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Review

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Respiratory functions after lung surgeries in children: review of the literature

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ABSTRACT

In pediatric surgery, the operation of the lung parenchyma tissue is generally performed with limited essential evaluations both before and after the operation. Decisions to be taken are formed around some basic examination methods. For this reason, this review aims to determine the routine and more specific methods in the literature, which are evaluated in pre-and postoperative processes related to lung parenchyma surgeries, and to examine how these methods are applied to which diseases. In the study, pre-and postoperative examination methods of the lung were primarily examined. Later, these evaluations were classified into two separate groups: congenital and acquired diseases. Rare surgeries were excluded from the study. Among the congenital diseases, congenital pulmonary airway malformation, congenital lobar emphysema, and primary ciliary dyskinesia are discussed. Among acquired diseases, infections and cancer are discussed. In general, it has been determined that there is no regular follow-up and no standard practice. The reason for this was that the evaluation processes were not based on a particular algorithm; personal approaches came to the fore, and it was determined that the individual characteristics of the patients were very variable. The literature regarding pre- and postoperative evaluations of patients undergoing lung parenchymal surgery is impoverished. There is an information gap where multicenter systematization studies can be made of the decision-making mechanisms initiated on an institutional basis regarding those who have these surgeries.

Keywords: Lung, function, surgery, children, congenital, acquired

INTRODUCTION

Evaluating lung functions before and after surgeries in children usually needs to be appropriately formed. At first sight, lung surgeries in childhood are not as common as in adulthood. The main reason is the low incidence of lung disease in children. In addition, authors operating on children's lung diseases have their style of pre-, per-, and postoperative. Because of all these facts, concluding the functions of remaining lung tissue after surgery is controversial.[1]

There needs to be more studies evaluating lung functions after surgeries to solve this controversy.[2] There are reasons for this fact. First, infrequent lung operations in the childhood age group need more studies.[3,4] Second, due to the specific physiological changes at different ages in childhood, postoperative complications may show variations that make postoperative evaluations complex.[4] Third, physiotherapy procedures performed after surgeries must be standardized.[4] Since it will affect the level of recovery, physiotherapy standards are essential to make proper evaluations. Finally, different designations of lung surgeries in different institutions may affect the functions and exercise capacity differently.[2]

Despite foreseeing that pulmonary functions after lung surgeries seem complicated, it is well known that respiratory functions usually reach satisfactory levels.[5] Satisfying results are revealed at diagnosis, surgery technique, and postoperative care differences.[5] Nevertheless, a decrease in oxygen saturation and thoracic and lung compliance is expected in young children in the early periods of thoracic surgery.[4]

This study aims to examine the functions of the rest of the lung tissue postoperative in childhood in detail as soon as possible. Organ and tissue surgeries in the thoracic region, such as the esophagus, mediastinum, costae, and diaphragm, were excluded, and only lung parenchymal operations were evaluated.

METHODS

Literature was reviewed to prepare the manuscript. For this purpose, keywords such as "lung," "function," "surgery," "children," "congenital," and "acquired" were used. Nowadays, in English literature, there are 113.000 articles and publications in Google Scholar, but when keyword combination is

evaluated, only 19 articles are found to complete the aim of this study. Other literature in different languages should have been searched. When "surgery" was excluded, 209.000 publications were found, and when "children" was excluded, 241.000 publications were found.

The articles that did not define surgery, lung parenchyma, and evaluation techniques were excluded. Also, articles accomplishing the keywords but consisting of rare problems were excluded. Therefore, a few articles achieved the goal of this study.

First, preoperative and postoperative general aspects were investigated in these articles.

PREOPERATIVE LUNG FUNCTION GENERAL ASPECTS

Predictable postoperative pulmonary function may be necessary for the quality of life of a patient undergoing primary pulmonary resection.[6] Barikbin et al.[7] stated that early lung function tests could be helpful when deciding on surgery. In their study, the timing of the operations is essential, and when surgery is delayed, lung functions of sick children would be more limited in those whose operations were delayed.[7] Also, there were some other studies to calculate the possible loss amount of lung tissue to predict the postoperative conditions of patients. Werner et al.[1] formulated this amount and their predicted loss of function formulation, and this was expressed as Predcorr (corrected prediction)=(predicted for healthy subjectX% of lung remaining)/100.

