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The effects of sternotomy and thoracotomy on respiratory muscle strength

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Abstract

Objective: The aim of this prospective clinical study was to investigate the effects of sternotomy and thoracotomy on respiratory muscle strength (RMS).

Method: After obtaining ethics committee approval and written informed consent from patients, 60 patients who underwent open heart surgery using sternotomy (Sternotomy Group [SG], n=30) or lung surgery using thoracotomy (Thoracotomy Group [TG], n=30) were included. Pulmonary function test (PFT) and respiratory muscle strength (RMS) test were performed before and after surgery to compare forced expiratory volume during the first second of the breath (FEV1), forced vital capacity (FVC), maximal inspiratory pressure (PImax), maximal expiratory pressure (PEmax), and sniff nasal inspiratory pressure (SNIP) between groups.

Results: Preoperative FEV1, FVC, PImax, PEmax, and SNIP were similar between groups (p>0.05) and were found to be decreased significantly in the postoperative period (p<0.001). Postoperative FVC was significantly lower in SG than TG (p=0.021). The rates of decrease in FVC and PImax were significantly higher in SG than TG (48.71% vs. 34.95% for FVC; p=0.04 and 38.38% vs. %32.8 for PImax; p=0.04).

Conclusion: It is concluded that pulmonary functions and respiratory muscle strength may decrease after sternotomy and thoracotomy procedures. However; pulmonary function (FVC) and RMS (Pimax) were more adversely affected following sternotomy compared to thoracotomy during the early postoperative period.

Keywords: Respiratory function tests, anesthesia, general, sternotomy, thoracotomy

INTRODUCTION

Although open heart and thoracic surgeries are generally performed to treat life-threatening conditions of the heart and lung, they may result in serious complications during the postoperative period without intraoperative major bleeding or organ insufficiency (1,2). Among various factors, pulmonary function plays a major role in the success of

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the surgery and should be optimized before and after the procedure. Therefore, pulmonary function tests (PFTs) were implemented into routine preoperative screening for risk stratification in cardiothoracic surgery. On the other hand, it is reported that respiratory mechanics are disturbed even after sternotomy and thoracotomy; the most used surgical incisions in cardio-thoracic surgery to enter the thoracal cavity regardless of the procedure (3,4). Injury and underuse lead to a decrease in the strength of respiratory muscles and manifest clinically with abnormal breathing pattern and lung collapse.

In addition to PFTs, evaluation of the inspiratory and expiratory respiratory muscle strength (RMS) is of interest by clinicians especially for patients with chronic respiratory diseases and neuromuscular disorders (5). The procedure of RMS test provides a non-invasive measurement of maximal inspiratory pressure (Pİmax), maximal expiratory pressure (PEmax), and sniff nasal inspiratory pressure (SNIP) during maximum respiratory efforts of a patient against an occlusion valve system. In recent years, studies about this topic have arisen to assess RMS in patients undergoing cardiothoracic surgery. However, those studies are limited to a single surgical procedure such as coronary artery bypass grafting (CABG) surgery or to different types of a single surgery (posterolateral or transaxillary thoracotomy), (6,7).

The aim of this study is to evaluate and compare respiratory muscle strength before and after surgery in patients who underwent open-heart surgery via sternotomy and thoracic surgery via thoracotomy.

METHOD

After obtaining the hospital's ethics committee approval and written informed consent from patients, 60 adult patients between 18-80 years with American Society of Anesthesiologists (ASA) physical status I-III were included in this prospective clinical study. The patients were scheduled for elective open-heart surgery or lung surgery in a tertiary Dokuz Eylül University hospital. The study was conducted in accordance with the principles of the Declaration of Helsinki. The exclusion criteria were a history of neuromuscular or rheumatologic disease, previous sternotomy or thoracotomy, chest wall deformity, and morbid obesity. The patients were also excluded who were not able to perform PFT and RMS test and who underwent a revision surgery or required mechanical ventilation for longer than 24 hours in the postoperative period. The patients were divided into two groups according to the type of the surgery: Sternotomy group (SG; n=30) underwent open heart surgery using sternotomy, and thoracotomy group (TG; n=30) underwent lung surgery using thoracotomy.

