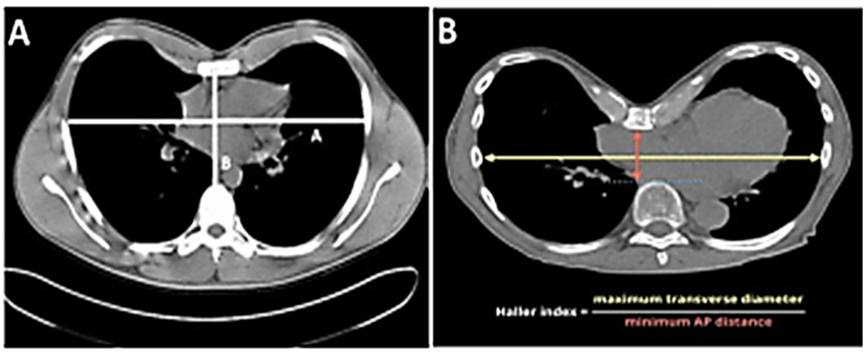

Figure 1. A: computed tomography of the chest (CT) A: transverse diameter at the deepest level of the deformity; B: At the same level, anterior-posterior diameter. Normal individuals have a Haller index of 2.60.4 (A/B HI) (13).

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The HI for healthy individuals is 2.60.4. Surgery is suggested when 3.25 is reached. The deformity is regarded as minor when the index is lower than 2.5, moderate when it is between 2.5 and 3.2, and severe when it is larger than 3.2 (12). The standard cutoff point for surgical indication is 3.25. Despite the fact that some researchers advise surgical treatment for patients with HI greater than 3.25 (13).

Pulmonary function tests

A nitrogen washout approach was used to quantify lung volumes during pulmonary function tests (PFT) in order to determine functional residual capacity (FRC), vital capacity (VC), and forced expiratory volume (FEV). FEV, FVC, and total lung capacity (TLC) were selected as outcome measures for pulmonary function because they are well-studied indicators of pulmonary function and disease.

Exercise stress testing was performed on a treadmill

Progressive work exercise protocol was used to estimate maximum work capacity. The patient was seated for a five-minute rest period, and data were initially measured, then instructed to start exercise at a constant rate. The workload was raised minute by minute until the patient was unable to keep up the same pace. The ECG, heart rate, total exercise time, pulse oximetry, as well as arterial saturation, were all constantly recorded while exercising on the chart recorder. Data for 3 minutes of recovery were collected.

Surgical procedure (Modified Ravitch repair)

All patients were operated on using the same surgical procedures. Vertical Midline incision was used, Pectoral muscle flab, subperichondrial resection of deformed costal cartilage (usually three and never more than five), and xiphoid process. After that, a transverse sternal osteotomy was carried out. This makes it possible to flatten the chest wall by bringing the inferior part of the sternum forward and stabilizing it with titanium plates and screws to maintain its new shape (14) as shown in chest radiographs (Figure 2). Dissection of the rectus muscle and its reattachment to the pectoralis major muscle. Closure in anatomical layers leaving suction drainage.

Follow up studies

Most patients postoperatively will repeat all preoperative evaluations. We have performed a preoperative and post-operative comparisons of exercise tolerance, cardiopulmonary functions and postoperative complications. Also, a postoperative survey called the single-step questionnaire[6] was used to evaluate the quality of life outcomes and satisfaction at the 6-month postoperative visit in the patients over a three year period to investigate the value of surgical correction of this deformity.

Data analysis

The paired sample t-test was used to compare initial and follow-up data for the same sample. The Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL, USA) version 15.0 was used to analyze the data that had been collected. Results were shown as mean, standard deviation, lowest and highest values. p-value was regarded as statistically significant at 0.05.

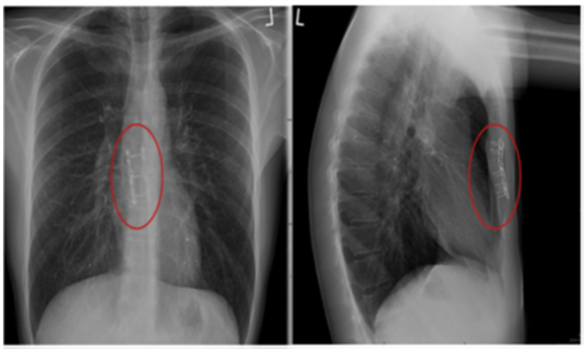

Figure 2. Chest radiographs from the Anteroposterior and lateral views that showing a titanium plate fixed with screws (6).