In another study, carbon monoxide diffusion capacity measurement is a method to calculate the possible surgical resection area.[6] It is advised that it will be helpful to measure the diffusion capacity of carbon monoxide with FEV_1 in the lung to predict postoperative lung function, especially in lung cancers.[6]

Preoperative radio diagnostic evaluations are essential in our practice, but investigating lung capacity is only sometimes possible due to a lack of staff. There are few pediatric lung disease specialists working in a few amounts of hospitals. As their lung capacity evaluations preoperatively depend primarily on pediatric pulmonology practice, we operated on our patients without this type of support.

POSTOPERATIVE LUNG FUNCTION-GENERAL ASPECTS

Regardless of the method used, one of the most essential conditions to evaluate respiratory function as a standard criterion after surgery is a period without respiratory infection.[1] In addition, attention should be paid to the height and weight of the patient to compare them with average results appropriate for the patient's age.[1] It has been stated that ventilation, respiratory rate, oxygen consumption, carbon dioxide production, and respiratory parameters can be measured with maximal work capacity in patients older than five years of age who are thought to be able to comply with and meet height criteria.[9]

Postoperative evaluations are easier than preoperative assessments. Nevertheless, the principal evaluations are physical examinations, plain chest graphs, and computerized tomography. If these evaluations are insufficient to find results, then scintigraphy is planned. However, we seldom use other procedures as technical, and staff is generally lacking.

POSTOPERATIVE LUNG FUNCTION MEASUREMENT METHODS

Physical Examination

Physical examinations other than weight and height monitoring should be present in the literature. No scientific study has been found where physical examinations were carried out with long-term follow-up for postoperative lung surgeries.

Chest X-Rays

A chest X-ray is often helpful for understanding the condition of lung diseases before operations.[11] Evaluating the chest radiographs may also be helpful for postoperative periods.[1] In this examination, detecting rib changes, pleural reactions, and decreased pulmonary vascularization findings in the lung resection area can be meaningful.[1] Other X-ray examinations that can be performed are bronchography and high-resolution CT (HRCT).[10] Unfortunately, no systematic and explanatory study is present using the evaluation of these lung graphs in the literature.

Chest X-rays are the most used evaluation instrument for experienced surgeons especially. Combining the images with clinical symptoms and findings with X-ray images seems enough for most authors. Numeric findings might be less valuable because of this point of view.

Ventilation-Perfusion Ratio (V/Q)

A V/Q examination is performed to show whether the disease causes lung collapse, consolidation, aplasia, or severe hypoplasia, especially in patients with a closed lung.[11] The features and functions of the remaining tissue after lung surgery can also be examined with this method.[11] However, it is not a preferred method in the first place. If scintigraphy is chosen for this investigation, it would be better to use Xenon 133 inhalation, especially to examine the ventilation.[1] This method can evaluate breathing, equalization, and wash-out situations.[1] For perfusion, Technetium 99m macro-aggregate is one of the most used methods.[1]

In our country, it is only sometimes possible to perform this technique. However, it can be a well-structured follow-up device for these patients where available.

Lung Function Tests

Spirometry results of congenital problems were presented to be significantly lower in those who were operated on than those who were followed up without surgery.[8] According to another study, reliable spirometry can be performed at the age of 8.[8] Respiratory capacity measurements can also be performed with portable ergo spirometry systems.[2]

The measurement of total lung capacity (TLC), forced vital capacity (FVC), and forced expiratory volume in 1st second (FEV_1) are among the indicators of lung growth.[2,12]

When lung capacity is 80% or less or when the FEF25-75% value is below 70%, it is necessary to consider that lung functions are insufficient.[2,9,12]

When there is a restrictive defect, TLC will be detected below 80%.[2]

In hyperinflation, the residual volume (RV) will be expected to be greater than 135, and the RV/TLC ratio to be greater than 0.35.[2]

Performing function tests is restricted to a small age group for pediatric surgery. Some studies reported that children older than eight years old may be evaluated. Children must be older to have optimum results in our regions. Also, being an adolescent sometimes makes cooperation difficult. Therefore, function tests, if performed sparingly, may need to be more conclusive. Another restriction in performing lung function tests is, again, availability. So, routine practice may only be possible for some units.

