



Review

Physiologic function of mediastinum space

Ghasem Azimi ^a, Rama Bozorgmehr ^{b,**,*}, Parastesh Sattari ^c, Ali Azimi ^d, Hossein Azimi ^d, Saeid Marzban-Rad ^{e,*}

^a Department of Internal Medicine, School of Medicine, Shahed University, Tehran, Iran

^b School of Medicine, Chronic Respiratory Diseases Research Center, National Research Institute of Tuberculosis and Lung Diseases, Shahid Modarres Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran

^c General Practitioner, Institute of Health Education and Research, Chamran Hospital, Tehran, Iran

^d Student of Research Committee, Tehran Medical Sciences, Islamic Azad University, Tehran, Iran

^e Department of Surgery, Imam-Reza Hospital, Aja University of Tehran Medical Sciences, Tehran, Iran



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ABSTRACT

The mediastinum forms the central part of the thoracic cavity that is surrounded by pleural space on the two sides, thoracic vertebrae at the posterior, thoracic inlet on the top, and diaphragm at the bottom. It encompasses cardiopulmonary organs and organ systems. Pathological dysfunction or deformity in any part of the mediastinum can have adverse cardiovascular and respiratory effects. Pectus excavatum and pectus carinatum are the most common congenital chest deformities that are characterized by sternal depression and protuberance of the sternum, respectively. Together, these account for 90% of chest wall deformities. Patients are known to be represented with respiratory distress and cardiovascular dysfunction. The aim of the review article is to present the anatomical and physiological role of the mediastinum in association with important parts of the thoracic cavity and pathological dysfunction of the mediastinum (cardiopulmonary system) due to pectus excavatum and pectus carinatum.

1. Introduction

The mediastinum is limited by the sternal manubrium on the top, the diaphragm at the bottom (intervertebral space between 4th and 5th vertebral bodies), the sternum in the front, the spine at the back, and the pleura of the two lungs on the two sides. Anatomically, the mediastinal space is divided into superior, middle, anterior, and posterior mediastinum [1]. The superior mediastinum is composed of the space behind the manubrium of the sternum and the mediastinal pleural on the two sides filed [2]. Posteriorly, it is surrounded by T1 to T4 vertebrae. Important structures in this region include the thymus, thoracic duct, esophagus, and teaching field [2]. It is innervated by phrenic and vague nerves along with the cardiac plexus. Significant blood vessels surrounding this region are superior vena cava and aortic arch [3]. The middle mediastinum is mainly composed of two important structures: the heart and pericardium. The right side of the mediastinum includes right atrium and ventricle whereas the left atrium is on the left and posterior region while left ventricle is completely at the posterior. The

heart is surrounded by the pericardium. Middle mediastinum includes great vessels, entering and leaving the heart such as pulmonary trunk and vein, superior and inferior vena cava, and aorta. This region encompasses phrenic nerve and pericardiophrenic vessels. The anterior mediastinum is partitioned into inferior mediastinum which has a sternum at the anterior and a pericardium at the posterior. Internal thoracic vessels, lymphatic vessels, and nodes, and loose connective tissues are constituents of anterior mediastinum. Posterior mediastinum, like anterior mediastinum, is subdivided into inferior mediastinum that encompasses pericardium at the anterior and thoracic wall at the posterior. Structures in posterior mediastinum are the aorta, azygous vein, thoracic duct, esophagus, esophageal plexus, splenic nerve, and sympathetic trunk [4,5].

With its anatomical divisions, mediastinal space permits physiological functions of the organs to be performed. The physiology of mediastinal space has been discussed in practice, despite its anatomical importance, in regard to congenital chest wall abnormalities. Malignant hemopneumothorax or the presence of large tumors that occupy a

* Corresponding author. Aja University of Tehran Medical Sciences, Tehran, Iran.

** Corresponding author. Pulmonary Diseases, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

E-mail address: md.saeidmarzbanrad@gmail.com (S. Marzban-Rad).

volume of the mediastinal space can impair the physiological function of the mediastinal region [6]. The anatomical arrangement of the mediastinum permits disease or deformity to affect the different organs and associated functions, such as the spread of neck pathology to the inferior mediastinum and transmission of retroperitoneal and peritoneal disease into mediastinal space as a result of fibrous or muscular defects in diaphragm [7]. A number of physiological variants can be seen in different regions of the mediastinum, for example, Patent ductus arteriosus and Tracheoesophageal fistula in the superior mediastinum, Pectus excavatum, and Thymic aplasia in anterior [8], dextrocardia, patent foramen ovale, tetralogy of Fallot, ventricular septal defects in middle mediastinum and bronchogenic cysts and esophageal atresia and stenosis in posterior [7,9–11].