One day before the operation, all patients were informed about the use of the portable spirometry device (Spirolab MIR III, Italy) for PFT and the portable manometer device (microRPM, Micro Medical Limited, England) for the RMS test. The tests were performed under the supervision of a study research member. The values related to the PFT including forced vital capacity (FVC), forced expiratory volume at the first second (FEV1), FEV1/FVC ratio, and the values for the RMS test including Pİmax, SNIP, and PEmax were obtained. When the variation between three consecutive measurements was below 10%, mean values were recorded as basal values.

After arriving in the operating room, the patients were monitored with pulse oximetry, electrocardiogram and non-invasive blood pressure and given intravenous midazolam (1-2 mg) for premedication. Arterial cannulation was applied to the left radial artery under local anesthesia using 10 mg of 1% lidocaine for invasive arterial blood pressure monitoring and blood sampling. General anesthesia was induced using intravenous (IV) etomidate (0.2-0.3 mg/kg) or thiopental sodium (3-7 mg/kg), fentanyl (3-5 µg/kg) and rocuronium (0.6-1.0 mg/kg). Endotracheal intubation was performed with a properly sized endotracheal tube in SG patients, and endobronchial intubation was performed with a double-lumen endobronchial tube in TG patients. A central venous catheter was inserted into the right internal jugular vein. Sevoflurane (1-2%) was used as the hypnotic volatile agent for maintenance of anaesthesia, and mechanical ventilation settings were adjusted to provide adequate ventilation and normocarbia. Opioids and nondepolarizing neuromuscular blocker agents were repeatedly administered during the intraoperative period and before transport to the intensive care unit (ICU), where mechanical ventilation was continued until extubation after stable clinical and hemodynamic conditions were achieved. The duration of mechanical ventilation was recorded.

In the postoperative period, 1 g of IV metamizole sodium with eight-hour intervals and 100 mg of intramuscular tramadol hydrochloride were administered for postoperative pain relief. The dynamic pain scores were assessed using the visual analogue scale (VAS). An additional analgesic was given when the VAS score was>3. The RMS test and PFT were repeated on the postoperative third day.

Postoperative complications were defined as the occurrence of any of the following events during the hospital stay: pulmonary complications (atelectasis requiring physiotherapy or bronchoscopy, pneumonia diagnosed clinically and radiologically, pleural effusion requiring drainage), cardiac complications (new-onset atrial fibrillation or other arrhythmias requiring medical treatment), prolonged mechanical ventilation (>24 hours), need for re-intubation,

and wound-related complications (superficial or deep surgical site infection). All complications were recorded prospectively.

Statistical Analysis

SPSS 15.0 was used for the analysis of the data. Between the groups, the chi-square test was used for ASA classification; Fisher's exact test for postoperative complications, associated disease, previous surgical intervention, preoperative medication use, smoking history, and gender; and the independent-samples t-test was used for demographic variables. Intergroup and intragroup comparisons, including the duration of mechanical ventilation, surgery and the tests, intergroup and intragroup functions were compared with nonparametric tests following the Shapiro-Wilk normality test. The Mann-Whitney U test for the intergroup evaluation and the Wilcoxon Signed Rank Test for the intragroup evaluation were also applied. Data were presented as means ± standard deviation (SD) or as percentages (%). $p < 0.05$ was considered as statistically significant.

RESULTS

Of 67 patients who were included in the study, 7 were excluded: Two patients required a revision surgery (one patient each from SG and TG) and mechanical ventilation was continued for longer than 24 hours in 5 patients (4 patients from SG and 1 patient from TG). The study was completed after collecting data from 60 patients.

Demographic characteristics did not differ significantly between the study groups (p>0.05) except for ASA physical status. There were more ASA II-III patients in SG than TG (p=0.02), (Table 1). Duration of the surgery was significantly longer in SG compared to TG (267.00±68.05 min vs 214.33±42.21 min; p=0.001).