Cardiopulmonary Exercise (Treadmill) Tests

Treadmill tests can be performed on children whose age is appropriate regarding endurance.[1,2] In this study, FVC, FEV_1, FEV25-75%, TLC, RV, and functional residual capacity (FRC) can be evaluated.[13] Maximum work capacity (power) and maximal oxygen uptake (VO2-max) are also determined in this process.[12] One of the features that can be evaluated is "durability".[1] It is evaluated whether there is a moment of desaturation during exercise.[1]

During the treadmill procedure, reactions such as heart rate, blood pressure, transcutaneous oxygen saturation, flushing, and sweating must be appraised.[1] The treadmill can be accelerated from 2.7 km/h to 6.0 km/h with a speed increase of 2% per minute.[2] Comfortable breathing is allowed with a mask suitable for the face.[2] The procedure can be continued until the heart rate reaches 85% of its maximum value for age.[2] To calculate the maximum heart rate, the "heart rate=220-age (years)" equation can be used.[2] These data can be compared according to standard references of gender and body surface area.[12]

For authors, it is unlikely for thoracic and pediatric surgeons to use this technique in preoperative and postoperative evaluations. The main reasons are obtaining the device, sustaining staff, and, for children, the need for age selections.

Nitrogen Wash-out Test

Nitrogen measurements with multiple-breath nitrogen wash-out in 100% oxygen are worthy for assessing respiratory inhomogeneity in preschool children.[13] Lung clearance index (LCI) of 5%, LCI of 2.5%, average resistances at 8 Hz, and average reactance at 8 Hz are evaluated.[13]

We have no experience with this test. Also, there needs to be more literature on it. Therefore, the nitrogen wash-out test needs much evaluation before clinical practice.

Other Wash-out Techniques

Another method to measure the effect of surgeries on lung volume is to measure heptafluoropropane (HFP) level with multiple breath wash-out (MBWO) techniques.[14] It has been indicated that this method can be used, especially immediately after surgery.[14] HFP-MBWO examination shows the effects on FRC and V1 measurements.[14] Patient-specific trace gases can also be produced from nitrogen, helium, or sulfur hexafluoride.[14]

During the evaluation of all these tests, there is no reference information on postoperative respiratory functions for preschool and school-age children, so it seems necessary to use the "global lung function initiatives" scores.[13] According to these scores, the detection of 80 percent function can be considered normal.[13]

As nitrogen wash-out tests, other wash-outs are hardly available, and they are not used in practice in our country.

POSTOPERATIVE LUNG FUNCTIONS ACCORDING TO DISEASES

Lung functions after operations can be evaluated according to the origin of the diseases. So, they can be classified as postoperative functions of congenital and acquired diseases.

Postoperative Lung Features in Congenital Pulmonary Diseases

Congenital diseases can demonstrate clinical findings in any period of life.[3] The noticeable characteristic of this group of diseases is high morbidity and mortality.[7,13] Depending on their development mechanisms, these diseases may cause clinical progressions varying from preterm labor to cardiopulmonary insufficiency, pulmonary haemorrhage, and pneumothorax.[7,13]

The controversy becomes complicated if the patient is asymptomatic for some years.[9] How to treat these congenital diseases is contradictory.[9] Some centers advocated that the asymptomatic period of life is a disadvantage, and they said that congenital diseases should be operated on in the early period because it is thought that complications such as pulmonary infection, pneumothorax, and malignancy will be prevented.[9,13] However, most individuals with congenital diseases who underwent surgery in early childhood are not followed up for respiratory functions later in life. So, it will be hard to compare and predict the postoperative functional pulmonary capacity when an asymptomatic patient becomes indicative. Surgeons operate on congenital diseases mainly because of symptoms, lesion sizes, and imaging results.[7,8] As most patients recover their complaints after surgeries, further functional evaluations are ignored.