When examining the changes in the normal physiology of mediastinum, particular emphasis is required to examine volumetric and geometric alterations and corresponding clinical signs and symptoms [12]. These changes are particularly seen in the cardiovascular systems (changes in heart rhythm, changes in impact volume, changes in ECG and echocardiography) and the respiratory system (in the form of shortness of breath, premature fatigue, and changes in pulmonary function test).

In this review article, we discuss pectus excavatum and pectus carinatum and associated cardiopulmonary dysfunction and treatment in terms of recent literature. This will help clinicians and medical professionals understand the pathologies, possible therapeutic tools available, and anticipated outcomes.

2. Physiology of mediastinum

The mediastinum is known to house important cardiopulmonary structures in the thoracic cavity. Owing to the structural composition of mediastinum [13], the range of functions and clinical presentations is Broadfield [14,15]. Different divisions of mediastinum can develop benign or malignant tumors, based on the structure in the region [3]. Changes in the structure can lead to pathological changes in physiological functions, and the reduction of the anterior-posterior diameter relative to the transverse space of the mediastinal space, causing the compression of the mediastinal space and disruption of normal cardiac activity and its displacement [16]. A shift of heart to the left and alteration of the physiological activity of the heart leads to a decrease in the ejection fraction and an increase in the number of heartbeats, shortness of breath, and premature fatigue [17](Fig. 1).

3. Pectus Excavatum (PE)

PE is one of the common congenital diseases of the chest (6) which is prevalent in 1:100,000 live births, and familial in 1/3rd of the patients (10). It is more common in the male population (11). PE is characterized by depression in the anterior chest wall due to dorsal deviation of the sternum and 7th rib/costal cartilage [18]. Less than 1% of PE cases have underlying connective tissue involvement [19]. Depression of the sternum leads to the displacement of the heart and reduction in lung volume, as a result of which asthma, fatigue, heart murmur, respiratory distress, cardiac compression, and other cardiopulmonary presentations are seen [18,20].

Haller Index is effective in evaluating the severity of the disease. Measuring the Haller Index is essential to assess the severity of the deformity [21]. As high as 2.5, which is considered normal, the severity of the disease increases and the physiology of the mediastinal space is more affected (16). Complications of normal chest physiology following pectus excavatum include:

1. pressure on the atrium, the tricuspid valve, and the right ventricle. (13)
2. Shift of the heart to the left, which causes the heart tip to move to the left, and this rotation is evident in the ECG. (7)

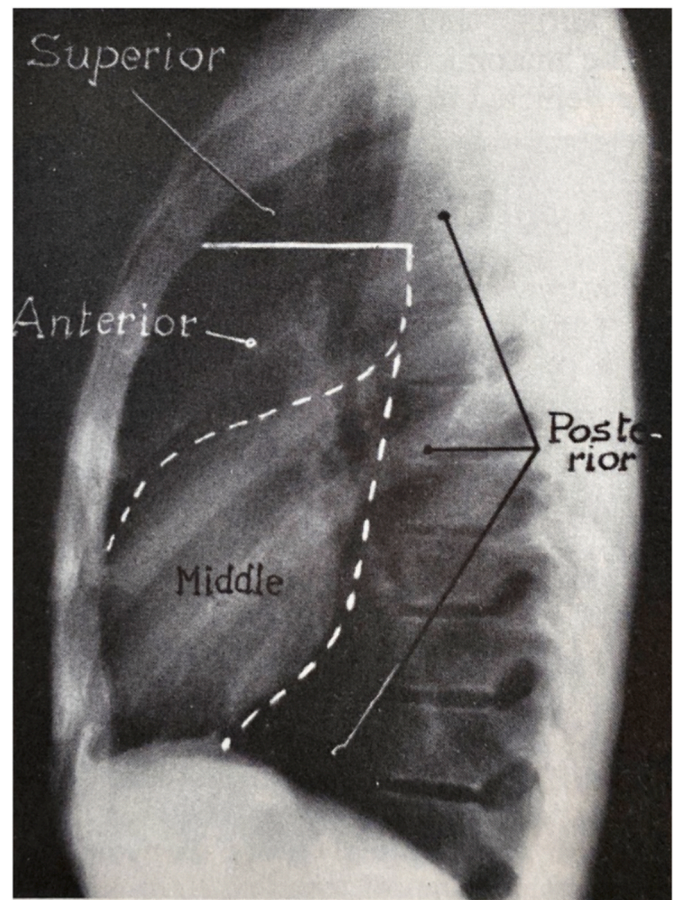


Fig. 1. The chest radiography illustrating the anatomic divisions of the mediastinum.