Results

Preoperative results

Pectus patients in this study were 12 males (92.3%) and 1 female (7.7%) of the patients, and the mean age was 16.4 ± 2.36 years which ranged from 12 to 19 years.

The most common preoperative symptoms were exercise intolerance in 9 patients (69%), Cosmetic impairment in 8 patients (61%), Shortness of breathing and dyspnea on exertion in 7 patients (54%), Chest pain in 6 patients (46%), Psychological disturbance in 5 patients (38%), We found no major abnormalities in preoperative ECG in any patient (Figure 3).

Intra-operative & post-operative surgical results

There were no operative deaths or major peri-operative

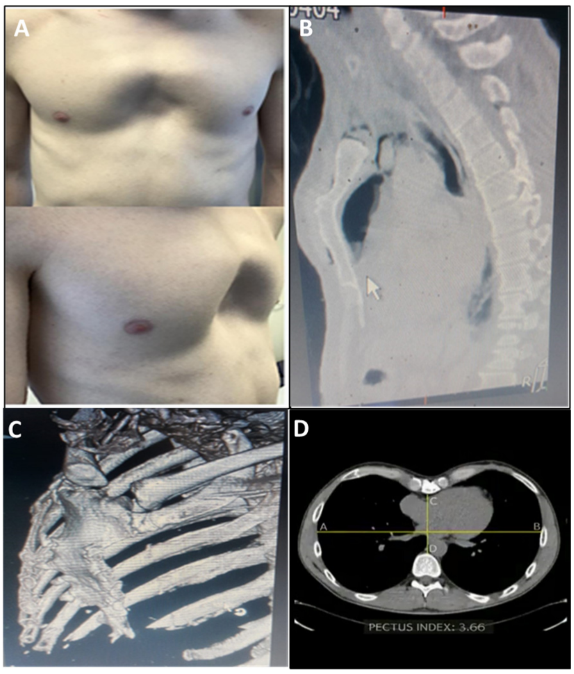

Figure 3. Preoperative pictures showing sternal deformity (AP and RT oblique view), B: Preoperative CT chest (Sagittal view) showing sternal deformity (pectus Excavatum), C: Preoperative 3D CT chest showing sternal deformity (Pectus Excavatum), D: Preoperative CT chest (Axial view) with HI 3.66.

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morbidity. The mean operation time of 120 minutes with estimated blood loss (EBL) was about 320 ml. We instructed the patient to avoid any impact on the front chest wall and to avoid lying prone or in a lateral position for at least two months. The overall mean hospital stay was 7 days (range, 5 to 9 days) (Table 1).

All patients were undergoing a follow-up examination as outpatients for a mean of 8 months (range 6 to 12 months). There was no recurrence. Seroma developed in one patient (7.69), which was easily managed by maintaining effective drainage, postoperative bleeding in one patient (7.69), which was reduced by hemostatic agents, and skin infection in one patient (7.69), which was limited to a small area (1- to 3-cm) of the incision, for which we prescribed oral antibiotics to treat wound infections. No cases of infection of the sternal plate or required operative re-exploration for infection were recorded (Table 1 and Figure 4).

Follow-up results

All patients were agreed to follow up and examined at 1 week, 1, 3, and 6 months after discharge and were subjectively satisfied with the excellent surgical results. The patients who were aware of subjective improvement postoperatively had less sensation of shortness of breathing and exercise intolerance despite increased exercise performance, and those who initially did not experience exercise intolerance also believed that they had recovered after surgery.

