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CLINICAL STUDY

Pulmonary sequestration in adulthood: clinical-morphological study

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ABSTRACT

OBJECTIVES: The aim of the study was to evaluate pulmonary sequestration (PS). We report on location, blood supply, histology, clinical manifestation, and surgical treatment of PS, as well as on postoperative course in patients with PS.

BACKGROUND: PS is a rare congenital defect of the lower respiratory tract, it represents *locus minoris resistentiae* of the body. Occasionally, PS is diagnosed for the first time in adulthood.

METHODS: We evaluated 7 cases of PS treated at the Centre of Thoracic Surgery in Vyšné Hágy, Slovakia, between years 2013 and 2020.

RESULTS: Four of our seven patients were asymptomatic; the PS was found incidentally upon chest imaging. Three patients had recurrent bronchopneumonia related specifically to the intralobar type of sequestration. The most significant complication, observed in a singular patient, was a life-threatening episode of haemoptysis, requiring urgent surgical intervention. In the other 6 cases, the *sequestra* were surgically resected during the period when they were asymptomatic. and their sputum was confirmed negative upon microbiological examination. Anatomical resection of the affected pulmonary lobe by thoracotomy was the most common type of operation performed (4 cases, n = 7). There was no surgical mortality.

CONCLUSION: To prevent complications, it is crucial to perform surgical treatment for pulmonary sequestration in patients who have sufficient functional capacity *(Tab. 2, Fig. 4, Ref. 30)*. Text in PDF *www.elis.sk*

KEY WORDS: pulmonary sequestration, anatomic lobectomy, haemoptysis.

Introduction

Pulmonary sequestration (PS) is a congenital lung malformation in which a segment or lobe of dysplastic lung tissue exists with no communication with the rest of the tracheobronchial tree and receives an anomalous systemic vascular supply, separate from the rest of the lung. It is, therefore, a nonfunctional tissue (1–4). It has generally been believed that the cause of PS lies in simultaneous formation of two or more pulmonary buds of the foregut. During embryonic development, one of the buds becomes dominant and represents the foundation of functional lungs. Pulmonary *sequestra* may develop from the redundant buds. The PS is divided into two types, intralobar sequestration (ILS) which is the more common type, where the lesion lies within pleural layer surrounding the lobar lung and extralobar sequestration (ELS) which has its own pleural covering and maintains a complete anatomic separation from the adjacent normal lung (Fig. 1) (5). The extralobar form is more commonly associated with congenital developmental disorders (6, 7). Associated congenital abnormalities usually dominate over the clinical consequences of sequestration itself. Pickwer et al (7) found that 50 % of infants diagnosed with ELS within the first six months after birth have accompanying abnormalities, primarily affecting the diaphragm and heart.

Extralobar pulmonary sequestrations are most commonly found in the left pleuropulmonary region under the lung base. In addition, ELS can be also developed in the interlobar fissure of the lung, or rarely in the mediastinum or retroperitoneal space. Approximately 10 % of detected extralobar pulmonary *sequestra* are localised below the diaphragm (8). The first description of ELS was provided by Rokitansky and Rektorzik in 1861. In the bibliography, the terms “accessory lung” or “accessory lobe” are used for ELS. The difference lies in the localisation that the abnormal lung bud had been developed in, i.e., whether it had been directly developed from the primitive foregut or more peripherally. For ELS, the eponymic term Rokitansky’s lobe is often used.

The intralobar form of pulmonary sequestration accounts for 75–86 % of cases and is more common in adulthood. The majority of intralobar sequestrations are identified in patients who are under the age of 20 years. ILS is more prevalent in males (9). The *sequestrum* tissue is incorporated into the parenchyma of pulmonary lobe