Preoperative PFT and RMS tests showed that FEV1, FVC, FEV1/FVC, Pİmax, SNIP, and PEmax values were not significantly different between study groups (p>0.05), (Table 2), while only postoperative FVC was significantly lower in SG than TG (p=0.021) (Table 3).

When preoperative and postoperative values were compared within each group, FEV1, FVC, Pİmax, SNIP, and PEmax decreased significantly after surgery in both the SG and TG (all p<0.001). In the SG, FEV1 decreased from 2.48±0.98 L to 1.21±0.51 L and FVC decreased from 3.17±0.96 L to 1.54±0.56 L (both p<0.001). Similarly, Pİmax decreased from 70.27±25.63 cmH_2O to 39.53±15.92 cmH_2O, SNIP from 64.37±22.41 cmH_2O to 39.80±12.45 cmH_2O, and PEmax from 78.07±26.02 cmH_2O to 55.17±16.03 cmH_2O (all p<0.001).

In the TG, FEV1 decreased from 2.17±0.61 L to 1.39±0.38 L and FVC decreased from 2.98±0.80 L to 1.87±0.56 L (both p<0.001). Likewise, significant postoperative reductions were observed in Pİmax (69.17±21.73 to 45.20±13.81 cmH_2O), SNIP (66.17±20.84 to 47.60±18.84 cmH_2O), and PEmax (80.53±25.21 to 53.37±16.70 cmH_2O) (all p<0.001).

Table 1. Demographic characteristics and surgery types in groups

	Sternotomy Group (n=30)		Thoracotomy Group (n=30)		p
Gender (M/F) (n;%)	21 / 9	70 / 30	25 / 5	83.3 / 16.7	0.36
Age (years)	55.67±16.18		59.77±11.15		0.25
Weight (kg)	71.27±12.31		73.13±14.88		0.59
Height (cm)	166.93±6.56		170.37±6.76		0.51
BMI (kg/m²)	25.61±4.57		25.08±4.06		0.63
ASA I/II/III (n;%)	0 / 3 / 27	0 / 10 / 90	1 / 11 / 18	3.3 / 36.7 / 60.0	0.02
Smoking habit (n;%)	20	66.7	25	83.3%	0.23
Surgical intervention	CABG	17	Pneumonectomy	4	
	Valve surgery	8	Wedge resection	12	
	Aneurysm repair	1	Lobectomy	12	
	Cyst /tumor resection	4	Cystectomy	2	

Abbreviations: M= Male, F= Female, BMI= Body Mass Index, ASA= American Society of Anesthesiologists physical status, CABG=Coronary artery bypass grafting. Values are given as mean±standard deviation or percentage (%).

Table 2. Comparison of preoperative respiratory muscle strength test and pulmonary function test

	Sternotomy Group (n=30)	Thoracotomy Group (n=30)	p
FEV1 (L)	2.48±0.98	2.17±0.61	0.11
FVC (L)	3.17±0.96	2.98±0.80	0.37
FEV_1/FVC (%)	75.37±15.38	72.97±10.93	0.18
$P_I$max (cmH_2O)	70.27±25.63	69.17±21.73	0.91
SNIP (cmH_2O)	64.37±22.41	66.17±20.84	0.62
$P_E$max (cmH_2O)	78.07±26.02	80.53±25.21	0.61

Abbreviations= FEV_1: Forced expiratory volume at first second, FVC: Forced vital capacity, $P_I$max: maximal inspiratory pressure, $P_E$max: maximal expiratory pressure, SNIP: Sniff nasal inspiratory pressure. Values are given as mean±standard deviation or percentage (%).

Inversely, FEV1/FVC ratio increased postoperatively in both groups; however, this increase reached statistical significance only in the SG (3.84%, p=0.04), but not in the TG (3.28%, p>0.05) (Table 4).

Those changes were also compared between groups and were found that the ratios of the change in FVC and Pİmax were significantly higher in the SG than TG at the preoperative period compared to the postoperative period (48.71% vs. 34.95% for FVC; p=0.04 and 38.38% vs. %32.8 for Pİmax; p=0.04). The ratios for the remaining values were not significantly different between the groups (p>0.05) (Table 4).