Comparison between results pre and postoperatively

HI was 3.8 (3.2-4.5) preoperatively compared with less

Table 1. Intra-operative & post-operative surgical results

Parameter		Results in pectus patients
OR duration (minutes)		120 (100-145)
EBL		200 (150-320)
Length of stay (days)		7 (5-9)
Complications	Postoperative bleeding	1 (7%)
	Seroma	1 (7%)
	Wound infection	1 (7%)

Discrete variables are listed as n (%), and continuous variables are listed as median (interquartile range), except where otherwise noted. OR; Operating room, EBL; estimated blood loss

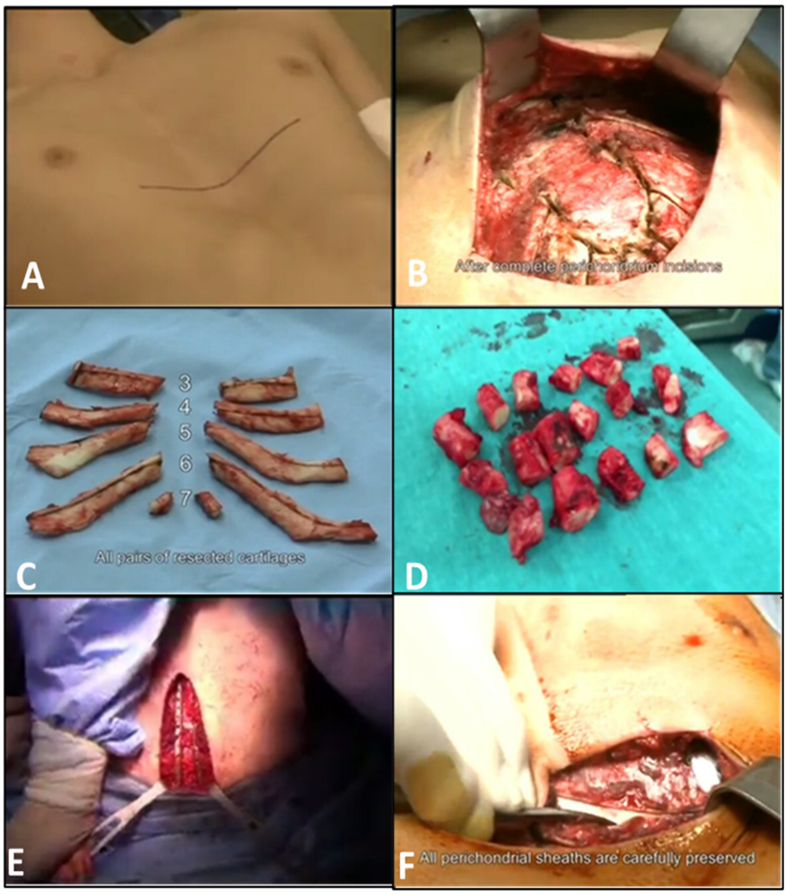

Figure 4. Intraoperative pictures showing A: Marking of incision for correction of sternal deformity, B: Intraoperative after complete pericondrial incision for correction of sternal deformity; C: All deformed costal cartilage removed (all pairs of resected cartilage); D: Showing all deformed costal cartilage removed; E: Intraoperative after correction of sternal deformity and fixation by plates and screw; F: Show preservation of perichondrial sheath.

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Table 2. Initial and Follow-up Pulmonary Function Tests

Parameter	Pectus excavatum (n = 13)		
	Preoperative	Postoperative	*P*-value
TLC	3.21± 1.12	3.69± 1.07*	0.025
FVC (L)	3.5 ± 1.0	3.7 ± 1.0*	0.047
FVC (%predicted)	83 ± 13	83 ± 16	0.831
RV(%predicted)	117± 33	109 ± 52	0.612
RV/TLC (%)	27 ± 5	27 ± 9	0.924
MVV	65.1± 31.5	78.9± 31.5*	0.033
FEV1	80 (69-89)	79 (71-90)	0.751
DLCO	82 (72-96)	85 (73-94.5)	1.684

Data are displayed as mean ± SD. RV: Residual volume, TLC: total lung capacity, FEV1: forced expiratory volume in 1 second, MVV: maximal voluntary ventilation, DLCO: diffusion capacity for carbon monoxide, * Significantly differ from the compared Preoperative result at the level of $P < 0.05$.