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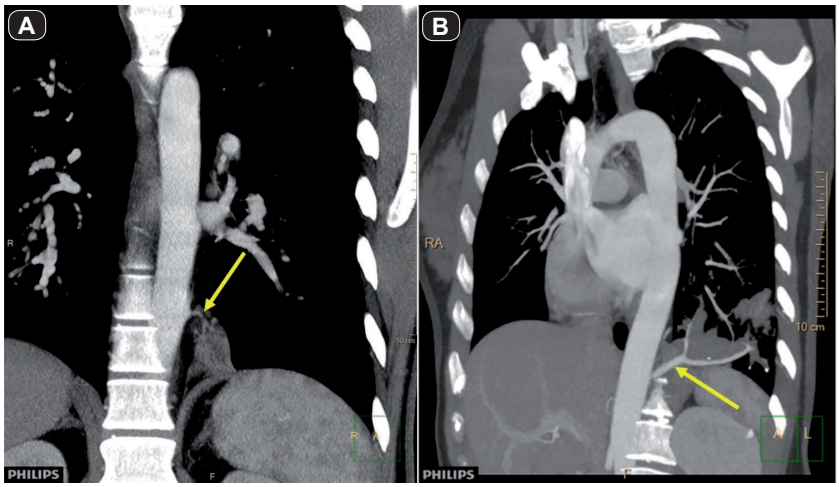

Fig. 1. Extralobar lung sequestration in the left pleuropulmonary area with afferent arteriole from the aorta (A) and intralobar lung sequestration in the inferior lobe of the left lung with afferent arteriole from the celiac trunk (B) (CT workplace of the National Institute for Tuberculosis, Lung Diseases and Thoracic Surgery in Vyšné Hágy, Vysoké Tatry, Slovakia)

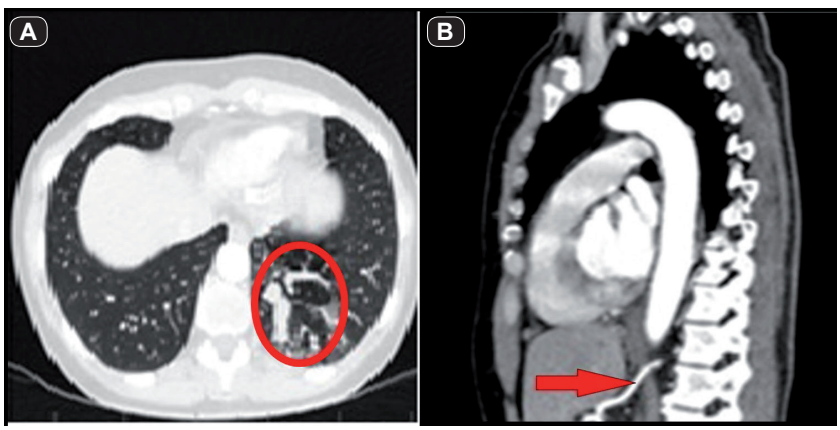

Fig. 2. Intralobar sequestration of the inferior left lung lobe with the afferent arteriole from the celiac trunk in axial projection (A) and sagittal projection (B) (Department of Radiology, National Institute for Tuberculosis, Lung Diseases and Thoracic Surgery in Vyšné Hágy, Vysoké Tatry, Slovakia)

Tab. 1. Types, location, symptomatology, and treatment of pulmonary sequestration in our patients (n = 7).

Characteristics	Number of patients
Type of sequestration (n =7)	
• Intralobar	6
• Extralobar	1
Location of intralobar sequestration (n =6)	
• Inferior pulmonary lobe	5
• Middle pulmonary lobe	1
Symptomatology (n = 7)	
• Asymptomatic patients [a]	4
• Recurrent bronchopneumonia [b]	3
Surgical resection of the sequestration (n=7)	
• Planned	6
• Urgent	1

[a] The group included also a patient with extralobar sequestration, [b] 1 patient had life-threatening haemoptysis.

and is not covered with a separate pleura. The lower lung lobes are affected the most frequently, especially the *segmentum basale posterius* (S10) of the left lung (Fig. 2) (10–13). ILS is usually uncorrelated with other associated congenital developmental disorders (14). Pryce first described and named the condition as intralobar lung sequestration in 1946 (11). He also mentioned the embryological associations between the intralobar and extralobar types of PS. Kafka and Beco described a case of simultaneous combination of ELS and ILS (15).