Table 3. Comparison of postoperative respiratory muscle strength test and pulmonary function test

	Sternotomy Group (n=30)	Thoracotomy Group (n=30)	p
FEV1 (L)	1.21±0.51	1.39±0.38	0.062
FVC (L)	1.54±0.56	1.87±0.56	0.021
FEV_1/FVC (%)	78.07±16.20	74.83±10.80	0.080
PImax (cmH_2O)	39.53±15.92	45.20±13.81	0.097
SNIP (cmH_2O)	39.80±12.45	47.60±18.84	0.096
PEmax (cmH_2O)	55.17±16.03	53.37±16.70	0.534

Abbreviations= FEV_1: Forced expiratory volume at first second, FVC: Forced vital capacity, $P_I$max: maximal inspiratory pressure, $P_E$max: maximal expiratory pressure, SNIP: Sniff nasal inspiratory pressure. Values are given as mean±standard deviation or percentage (%). p<0.05 was considered statistically significant.

Table 4. Comparing changes in the percentage of respiratory muscle strength and pulmonary function tests between groups

	Sternotomy Group	Thoracotomy Group	p
FEV1	−46.50	−33.90	0.05
FVC	−48.71	−34.95	0.04
FEV_1/FVC	+3.84	+3.28	0.70
$P_I$max	−38.38	−32.80	0.04
SNIP	−33.51	−25.67	0.11
$P_E$max	−26.09	−32.64	0.24

Abbreviations= FEV_1: Forced expiratory volume at first second, FVC: Forced vital capacity, $P_I$max: maximal inspiratory pressure, $P_E$max: maximal expiratory pressure, SNIP: Sniff nasal inspiratory pressure. Values are given as −: decrease or +: increase. p<0.05 was considered statistically significant.

The duration of postoperative mechanical ventilation was significantly higher in the SG than TG (760±320 min vs 325±211 min; p<0.001). Also, complication rates were significantly higher in the SG than TG (36.6% vs 9.9%; p=0.01). The most common complications in the SG were pulmonary complications, including atelectasis and pneumonia, followed by cardiac arrhythmias requiring medical treatment. In the TG, complications were mainly limited to minor pulmonary events. Those patients were treated and discharged from the hospital. No mortality was observed.

DISCUSSION

Based on the results of this study, it can be stated that pulmonary functions and respiratory muscle strength may be functionally impaired in various degrees after open heart surgery using sternotomy and after pneumotomy using thoracotomy. In the present study, several postoperative changes were observed, including: a) a significant decrease in baseline preoperative respiratory muscle strength parameters during the postoperative period in both groups, b) a parallel decline between respiratory muscle strength test results and pulmonary function test findings, and c) a greater reduction in FVC and PImax, reflecting impaired inspiratory effort, in the SG compared to the TG.

The results of this study comparing pre- and postoperative pulmonary function tests are consistent with previous reports demonstrating that cardiac surgery performed via median sternotomy is associated with a significant postoperative decline in pulmonary function. In the present study, postoperative reductions in lung volumes and expiratory flow parameters indicate a substantial impairment of respiratory mechanics during the early postoperative period following sternotomy. Ragnarsdottir et al. similarly reported significant decreases in FVC and FEV1 after open-heart surgery using median sternotomy (1). In addition, Berrizbeitia et al. demonstrated that postoperative pulmonary function was significantly reduced after coronary artery bypass surgery performed via sternotomy and reported that internal mammary artery harvesting may be associated with a greater degree of pulmonary function impairment compared to saphenous vein grafting alone (8). Taken together, these findings suggest that sternotomy itself plays a major role in postoperative pulmonary dysfunction, while the use of internal mammary artery grafts may further exacerbate this impairment. The postoperative decline in pulmonary function observed in the SG in the present study is in line with these observations.

In a study by Weiner et al., the effects of prophylactic inspiratory muscle training administered for two weeks prior to coronary artery bypass graft surgery were evaluated by comparing pulmonary function and respiratory muscle strength parameters between trained and untrained patients (9). The authors demonstrated that inspiratory muscle training attenuated the postoperative decline in pulmonary function and respiratory muscle strength observed after sternotomy. These findings suggest that the impairment of pulmonary function and respiratory muscle strength following CABG surgery may be, at least in part, related to respiratory muscle dysfunction, and that targeted inspiratory muscle training may help preserve respiratory muscle performance and pulmonary mechanics in the postoperative period.