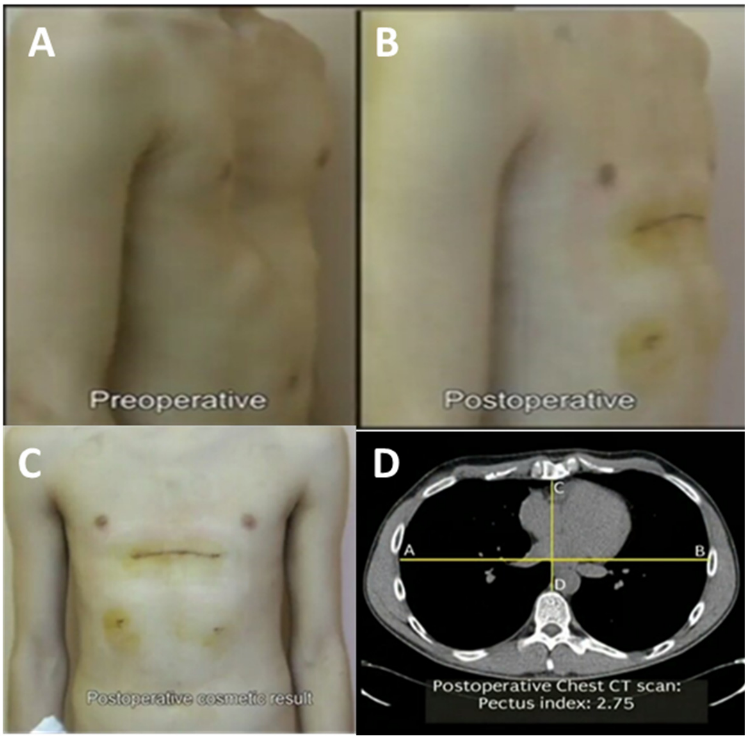

Figure 5. Postoperative pictures showing: A: comparison between Preoperative sternal deformity and B&C: postoperative results with a linear scar and good cosmetic result; D: Postoperative CT chest (Axial view) with HI 2.75.

than 3.0 (2.5 -2.8) postoperatively. All patients with displaced hearts showed a return of the heart to its normal site (Table 2 and Figure 5).

Pulmonary function testing

Preoperative showed forced vital capacity (FVC) 83±13 of predicted values, with Postoperative improvement to 83±16. The absolute FVC increased postoperatively in PE patients (from 3.5L to 3.7L). Also, Improvement of forced expiratory volume in 1 second (FEV1) from 78 (69-89) (80±14) to79 (71-90) of predicted values by 3rd month postoperatively. Significant improvement of MVV from 65.1± 31.5 preoperatively to 78.9± 31.5 postoperatively (Table 2).

Postoperative exercise stress tests

All patients with PE achieved a maximal heart rate of 180 beats/min or higher. No patients with PE had exercise-induced bronchospasm. When maximal heart rates during the two studies were compared for the same workload, heart rate was significantly lower during the follow-up study in patients with PE ($P < 0.05$) (Table 3).

Pulse oximetry (O2 pulse) was significantly higher during follow-up studies in patients with PE ($P < 0.05$). Preoperative and postoperative heart rate: Lower postoperative heart rate was found compared to the same work rate with better exercise performance. The observed decrease in heart rate at any given workload postoperative would support the theory that the enhancement in exercise capacity came because of an increase in cardiac stroke volume. The patients demonstrated improvement in total lung capacity and exercise performance as quantitated by total exercise time and lower heart rate (Table 3).

Postoperative surveys

Postoperative surveys were collected from all patients. 11 patients (84.61%) reported improved general health. A

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higher ability to exercise was noted by 12 patients (92.3%). Only 2 patients (15.38%) said that appearance had a slightly significant impact on social participation after the operation, compared to 9 patients (69.23%) who had said it was extremely affected previously. 12 people (92.3%) said they were satisfied with how they looked (appearance) following the procedure, with 7 (53.84%) of them stating they were very or extremely satisfied. Only 3 patients (23.07%) of people said their surgical scars troubled them from very slightly to somewhat. Four patients (30.76%) reported improved social life and a major improvement was recorded in 4 patients (30.76%). The operation led to improved breathing in 4 patients (30.76%) and a major improvement was recorded in 9 patients (69.23%). Eight patients (61.53%) reported improvement in chest pain and a major improvement was recorded in 5 patients (38.46%). There were no complaints of increased chest pain from any patients. Mean self-esteem score improved significantly from 4.5 to 8.35 of 10 from the pre- to postoperative state ($P < 0.05$). Pain was mild in 3 patients (23.07%) and moderate-severe during hospital stay in 1 patient (7.69%) and very severe in 2 patients (15.38%). At 6 months, 8 patients (61.53%) reported "Very slight" pain with day-to-day activity, with only 1 patient (7.69%) reporting needing "moderate" painkillers. All patients expressed their level of satisfaction with the overall outcome with 9 patients (69.23%) of those reporting that they were very or extremely satisfied. Eleven patients (84.61%) reported improved chest appearance after the operation. If faced with the same decision, 12 patients (92.3%) said they would select the procedure again if given the chance to make the same choice (Table 4).

