Comparison of Respiratory Mechanics in Adult Patients Undergoing Minimally Invasive Repair of the Pectus Excavatum and Removal of a Pectus Bar

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Objective: The objective of this study was to compare the respiratory mechanics and gas exchange in adult patients undergoing minimally invasive repair of the pectus excavatum (MIRPE group) and removal of a pectus bar (bar removal group).

Design: A prospective observational study.

Setting: A tertiary university hospital.

Participants: Thirty-two patients scheduled for elective MIRPE or removal of a pectus bar.

Interventions: None.

Measurements and Main Results: Spirometry was used to measure the peak inspiratory airway pressure (PIP), static compliance, and respiratory resistance. The measurements were recorded at 1 minute after beginning mechanical ventilation (T0), 15 minutes after beginning sevoflurane inhalation (T1), and after the insertion (or removal) of a pectus bar through the chest wall (T2). Pulmonary gas exchange was assessed by calculating the alveolar arterial oxygen tension difference ($AaDO_2$) before surgical incision and after insertion (or removal) of the pectus bar. In the MIRPE group, static compliance was decreased significantly ($p < 0.001$), and PIP was increased significantly ($p < 0.001$) after insertion of the pectus bar (T2) compared with baseline. In contrast, the bar removal group showed the opposite results. There were significant differences in static compliance and PIP at T2 between the groups ($p = 0.002$ and 0.026, respectively). $AaDO_2$ was increased significantly in the MIRPE group compared with the bar removal group ($p = 0.012$).

Conclusions: Insertion of the pectus bar through the chest wall results in significant changes in respiratory mechanics and gas exchange. Therefore, close attention to pulmonary function is required during and after these surgical procedures.

KEY WORDS: pectus excavatum, respiratory mechanics, airway pressure, static compliance, respiratory resistance, alveolar arterial oxygen tension difference

MINIMALLY INVASIVE REPAIR of the pectus excavatum (MIRPE) was introduced by Nuss et al[1] and has been used widely to correct this chest wall deformity. The procedure requires 2 small incisions on the lateral aspect of the chest, through which 1 or more curved metal bars is inserted retrosternally and then flipped to lift the depressed chest wall. The bars are removed after 2 to 4 years when permanent chest wall remodeling has occurred.[1,2] Common complications associated with MIRPE are pneumothorax, pleural effusion, postoperative pain, wound infection, and bar displacement.[2-4]

After inserting or removing the pectus bar through the chest wall, several serious changes in respiratory physiology are expected. Previous studies showed a significant reduction in the forced vital capacity, forced expired volume in 1 second, and vital capacity after insertion of the pectus bar.[5] In addition, changes in pulmonary function after repair of the pectus excavatum have been studied and have shown conflicting results.[6-8] However, there are no referential data that showed the changes in pulmonary function during the procedure.

This study was conducted to evaluate and compare the intraoperative changes in respiratory mechanics and gas exchange in adult patients undergoing MIRPE and bar removal. The authors hypothesized that insertion of the pectus bar would restrict the chest wall movement and attenuate pulmonary function.

METHODS

After institutional review board approval and informed consent, patients older than 18 years of age with an American Society of Anesthesiologists physical status of I or II were enrolled consecutively. The exclusion criteria were patients with respiratory, cardiovascular, or neurologic abnormalities and those taking bronchoactive drugs (eg, β-agonists or antagonists, theophylline, anticholinergics, and corticosteroids).

The patients were scheduled for elective MIRPE (MIRPE group) or the removal of a pectus bar (bar removal group). All procedures were performed by the same team of surgeons using the same surgical technique. If there were severe or wide deformities, a second bar was used. The operative procedure is described in detail elsewhere.[2]

Standard monitoring comprised of noninvasive blood pressure, end-tidal carbon dioxide, oxygen saturation, electrocardiography, and body temperature was applied (IntelliVue MP70; Philips, Aachen, Germany). The bispectral index was monitored to measure the depth of anesthesia and sedation using an Aspect A-3000 EEG monitor (Aspect Medical Systems Inc, Newton, MA).