Werner et al.[1] emphasized in their article published in 1993 that the stamina in exercise of the remaining lung is essential. They wrote that exercise tolerance is good after lung resections in children.[1] On the contrary, others wrote that exercise tolerance was low in those operated on.[8] According to those who thought functions were ruined, TLC is lower on body plethysmography after early operations.[8] In addition, it was shown in the bronchodilator reversibility test that only 2 out of 19 patients included in the study had significant improvement in lung functions.[8]

One problem that Werner et al.[1] found was the decrease in FEV_1, FEV25-75, and mid-expiratory time in patients operated on for congenital reasons.This situation is also expressed in other similar studies.[1] Some authors have linked this situation to losing the elastic coil property.[1] It is also stated that it can be explained by the cessation of parenchymal growth.[1]

A significant disorder was also detected in the perfusion distribution of these patients.[1] It has been stated that this may

be the deterioration of the vascular structure or the formation of dead spaces.[1]

Congenital pulmonary diseases were followed up with their clinical wellness and with X-rays in general. As surgeons only sometimes consult these postoperative patients with pediatric thoracic disease specialists, further systematic evaluations were not done in our country.

Congenital Pulmonary Airway Malformations (CPAM)

CPAM is a cystic disease that can be noticed during fetal life and can affect part or all of the lung lobes.[12] It is among the most common causes of congenital pulmonary diseases.[15] It occurs in 1 in 10-35.000 live births.[12,15] It is primarily fixed in size; or may be reduced.[12] The way it gives clinical symptoms and its course over time is variable.[15] It is generally accepted that symptomatic CPAMs require resection, but there is no consensus for asymptomatic ones.[12,15] Excision may be recommended to prevent infection, pneumothorax, and, albeit to a lesser extent, to prevent malignancy.[12,15] Various studies have been carried out in order to perform parenchyma-sparing surgery for better and more effective respiratory recovery in the postoperative period of the patients.[7] These studies may prevent behavioral, cognitive, and language problems that the neonatal or infant may experience in the future.[7]

In preoperative pulmonary function tests, respiratory compliance and respiratory patterns in CPAM are significantly reduced.[7] As pressure changes of the esophagus and the chest wall compliance measurements are necessary to find a precise result, it is difficult to measure the compliance of the lungs in patients with pulmonary cyst diseases such as CPAM.[7] Since chest wall compliance is deficient in newborns compared to lung compliance, it may be convenient in this respect.[7]

Pulmonary compliance usually increases in CPAM after operations.[7] Suppose improvement in lung functions appears after surgery. In that case, it is controversial whether this is due to the distension of the remaining lung tissues or the increase in the alveoli in the lung parenchyma.[1] In animal models, the number of alveoli increases, and it is also known that alveoli numbers increase in humans.[1] In addition, the increase in the ratio of RV/TLC is predicted to be inexplicable with over-distention alone.[1]

The age of surgery is controversial for CPAM. In a study, when newborn and non-neonatal CPAM patients were compared, it was stated that surgery in newborns had a worse prognosis.[15] Nevertheless, in another study, it was said that babies operated on under one year old were better than those operated on older than one year because the alveolar tissue continues to develop.[13] Finally, a third study showed that age during lobectomy does not affect pulmonary function or maximum work capacity.[12] Nevertheless, in this last study, the authors revealed the same conclusion as others: an increase in lung functions and exercise capacity immediately after surgery, even in the lung that experienced pneumonia.[12] Interestingly, Naito and colleagues[12] found that patients who underwent right-sided lobectomy had a significantly higher TLC than left lobectomy. A study examining respiratory functions showed that while there was a moderate decrease in vital capacity, TLC, and forced expiratory volume (1st second) in long-term follow-ups, the FRC level could be higher than usual.[7]

Werner et al.[1] stated that the "endurance" of all operated patients, regardless of the age of surgery, was good, and their saturation did not decrease during exercises. However, only 2 of 14 patients reached an expected level for pulmonary functions in all criteria.[1]

Werner et al.[1] also discussed the weight and the volume of the lost lung part as a primary factor for postoperative improvement. However, further clinical investigations could not be found on weight.