Discussion

In this study, we performed a modified Ravitch technique for the repair of pectus excavatum (PE) to assess the functional and aesthetic outcomes.

In this study, most of the Pectus patients were males, 12 (92.3%) and 1 female (7.7%) with a mean age of 16.4 years which ranged from 12 to 19 years. The findings of this

Table 3. Initial and follow-up exercise test results in pectus patients:

Parameter	Pectus excavatum (n = 13)		
	Preoperative	Postoperative	*P*-value
Duration (min)	12 ± 3	13 ± 2*	0.001
Speed (km/hr)	7 ± 1	8 ± 2*	0.018
Grade (%)	17 ± 5	19 ± 2*	0.049
Maximal heart rate (beats/min)	192 ± 12	190 ± 10	0.782
Respiratory exchange ratio	1.17 ± 0.14	1.31 ± 0.29	0.352
O_2 pulse (ml/beat)	11.5 ± 3.7	12.9 ± 3.65*	0.025
V_E (L/min)	88 ± 30	92 ± 30	0.102
ΔV_T (%)	299 ± 80	316 ± 89	0.284
Maximal VO_2 (ml/kg/min)	40 ± 8	40 ± 7	0.025
Anaerobic threshold (ml/kg/min VO_2)	23 ± 6	23 ± 4	0.487
Maximal V_E/VO_2	27± 20	30 ± 16	0.143
Breathing reserve (L/min)	40 ± 6	44 ± 10	0.405
Maximal $PETCO_2$ (mm Hg)	41 ± 5	45 ± 4	0.336
Minimal SaO_2 (%)	96 ± 1	96 ± 2	0.291

Data displayed as mean ± SD, * significantly differ from the compared Preoperative result at the level of $P < 0.05$.

Table 4. Survey results

Variable		Value
General health after operation	Much better	11 (84.61)
	Somewhat better	1 (7.69)
	About the same	1(7.69)
	Much worse	0 (0.0)
Exercise capacity after operation	Much better	12 (92.30)
	Somewhat better	1 (7.69)
	About the same	0 (0.0)
	Much worse	0 (0.0)
Appearance interfered with social activity before the operation	Not at all	1 (7.69)
	Slightly	1 (7.69)
	Moderately	1 (7.69)
	Quite a bit	1 (7.69)
	Extremely	9 (69.23)
Appearance interfered with social activity after the operation	Not at all	11 (84.61)
	Slightly	2 (15.38)
	Moderately	0 (0.0)
	Quite a bit	0 (0.0)
	Extremely	0 (0.0)
Satisfaction with appearance after operation	Extremely satisfied	7 (53.84)
	Very satisfied	4 (30.76)
	Satisfied	1 (7.69)
	Dissatisfied	1 (7.69)
	Very dissatisfied	0 (0.0)
Bothered by surgical scars	Not at all	10 (76.92)
	Very slightly	1 (7.69)
	Slightly	1 (7.69)
	Somewhat	1 (7.69)

Table 4. Continued

Variable		Value (%)
Operation effect on social life	Major improvement	4 (30.76)
	Improved	4 (30.76)
	No change	5 (59.0)
	Worse	0 (0.0)
	A lot worse	0 (0.0)
Operation effect on breathing	Major improvement	9 (69.23)
	Improved	4 (30.76)
	No change	0 (0.0)
Operation effect on the level of chest pain	Major improvement	5 (38.46)
	Improved	8 (61.53)
	No change	0 (0.0)
	Worse	0 (0.0)
Pre-operative self-esteem (1-10)	1 = poor, 10 = excellent (mean)	4.5
Post-operative self-esteem (1-10)	1 = poor, 10 = excellent (mean)	8.35
Pain during hospital stay	Very mild	7 (53.84)
	Mild	3 (23.07)
	Moderate-severe	1 (7.69)
	Very severe	2 (15.38)
Pain interferes with day-to-day activity now	Not at all	5 (38.46)
	Very slightly	8 (61.53)
	Slightly	0 (0.0)
	Some	0 (0.0)
Pain now	None	10 (76.92)
	Occasional	1 (7.69)
	Mild; no painkillers	1 (7.69)
	Moderate; painkillers	1 (7.69)
How do you feel about the final result	Extremely satisfied	9 (69.23)
	Very satisfied	2 (15.38)
	Satisfied	2 (15.38)
	Dissatisfied	0 (0.0)
How does the chest look now	Major improvement	11 (84.61)
	Improved	2 (15.38)
	No change	0 (0.0)
Going back, I would have the operation again	Yes	12 (92.30)
	Unsure	1 (7.69)
	No	0 (0.0)