Anesthesia was induced intravenously using 2 mg/kg of propofol, 1 μg/kg of fentanyl, and 1 mg/kg of rocuronium. The patient's trachea was intubated using a cuffed tracheal tube with an internal diameter of 8.0 (male) or 7.0 mm (female). The tracheal cuff was inflated until no leak could be heard. The cuff inflation pressure was monitored using a hand pressure gauge (Tyco Healthcare, Bayern, Germany) and maintained according to the manufacturer's manual.

After the induction of anesthesia and intubation, the concentration of sevoflurane was adjusted to maintain the bispectral index value at 40 to 60. All patients received fentanyl as an analgesic agent in a dose suitable to the surgery performed. A neuromuscular blockade was maintained with the intermittent administration of rocuronium and monitored with train-of-4 responses at the adductor pollicis muscle.

The patient's lungs were ventilated in the constant-flow, volume-controlled mode using an Avance ventilator (Datex-Ohmeda, Madison, WI) with the following settings: tidal volume, 10 mL/kg; inspiratory: expiratory ratio, 1:2; inspired oxygen concentration, 50% with air; and inspiratory fresh gas flow, 3 L/min. The end-inspiratory pause was set to 20% of the total breathing cycle. Positive end-expiratory pressure was not used. The respiration rate was adjusted to maintain an end-tidal

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carbon dioxide value of 33 to 35. These ventilator settings were maintained throughout the study period.

A patient spirometry monitor (E-CAiOV; GE Healthcare, Helsinki, Finland) was used to measure respiratory mechanics. A flow sensor (D-lite, GE Healthcare) was connected between the tracheal tube and "Y" piece of the respiratory circuit to measure the peak inspiratory pressure (PIP), static compliance, and respiratory resistance. The measurements were recorded at 1 minute after beginning mechanical ventilation (T0), 15 minutes after beginning sevoflurane inhalation (T1), and after insertion (or removal) of the pectus bar through the chest wall (T2). Each variable was measured 5 times consecutively, and the average values were calculated. Airway secretions were removed with suction through the tracheal tube before measuring.

An arterial catheter was inserted into the radial artery for continuous monitoring of the arterial blood pressure and blood sampling. Arterial blood samples were analyzed before surgical incision and after insertion (or removal) of the pectus bar using a blood gas analyzer (ABL800 FLEX; Radiometer, Copenhagen, Denmark).

Pulmonary oxygenation and gas exchange were assessed by calculating the alveolar arterial oxygen tension difference ($AaDO_2$). $AaDO_2$ was the difference between the partial pressure of oxygen in the alveoli (P_AO_2) and arterial blood (PaO_2). The P_AO_2 was estimated as $P_AO_2 = P_IO_2 - (P_ACO_2/R)$, where P_IO_2 is inspired oxygen tension, P_ACO_2 is alveolar CO_2 tension (assumed to equal arterial $PaCO_2$), and R is the respiratory quotient (assumed to be 0.8). P_IO_2 was calculated as $(P_B - P_{H2O}) \times F_IO_2$, where P_B is the barometric pressure (assumed to be 760 mmHg) and P_{H2O} is the saturated water pressure (47 mmHg at 37°C).

After insertion or removal of the pectus bar, an intraoperative chest x-ray was taken to confirm the bar position and to detect pulmonary complications, such as pneumothorax or pleural effusion. Patients who developed pneumothorax or pleural effusion during surgery were excluded from the study.

The sample size calculation was based on the preliminary data in which the static compliance in the MIRPE group was 10 mL/cmH_2O greater than that in the bar removal group, with a standard deviation of 10 mL/cmH_2O. A minimum of 16 patients per group were required for the study to have an α error of 0.05 and a power of 80%.