Airway resistance measured by body plethysmography partially increases, but body plethysmography in patients with pulmonary cysts may not be sufficient to measure all compressible gas volume, as stated above.[7]

Blood gas values are insignificant for CPAMs before and after surgery.[7] These values show that the limitations in the lungs do not cause any impairment in gas exchange.[7]

Despite all these findings, there is little information in the literature about the course of pulmonary functions in CPAM patients who underwent this surgery.[13] There is no reliable guideline.[15]

Congenital Lobar Emphysema

Inadequate parenchymal growth or residual tissue remnants cause air trapping in congenital lobar emphysema.[1] Tissue anomalies are the reason for respiratory function disorders. Therefore, breathing is not homogeneous in patients with congenital lobar emphysema.[1] Very few studies examine the lung's functional properties after congenital lobar emphysema surgeries. One study showed that the lungs increased volume after surgery, and expiratory flow rates decreased.[2] These entities normalized within two years.[2] It has been stated that the cause of the hyperinflation may be related to the increase in the RV/TLC ratio.[2]

Primary Ciliary Dyskinesia

Primary ciliary dyskinesia is often seen with cystic fibrosis. Cystic fibrosis may cause bronchiectasis, so that lung resections may be required.[16] In a multicenter cohort study, Kouis et al.[16] showed that operations due to primary ciliary dyskinesia were mostly in childhood and more in girls. In this study, it was stated that gender is an essential factor.[16] Apart from this, it was seen that there was no difference in the comparisons of FVC, FEV_1, and BMI between patients who were operated on and those who did not.[16] Loss of lung function was observed in both patient populations.[16] *Pseudomonas* infection was detected more in those who had surgery.[16]

Rarely, cystic fibrosis may affect only one lobe or limited segments.[17] These patients may benefit from the surgical procedure.[17] Lucas et al.'s[17] study showed that the lung functions of 7 patients with localized primary ciliary dyskinesia operated on were preserved or improved. However, the operations' long-term effects could not be thoroughly evaluated in this study.[17] Some publications show no improvement in lung functions after cystic fibrosis surgeries.[16]

Other Diseases

Studies investigating postoperative respiratory functions of bronchopulmonary dysplasia (BPD) and particularly

sequestration cases are scarce. The literature states that the ventilation is normal but slightly reduced perfusion.[1]

In those with BPD, it was observed during spirometry that there was a statistically significant decrease in FEV1 values at the age of 9 and 15 years.[18] If the respiratory function is good in the first two years after birth, it can improve.[18]

LUNG FEATURES IN OPERATIONS PERFORMED FOR ACQUIRED REASONS

Infections and cancers can be evaluated in this part. Lung operations according to acquired disease with destroyed lungs can be performed at any age.[10] Many authors prefer delayed surgery as much as possible.[19] Generally, 13-14 years of age are considered the best surgery period.[10] Also, being asymptomatic before surgery is a good predictive factor for an effective treatment.[10]

Infections

The most common operations for acquired diseases are infectious-based diseases such as bronchiectasis, lung abscess, necrotizing pneumonia, fungal infections, and tuberculosis.[3,11,19] Factors like foreign body, stricture, and bronchial suppression can be encountered in these diseases, and surgical decisions may be required.[10]