The postoperative decline in pulmonary function has also been well documented in patients undergoing thoracotomy. In a study evaluating pulmonary function after lobectomy performed via thoracotomy, a marked reduction in FEV1 was reported during the early postoperative period, particularly within the first postoperative days, with a gradual recovery thereafter (10). These findings indicate that thoracotomy is associated with a significant, albeit partially reversible, impairment in expiratory flow parameters. Consistent with these reports, the present study demonstrated a statistically significant postoperative reduction in FEV1 in patients who

underwent thoracotomy, reflecting impaired pulmonary mechanics in the early postoperative period. In addition to pulmonary function changes, previous studies have shown that thoracotomy may adversely affect respiratory muscle performance. Bernard et al. reported a postoperative reduction in respiratory muscle strength following thoracotomy, suggesting that surgical trauma and altered chest wall mechanics may contribute to inspiratory and expiratory muscle dysfunction (7). The postoperative decline in respiratory muscle strength observed in the TG in the present study is in agreement with these observations and further supports the close relationship between pulmonary function impairment and respiratory muscle weakness after thoracic surgery.

This finding indicated that RMS tests may be used compatible with PFTs to evaluate respiratory muscle impairment and related pulmonary dysfunction after surgery. This opinion is supported by Steier et al., who showed that using multiple measures of respiratory muscle strength (e.g., PImax and PEmax) improves the clinical assessment of respiratory muscle weakness and reduces the risk of misclassification when a single test is used (11). Evaluation of RMS via multiple tests influences clinical management positively and decreases the possibility of misdiagnosis.

Pulmonary function impairment and respiratory muscle weakness observed after cardiothoracic surgery in the present study underline the clinical relevance of postoperative respiratory muscle dysfunction. In particular, the greater reduction in inspiratory muscle strength parameters observed in the SG suggests that surgical approach plays an important role in the severity of postoperative respiratory muscle impairment. These findings emphasize the importance of careful postoperative respiratory assessment in patients undergoing sternotomy or thoracotomy, especially during the early postoperative period.

The pain originating from sternotomy or thoracotomy may contribute to pulmonary function disorder. Tengling et al. reported that even thoracic epidural analgesia (TEA) failed to prevent the decline in FVC, FEV1, and PImax at the first postoperative day in patients underwent CABG (12). Bauer et al. compared TEA with IV morphine in patients underwent lobectomy via thoracotomy revealed that the decline in FVC and FEV1 was lower in the TEA group, but the SNIP changes were similar (2). However, in another study involving 100 posterolateral thoracotomy cases to examine the influence of cryoanalgesia on RMS test results, it was found that postoperative pain was lower in the intercostal cryoanalgesia group than the control group. However, there was no significant difference in PImax between the groups and PEmax was decreased significantly in the two groups postoperatively (13).

This study is considered important since it is the first to compare the effects of sternotomy and thoracotomy on RMS, apart from studies in the literature that have been conducted separately in heart surgery or lung surgery (6,7). The marked increase in the FEV1/FVC ratio and the decrease in respiratory muscle strength observed in the present study are consistent with findings from previous studies comparing video-assisted thoracoscopic surgery (VATS) with open thoracotomy (14,15). These studies demonstrated that minimally invasive surgical approaches are associated with less pronounced impairment in pulmonary function and respiratory muscle performance compared to thoracotomy, highlighting the role of surgical trauma and chest wall disruption in postoperative respiratory dysfunction.

Additionally, incorporation of preoperative respiratory muscle training into protocols for elective cases is highly recommended particularly in high-risk patients to reduce pulmonary complications in the literature (16). It was also reported that the incidence of diaphragm dysfunction was found to be high after cardiac surgery which may explain the reduction in respiratory muscle strength in sternotomy patients. Therefore, ultrasonographic evaluation of diaphragm function is also recommended for these patients (17,18).