study were consistent with a prior study (15) that found that the mean age of patients with pectus excavatum was 17 years and the male predominance was similar to the results of a previous study on pectus excavatum (1, 16).

In this study, exercise intolerance accounted for 69% of the preoperative symptoms, cosmetic impairment for 61%, dyspnea and shortness of breath upon exertion for 7 patients (54%), chest discomfort for 6 patients (46%), and psychological disturbance for 5 patients (38%). None of the patients had any significant abnormalities in their preoperative ECG. Like our results, a recent study (17) discovered that PE deformity was prominent with rapid vertical growth during puberty in younger children. The symptoms, which were supported by metrics like the severity index and indications of physiologic impairment, included pain in the affected costal cartilages, intolerance to exercise, shortness of breath, and the patient's sense of cosmetic discomfort.

The mean operation time was 120 minutes. The mean operation time in another study (6) was 98 minutes. Other reports of the modified Ravitch technique have mean times ranging from 135 minutes to more than 250 minutes (14, 18). The length of the procedure might vary greatly depending on the surgeon's competence and multiple intraoperative variables.

In this study, there were no operative deaths. Similar results of no intraoperative mortality were recorded in either a systematic review and meta-analysis (19) comparing Ravitch versus Nuss procedure for patients with pectus excavatum or a previous study (20) comparing Modified Ravitch Procedure for Pectus Excavatum Combined With Complex Cardiac Surgery.

The EBL in this study was about 320 ml. Similar to our results, The EBL in previous studies (21, 22) ranged from 33 mL to 359 mL. Also, the overall mean hospital stay (LOS) in our study was 7 days (5 to 9 days). In line with earlier publications, the median LOS for other recent cohort studies (6) was 4 days which was similar to other reports (16, 21). The fact that our study's operations took place in shorter amounts of time while still maintaining acceptable EBL and LOS suggests that our strategy is still a useful one.

Complications occurred, including seroma in 1 (7.69%) patient, postoperative bleeding in 1 (7.69%) patient, and skin infection in 1 (7.69%) patient. No cases of infection of the sternal plate or required operative re-exploration for infection were recorded. Similar to our results, a previous study by Masaoka and colleagues (23) recorded complications in about 6% of cases in a large series (n = 426) during the modified Ravitch technique. The majority of potential complications are wound-related (such as seroma and wound dehiscence).

Contrary to our results, no complications were recorded in a pilot study (24) on pectus patients (n = 9). This could be due to the safety and feasibility of rigid fixation by

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Sterna Lock Blu plates during the modified Ravitch procedure.

In our study, CT chest was an appropriate radiological tool in the diagnosis of PE and calculation of HI pre- and post-operatively which was 3.8 (3.2-4.5) preoperatively compared with less than 3.0 (2.5 -2.8) postoperatively. All patients with displaced hearts showed a return of the heart to its normal size. In agreement with our results, a CT chest scan and the HI was used in all published research on the pectus excavatum as the degree of HI and the obvious clinical finding were directly correlated with the degree of compression on mediastinal structures (18, 20).

Pulmonary function tests

In this study, the pulmonary function testing was positively correlated with the remarkable decrease of HI as the preoperative showed forced vital capacity (FVC) 83±13 of predicted values, with Postoperative improvement to 83±16. The absolute FVC increased postoperatively in PE patients (from 3.5L to 3.7L). And Improvement of forced expiratory volume in 1 second (FEV1) from 78 (69-89) (80±14) to79 (71-90) of predicted values by 3rd month postoperatively. Significant improvement of MVV from 65.1± 31.5 preoperatively to 78.9± 31.5 postoperatively.