The most common lung problem among acquired diseases is bronchiectasis.[19] A bronchiectasis is a clinical form of lung injury mostly related to infection development.[3] Publications show no functional benefit in the surgeries of acquired bronchiectasis, but it has been shown that these surgeries reduce the use of antibiotics.[16] Surgery varies from segmentectomy to pneumonectomy in these patients. Indications to perform pneumonectomy must be absolute, such as life-threatening clinical circumstances.[10] In these patients, respiratory functions are, therefore, somewhat restrictive.[10] The advanced enlargement of the remaining lung for compensation always results in some amount of herniation.[10] In long-term follow-up, it was stated that the lungs were still emphysematous, and the lung volume was more extensive than expected.[10] The reason for staying enlarged in this way may be related to the increase in the number of alveoli or the increase in volume.[10] Nevertheless, there is no significant change in FVC values in these patients' postoperative respiratory function tests.[3] After surgery, it is reported that the patients continue their lives usually.[10] However, proper lung total excisions have a specific problem. In right pneumonectomy, if the expansion in the opposite lung is significant, this will cause the bronchus to be under pressure by pushing the mediastinum counterclockwise. As a result, respiratory distress and even death may occur.[10] This condition is called "postpneumonectomy syndrome".[10]

Surgery can also be performed in case of persistent lobar atelectasis after infection.[3] It has been shown that complications resulting in restrictive defects developed in 3 out of 5 patients who were operated due to lung infections.[2] Hydatid cyst is a type of infectious disease.[3] Unfortunately, no specific research examines lung functions after the operations of hydatid cysts in the lungs and persistent lobar atelectasis after infections.

We know that infectious diseases are the most followed-up patients. Although some tests mentioned above, like treadmill, are not used in routine tests like lung functions are used. The reason for this strongly depends on pediatric thoracic specialists or even on general pediatricians. These health providers perform evaluations of operated infectious patients and non-surgical patients without consultant surgeons.

Lung Cancer

Another acquired problem requiring surgical procedures to the lung tissue is lung cancer.[6] The stage of cancer is essential to investigate respiratory function. Severe respiratory problems may be seen in low-stage cancer operations due to the mechanisms that affect pulmonary functions.[6]

Studies for lung functions are generally in adult patients. A prospective study demonstrated that lung functions returned to an expected level one month after cancer surgery.[6] It is also shown in the same study that the functions continue to improve until three months after the operation and after a year. At the same time, the FEV_1 value increased up to 84% and remained constant, and the CO diffusion value increased to 97%.[6] Recovery is better in those operated with VATS.[6] Less pain, unaffected respiratory muscles, and no damage to the thoracic wall are the most relevant reasons for postoperative functional differences between VATS and open surgery.[6]

Chemotherapy may affect pulmonary functions. Ten percent of lung cancer patients receiving chemotherapy have pulmonary toxicity.[6] This toxicity may be due to pneumonitis or interstitial lung disease.[6] While there was no significant change in FEV_1 values in patients who did not receive adjuvant chemotherapy compared to those who received adjuvant chemotherapy, it was shown that CO diffusion was at 98% in those who did not receive adjuvant chemotherapy and almost did not change at all in adjuvant patients.[6]

Lung cancer is one of the rarest diseases in the pediatric age group. Therefore, finding fewer postoperative evaluation articles for this entity is not surprising. In our country, this result is not different.

CONCLUSION

As respiratory functions improve significantly after surgeries, lung function improvements during the follow-up period do not attract much attention. The examinations are usually done with small groups of patients and using only one technique. As a result, more than the literature is needed to find determinative conclusions. The literature on the subject needs to be increased, and a detailed examination should be done.

In the process leading to the surgery of lung diseases in children, the most significant complaint is shortness of breath and severe impairment in respiratory functions detected with it. Although the clinical condition of the patients generally improves rapidly after surgery, it is stated that some children may not change. However, the evaluation protocol for postoperative lung functions is not standard, and factors such as the patient's height and age may need to be carefully considered in studies with such discourses. As a result, postoperative follow-up protocol must be developed for these children.

The methods used to evaluate respiratory functions in the postoperative period are generally spirometry/whole body plethysmography, forced oscillation technique, and multiple-breath nitrogen wash-out method in 100% oxygen. Some less preferred methods can also be found in the literature.

These techniques can hardly be used in confident children's age groups. So, it seems essential to find a way to ease these laboratory examinations.

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Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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