The higher ASA physical status observed in the SG, together with the longer duration of surgery and prolonged postoperative mechanical ventilation, reflects the greater procedural complexity and physiological burden associated with open heart surgery. Previous studies have shown that higher ASA class and longer operative times are associated with impaired postoperative pulmonary function and prolonged ventilatory support in cardiothoracic surgery patients (19,20). In addition, extended duration of mechanical ventilation has been linked to respiratory muscle weakness and delayed recovery of pulmonary function. Therefore, the observed differences in respiratory muscle strength and pulmonary function between the groups in the present study may, at least in part, be influenced by these perioperative factors and should be interpreted within this clinical context.

Limitations of the Study

This study has several limitations. Firstly, the limited sample size prevented adjustment for potential confounders using multivariable analysis. Secondly, postoperative pain intensity was not quantitatively compared between the groups, which might have provided additional insight into the relationship between pain and respiratory muscle strength.

CONCLUSION

Pulmonary function and respiratory muscle strength decreased significantly after both sternotomy and thoracotomy during the early postoperative period. However,

RMS (Pİmaxi) and pulmonary function (FVC) were more adversely affected following sternotomy compared to thoracotomy.

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Ethical Declaration: Ethical permission was obtained from the Dokuz Eylül University, Medical Faculty Clinical / Human Research Ethics Committee for this study with date 08.11.2010 and number 2010/10-06 and Helsinki Declaration rules were followed to conduct this study.

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REFERENCES

1. Ragnarsdóttir M, KristjAnsdóttir A, Ingvarsdóttir I, Hannesson P, Torfason B, Cahalin L. Short-term changes in pulmonary function and respiratory movements after cardiac surgery via median sternotomy. Scand Cardiovasc J. 2004;38(1):46-52. doi: 10.1080/14017430310016658. PMID: 15204247.
2. Bauer C, Hentz JG, Ducrocq X, Meyer N, Oswald-Mammosser M, Steib A, Dupeyron JP. Lung function after lobectomy: a randomized, double-blinded trial comparing thoracic epidural ropivacaine/sufentanil and intravenous morphine for patient-controlled analgesia. Anesth Analg. 2007;105(1):238-44. doi: 10.1213/01.ane.0000266441.58308.42.
3. Varela G, Brunelli A, Rocco G, Novoa N, Refai M, Jiménez MF, Salati M, Gatani T. Measured FEV1 in the first postoperative day, and not ppoFEV1, is the best predictor of cardio-respiratory morbidity after lung resection. Eur J Cardiothorac Surg. 2007;31(3):518-21. doi: 10.1016/j.ejcts.2006.11.036.
4. Endoh H, Tanaka S, Yajima T, Ito T, Tajima K, Mogi A, Shitara Y, Kuwano H. Pulmonary function after pulmonary resection by posterior thoracotomy, anterior thoracotomy or video-assisted surgery. Eur J Cardiothorac Surg. 2010;37(5):1209-14. doi: 10.1016/j.ejcts.2009.11.016.
5. Kabitz HJ, Walterspacher S, Walker D, Windisch W. Inspiratory muscle strength in chronic obstructive pulmonary disease depending on disease severity. Clin Sci (Lond). 2007;113(5):243-9. doi: 10.1042/CS20060362. PMID: 17391105.
6. Stein R, Maia CP, Silveira AD, Chiappa GR, Myers J, Ribeiro JP. Inspiratory muscle strength as a determinant of functional capacity early after coronary artery bypass graft surgery. Arch Phys Med Rehabil. 2009;90(10):1685-91. doi: 10.1016/j.apmr.2009.05.010.
7. Bernard A, Brondel L, Arnal E, Favre JP. Evaluation of respiratory muscle strength by randomized controlled trial comparing thoracoscopy, transaxillary thoracotomy, and posterolateral thoracotomy for lung biopsy. Eur J Cardiothorac Surg. 2006;29(4):596-600. doi: 10.1016/j.ejcts.2005.12.041.
8. Berrizbeitia LD, Tessler S, Jacobowitz IJ, Kaplan P, Budzilowicz L, Cunningham JN. Effect of sternotomy and coronary bypass surgery on postoperative pulmonary mechanics. Comparison of internal mammary and saphenous vein bypass grafts. Chest. 1989;96(4):873-6. doi: 10.1378/chest.96.4.873.
9. Weiner P, Zeidan F, Zamir D, Pelled B, Waizman J, Beckerman M, Weiner M. Prophylactic inspiratory muscle training in patients undergoing coronary artery bypass graft. World J Surg. 1998;22(5):427-31. doi: 10.1007/s002689900410.
10. Bastin R, Moraine JJ, Bardocsky G, Kahn RJ, Mélot C. Incentive spirometry performance. A reliable indicator of pulmonary function in the early postoperative period after lobectomy? Chest. 1997;111(3):559-63. doi: 10.1378/chest.111.3.559.
11. Steier J, Kaul S, Seymour J, Jolley C, Rafferty G, Man