According to our findings, numerous studies (8, 25) have demonstrated that surgical repair of pectus excavatum improves lung functions. One year after surgery, forced expiratory volume in one second (FEV1) and forced vital capacity (FVC) significantly increase when compared to pre-surgery values. These results imply that pectus excavatum surgical treatment can help afflicted patients' pulmonary function. The postoperative findings on adolescent patients by Sakamoto and colleagues (26) indicated little to no increase in lung function, which is opposite to our findings. This might be because our study's inclusion and exclusion criteria differed based on age groups.

Exercise stress test

The patients who were aware of subjective improvement postoperatively had less sensation of shortness of breathing and exercise intolerance despite increased exercise performance, and patients who did not initially indicate exercise intolerance also believed that their postoperative condition had improved.

The maximum heart rate for all PE patients was 180 beats per minute or greater. When the maximal heart rates from the two investigations were evaluated for the same workload, the follow-up study's heart rate in individuals with PE was significantly lower. Preoperative and postoperative heart rate: Llower postoperative heart rate was found compared to the same work rate with better exercise performance. The observed decrease in heart rate at any given postoperative workload, would be consistent with the theory that the increased cardiac stroke volume was the cause of the improvement in exercise capacity.

Similarly to our results, a recent study revealed that the majority of PE patients reported improvement in exercise tolerance and general health after surgery (27). Moreover that, twelve of sixteen studies that investigated exercise tolerance testing (cardiopulmonary exercise testing, or CPET) after surgery showed a significant improvement (28).

Also, Pulse oximetry (O_2 pulse) was significantly higher during follow-up studies in patients with PE ($P < 0.05$). In line with this result, a study conducted by Park et al. 2008, showed that patients who underwent surgical repair of PE had a significant increase in maximal oxygen uptake (VO_2max) at one year post-surgery (29). Along with similarity, a previous study investigated the change in cardiorespiratory parameters in thoracic wall deformities following surgical correction and demonstrated an improvement in exercise capacity in patients who underwent the Ravitch procedure (30).

Initial meta-analyses following surgical treatment of PE showed a significant improvement in cardiovascular parameters but no change in resting pulmonary function, which is contradictory to our findings (31). Per pulmonary function meta-analyses, improvements in forced expiratory volume in one second were associated with minimally invasive surgical approaches rather than open Ravitch operations once the bar was removed (32). The increased ability to exercise that PE participants felt may have resulted from the lowered rib cage relieving pressure on the heart and lungs, which enhanced chest wall compliance and/or tidal volume (6).

Regarding the post-operative survey results in our study, most of the patients were satisfied with the operation after 6-months of follow-up and revealed positive results in all the survey questions indicating favorable results after the operation which were similar to the results of the previous studies in either the same period or long period of follow up (6, 27).

From the findings above, we hypothesize that surgical correction of the deformity using a modified Ravitch approach can alleviate both the reduced cardio-pulmonary functions and the increased work of breathing that have been described in pectus patients. Also, it has been shown to improve exercise tolerance in individuals with pectus excavatum.

Limitations of this study

the small sample size number and the short period of postoperative follow-up were the known limitations of this study.

Conclusion

Modified Ravitch-type repair is a secure and reliable method for treating pectus excavatum with better relief of preoperative symptoms.

Authors' Contributions

Gamal Farag, Ahmed Omran, Sheif Yousef, Ramadan Abd Alaziz, Samir Nematallah, Ahmed Abd El Salam, Husseini El boraey, Tarek Zahra, Ahmed Zeina contributed in research conceptualizing, methodology, and Gamal Farag, Ahmed Omran, Sheif Yousef, Ramadan Abd Alaziz, Samir Nematallah, Ahmed Abd El Salam, Husseini El boraey, Osama Ramadan, Tarek Zahra, Ahmed Zeina contributed in suggesting the idea, writing the original draft, editing the manuscript, data collection, data analysis, and final approval.

Ethical Considerations

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Damietta Faculty of Medicine, Al-Azhar University (DFM-IRB 0001267-21-05-011).

Acknowledgment

None declared.

Conflict of Interests

The authors declare that they have no competing interests.

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