All data are expressed as the mean ± standard deviation or number of patients. All variables were distributed normally as analyzed by the Shapiro-Wilk test. The categoric variables were analyzed using the chi-square test or the Fisher exact test as appropriate. Continuous variables were analyzed using the unpaired *t* test. Differences in respiratory mechanics within each group were determined using repeated measures analysis of variance with the Bonferroni test for post hoc comparisons, and the *p* value was corrected. Comparisons of $AaDO_2$ within groups were performed using the paired *t* test. A *p* value of less than 0.05 was considered statistically significant. All statistical analyses were performed using Statistical Package for the Social Sciences version 17.0 (SPSS Inc, Chicago, IL).

RESULTS

Thirty-two patients were enrolled in this study. No patient was excluded because of intraoperative pulmonary complications. The clinical characteristics of the patients are shown in Table 1. The demographic data for both groups did not differ significantly with the exception of the anesthesia time. It was because the procedure of MIRPE took longer than removal of the bar. Because all patients were older than 18 years of age, more patients required 2 pectus bars, whereas children usually required 1 pectus bar. The concentration of the anesthetic agent (sevoflurane) and the dose of fentanyl did not differ between the groups.

Table 1. Demographic Data and Clinical Profiles

	MIRPE Group (n = 16)	Bar Removal Group (n = 16)	*p* Value
Age (y)	21.5 ± 2.6	23.8 ± 4.2	NS
Sex (M/F)	13/3	14/2	NS
Height (cm)	172.9 ± 8.3	173.1 ± 5.4	NS
Weight (kg)	55.5 ± 7.8	59.0 ± 7.7	NS
Body mass index (kg/m²)	18.5 ± 1.7	19.6 ± 1.7	NS
Number of bar (1/2)	6/10	9/7	NS
Expiratory concentration of sevoflurane (vol%)	1.97 ± 0.2	1.90 ± 0.2	NS
Fentanyl (μg/kg/h)	1.50 ± 0.42	1.75 ± 0.79	NS
Anesthesia time (min)	101.5 ± 26.8	72.0 ± 22.5	0.009

NOTE. Values are expressed as mean ± standard deviation or number of patients.

Abbreviations: MIRPE, minimally invasive repair of the pelvic excavatum; M, male; F, female; NS, not statistically significant between the groups.

The patients' respiratory mechanics are shown in Figure 1. There were no significant differences in static compliance at T0 and T1 between the groups. In the MIRPE group, static compliance was decreased significantly after insertion of the pectus bar (T2) compared with that at T0 ($p < 0.001$). By contrast, there was a significant elevation in static compliance at T2 in the bar removal group ($p < 0.001$). At T2, the levels of static compliance were significantly different between the groups ($p = 0.002$).

At T1, the PIP levels decreased significantly in both groups compared with the baseline values (T0). In addition, the levels were lower in the MIRPE group than in the bar removal group. At T2, the PIP level was increased significantly in the MIRPE group ($p < 0.001$), whereas the opposite result was obtained in the bar removal group ($p = 0.003$). There was a significant difference in the PIP level at T2 in the MIRPE group versus the bar removal group ($p = 0.026$).

The values of respiratory resistance were similar at baseline in both groups and then decreased continuously in the bar removal group. In the MIRPE group, respiratory resistance was decreased significantly at T1 and then increased slightly at T2. However, there was no significant difference between the 2 groups. $AaDO_2$ increased significantly after insertion and removal of the pectus bar in both groups (Fig 2). In addition, the value of $AaDO_2$ was greater after insertion of the pectus bar than after removal of the pectus bar ($p = 0.012$).

DISCUSSION

In the present study, it was found that surgical repair of the pectus excavatum using a minimally invasive technique can significantly affect pulmonary function. These results show that after MIRPE there is a decline in respiratory mechanics and an increase in $AaDO_2$. In contrast, removal of the pectus bar significantly improved chest wall dynamics.

During mechanical ventilation, PIP indicates the pressure needed to distend the respiratory system at the chosen values for tidal volume and inspiratory flow. Plateau pressure is measured during inspiratory pause under stop-flow conditions and reflects alveolar pressure even though it is measured in the