W, Luo YM, Roughton M, Polkey MI, Moxham J. The value of multiple tests of respiratory muscle strength. Thorax. 2007;62(11):975-80. doi: 10.1136/thx.2006.072884.

12. Tenling A, Joachimsson P-O, Tydén H, Hedenstierna G. Thoracic epidural analgesia as an adjunct to general anaesthesia for cardiac surgery. Effects on pulmonary mechanics. Acta Anaesthesiol Scand. 2000;44(9):1071-6. doi: 10.1034/j.1399-6576.2000.440906.x.
13. Pastor J, Morales P, Cases E, Cordero P, Piqueras A, Galán G, París F. Evaluation of intercostal cryoanalgesia versus conventional analgesia in postthoracotomy pain. Respiration. 1996;63(4):241-5. doi: 10.1159/000196553. PMID: 8815972.
14. Kocjan J, Rydel M, Czyżewski D, Adamek M. Comparison of Early Postoperative Diaphragm Muscle Function after Lobectomy via VATS and Open Thoracotomy: A Sonographic Study. Life (Basel). 2024 9;14(4):487. doi: 10.3390/life14040487.
15. Sirakaya F, Calik Kutukcu E, Onur MR, Dikmen E, Kumbasar U, Uysal S, Dogan R. The Effects of Various Approaches to Lobectomies on Respiratory Muscle Strength, Diaphragm Thickness, and Exercise Capacity in Lung Cancer. Ann Surg Oncol. 2024;31(9):5738-5747. doi: 10.1245/s10434-024-15312-x.
16. Cursino de Moura JF, Oliveira CB, Figueira APC, Elkins MR, Pacagnelli FL. Preoperative respiratory muscle training reduces the risk of pulmonary complications and the length of hospital stay after cardiac surgery: a systematic review. J Physiother. 2024;70:16–24. doi:10.1016/j.jphys.2023.10.012.
17. Somers T, Iskander S, Verhagen AFTM, Li WWL. Diaphragm Dysfunction After Cardiac Surgery. Braz J Cardiovasc Surg. 2025;40(4):e20230239. doi:10.21470/1678-9741-2023-0239.
18. Huai H, Ge M, Zhao Z, Xiong P, Hong W, Jiang Z, Wang J. Early diaphragm dysfunction assessed by ultrasonography after cardiac surgery: a retrospective cohort study. Front Cardiovasc Med. 2024;11:1457412. doi: 10.3389/fcvm.2024.1457412.
19. Wang Q, Tao Y, Zhang X, Xu S, Peng Y, Lin L, Chen L, Lin Y. The Incidence, Risk Factors, and Hospital Mortality of Prolonged Mechanical Ventilation among Cardiac Surgery Patients: A Systematic Review and Meta-Analysis. Rev Cardiovasc Med. 2024 20;25(11):409. doi: 10.31083/j.rcm2511409.
20. Kumalasari RI, Kosasih CE, Priambodo AP. Risk Factors of Prolonged Mechanical Ventilation in Post Coronary Artery Bypass Graft Patients: A Scoping Review. J Multidiscip Healthc. 2025;18:903-915 https://doi.org/10.2147/JMDH.S483973