3. Reduction of the anterior and posterior diameter compared to the transverse diameter of the chest and decrease in the chest volume, which leads to a decrease in the volume of the lungs. (6)

Pectus Excavatum and Cardiopulmonary dysfunction.

PE patients are presented with an increase in residual volume and residual volume to total lung capacity ratio [22], suggesting an air trap which could be due to an inability of the ribcage to return to its original position at the end of expiration thereby leaving the lungs inflated [23].

In a study of 25 Air Force employees with pectus excavatum who were intolerant to exercise, there was a decrease in FEF (forced expiratory flow) and MVV (Maximal voluntary ventilation) (9). Some studies have reported that surgical correction is associated with the improvement in cardiovascular but not respiratory function [24,25]. Metal crossed blades are used to stabilize the chest wall, surgically [26]. The open approach incorporates sub-perichondrial resection of deformed cartilages along with xiphoid resection (Ravitch procedure), where the sternum is fixated, and metal bars are implanted [27]. Later, Nuss introduced a minimally invasive procedure that is based on the insertion of 1–3 metal bars behind the sternum, to exert pressure in order to correct the deformity [18].

Another study including 16 patients with pectus excavatum, aged 15 to 63, reported that physical working capacity while sitting was 15.4%, which was 40% less than sleeping [28]. It led to compensatory tachycardia to compensate for the lack of tissue oxygen uptake [29]. Heart rate decreased during sitting and other activities in all the patients compared to sleep and was associated with increased heart rate to compensate for the relative lack of oxygen, which was corrected after physiological dysfunction surgery [30]. If pectus excavatum surgery is

performed and the anatomical defects of the chest are corrected, its normal physiological condition can be restored, which will increase the ability of intense activity after surgery and the elimination of fibrillation and resulting heart failure [31]. Also, tachycardia and progressive fatigue improve, postoperatively. A patient, who underwent surgery by Dr. Dorner in 1950, suffered from shortness of breath supraventricular tachycardia with atrial-ventricular block, and systolic murmur, which were all corrected postoperatively [32].

Data reported by Kelly and Goretsky [33] on 1215 PE patients showed that the median age of surgical repair was 14 years. In addition to the age of referral, the choice of surgery was made near puberty if respiratory and cardiopulmonary symptoms were not presented. In the second decade of the study, newer surgical techniques (Nuss procedure) and instruments were implied such as introducer, bar flipper, and stabilizer [34]. Preoperatively, these patients were presented with a significant reduction in FVC, FEV, and FEF along with dysrhythmia in 16% of patients, mitral valve prolapse in 18%, Marfan syndrome in 2.8%, and scoliosis in 28% of these patients [35]. Increased bar placement (Nuss bar) was reported in older patients and those who presented with Marfan syndrome [36].

4. Pectus Carinatum (PC)

PC, also known as pigeon breast, is the second most common chest wall deformity, that is characterized by protrusion of the sternum and adjacent costal cartilages [37]. It is reported in 1 of 2500 live births and is more prevalent in males. Chondrogladiolar and chondromanubrial are two different variants of PC [38]. It can also be seen in combination with PE [39]. It is usually seen in combination with congenital heart disease due to the pressure from the hypertrophic right ventricle. Decreased thoracic vertebrae lead to an inability of the heart to increase stroke volume during vigorous activities and rotation of vessels further adds to cardiopulmonary dysfunction [40]. Intolerance to exercise is one of the common symptoms in PC and PE patients [41]. The patients are marked with a significant reduction in maximal inspiratory and expiratory pressure [42]. Elevated pressure on the spine, due to deformity can also cause the displacement of the vertebrae and cause scoliosis [23]. Correction of PC using non-surgical orthotic braces has shown good results [43,44].

5. Discussion

PC and PE are structural chest deformities. In the early stages, these might not be presented with physiological disturbance, however, near puberty cardiopulmonary dysfunction and comorbidities are reported in these patients, Fig. 2. Surgical and non-surgical correction (only for PC) has shown clinically satisfactory outcomes. Our article highlights the importance and outcomes of these therapeutic methods. 85% and 15%

of anterior chest wall anatomical deformities are attributed to PE and PC, respectively [45]. Severe PE can also lead to death, therefore, treatment may be necessary in such cases particularly when the cardiopulmonary system is involved [45].

Patients with restricted mediastinal disorders and anterior-posterior diameter reduction suffer from physiological cardiopulmonary disorders in the form of arrhythmias, hypotension, tachycardia, active shortness of breath, and premature fatigue, which can be treated with surgery. A patient can soon improve his physical working capacity [46]. It is recommended to evaluate the activity of the cardiovascular system and respiration by measuring the central venous pressure in the sitting and lying position without activity and after performing the activity before and after the operation [47].

Chest deformation, by pressing on the chin, causes coughing, stridor, dyspnea, and exacerbation of clinical symptoms along with inflammation that requires urgent medical treatment [48]. Echocardiography, ECG, and tests related to rheumatic and thyroid diseases must be performed for patients with severe chest deformity, Fig. 3. In severe pectus excavatum thoracic deformity diseases that require major thoracic surgery, it is necessary to apply pressure to the anterior central vein during surgery [49]. At the end of the operation, control should be performed and if the pressure in the central vein increases, the sternal pressure should be released by bilateral resection of the altered parasternal and sternotomy elements to reduce the central venous pressure (20).

6. Conclusion

Timely diagnosis and management of these deformities are important to achieve therapeutic efficacy. Studies regarding pathophysiology of the mediastinum and associated deformities are required to develop better treatment strategies. Though the prevalence of some of these deformities may not be high, clinicians should consider them when diagnosing patients with cardiopulmonary dysfunction.

Provenance and peer review

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Human and animal rights

No animals were used in this research. All human research procedures followed were in accordance with the ethical standards of the committee responsible for human experimentation (institutional and national), and with the Helsinki Declaration of 1975, as revised in 2013.

Consent for publication

Informed consent was obtained from each participant.

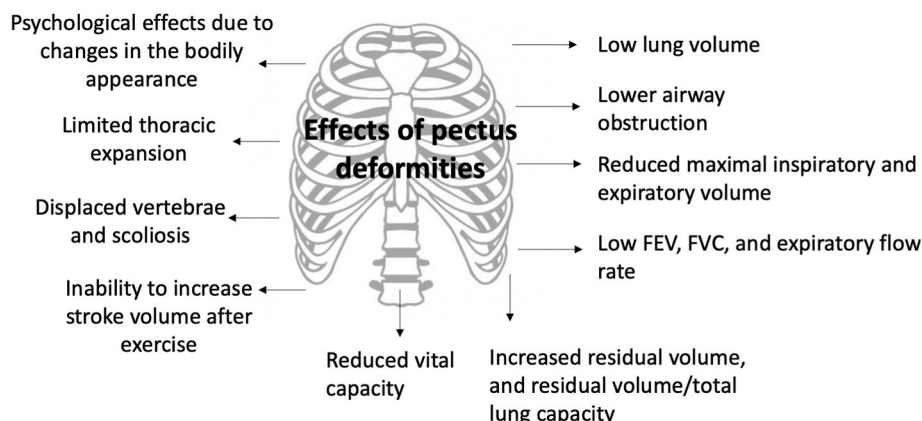


Fig. 2. Illustrate some of the commonly reported effects of pectus excavatum and carinatum.

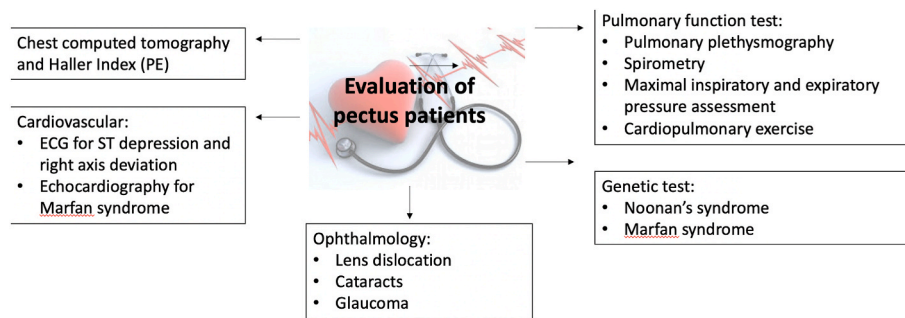


Fig. 3. Summarize clinical assessments performed on pectus patients for the evaluation of clinical presentation.

Availability of data and materials

All relevant data and materials are provided with in manuscript.

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Ethical approval

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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Author contribution

Dr. Saeid Marzban-Rad and Dr. Rama Bozorgmehr: conceptualized and designed the study, drafted the initial manuscript, and reviewed and revised the manuscript.

Dr. Dr.Parastesh Sattari and Dr. Hossein Azimi: Designed the data collection instruments, collected data, carried out the initial analyses, and reviewed and revised the manuscript.

Dr. Ghasem Azimi and Dr. Ali Azimi: Coordinated and supervised data collection, and critically reviewed the manuscript for important intellectual content.

Consent

Not applicable.

Registration of research studies

1. Name of the registry: N/A
2. Unique Identifying number or registration ID: N/A
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Guarantor

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Declaration of competing interest

The authors deny any conflict of interest in any terms or by any means during the study.

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