Patients and methods

In this article, we evaluate a series of seven patients with pulmonary sequestration, who were hospitalised and operated on at the Centre of Thoracic Surgery of the National Institute of Tuberculosis, Lung Diseases and Thoracic Surgery in Vyšné Hágy, Slovakia, between years 2013 and 2020.We were focused on the localisation of *sequestra*, their vascular supply and clinical manifestations of complications associated with pulmonary sequestration. Clinical and radiological data were collected.

This study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study. Patients signed informed consent regarding publishing their data and photographs.

Results

In years 2013–2020, we identified 7 adult patients with PS. Four women and three men were affected. The average age values were 45.8 and 36.7 years for women and men, respectively. There were no associated congenital developmental disorders in any of the reported cases. The type of sequestration was intralobar in 6 cases (86 %) and extralobar in 1 case (14 %). The most common location of PS was the inferior pulmonary lobe (5 patients, 71 %).

In 4 patients, the PS was asymptomatic and represented an incidental finding upon chest imaging. One of the asymptomatic cases was that of an extralobar pulmonary sequestration in the left pleuropulmonary space. The other three asymptomatic cases had intralobar pulmonary sequestration (Tab. 1).

All three symptomatic patients had the intralobar type of sequestration. They experienced unexplained recurrent episodes

of bronchopneumonia in adolescence or early adulthood. In one patient, a life-threatening burst of haemoptysis occurred as a complication of the most recent episode of pneumonia. The disposition to recurrent bronchopneumonia in these patients was discerned from their anamnesis, showing that the patients were frequently treated with empiric antibiotic therapy for community-acquired bacterial bronchopneumonia. As a result of seeking the particular reason behind the repetitive occurrence of pneumonia, pulmonary sequestration was detected. In two of three symptomatic patients, the pulmonary sequestration was surgically managed during a period when they were asymptomatic, and their sputum was confirmed sterile. In the patient with haemoptysis, an emergency surgery was required due to life-threatening bleeding into the respiratory tract. Histological examination revealed destructive pulmonary actinomycotic pneumonia in the resected lung tissue of the patient (Fig. 3).

Out of the reported group of six ILS cases, the sequestration was localised in the middle lobe of the right lung in one patient, and in the inferior lobe of the right lung in two patients, while the remaining three cases had an intralobar sequestration in the inferior lobe of the left lung. In all patients, aberrant arteries supplying the supernumerary pulmonary bud from which the sequestration developed were identified during surgery. The patient with extralobar sequestration and four patients with intralobar sequestrations had specific arteries arising directly from the thoracic part of the descending aorta (Tab. 2). In two cases of intralobar sequestrations, the arteries originated more peripherally, namely from the intercostal arteries or from the coeliac trunk (Fig. 4).

The definitive surgical treatment was as follows: in the case of asymptomatic extralobar pulmonary sequestration, extirpation of the left pleuropulmonary sequestration by thoracotomy was indicated. Intralobar pulmonary sequestration was treated by means of anatomical resection of the affected pulmonary lobe by thoracotomy (four cases), anatomical sublobar resection by thoracotomy (one case) or video-assisted thoracoscopic lobectomy (one case).

The postoperative course was uncomplicated in 6 patients, who were discharged to ambulatory care on postoperative day 7–10. In the patient who underwent an urgent median right-lung lobectomy for haemoptysis concurrent with destructive actinomycotic inflammation in the sequestered tissue, the postoperative course was complicated by effusion in the right pleural cavity and infection in the thoracotomy wound.

The histological examination of the resected pulmonary sequestred tissue revealed malformed lung parenchyma with varying degree of evidence of acute inflammation in all patients. Post-inflammatory changes were also found in cases of asymptomatic sequestrations. In addition, the patient with intralobar sequestration complicated by actinomycotic inflammation and haemoptysis had PAS (Periodic Acid Schiff)-positive actinomycete colonies localized inside alveoli, and masses of erythrocytes in alveoli and bronchi due to the haemorrhage into the sequestrated parenchyma as well as into the surrounding lung parenchyma (Figure 3).

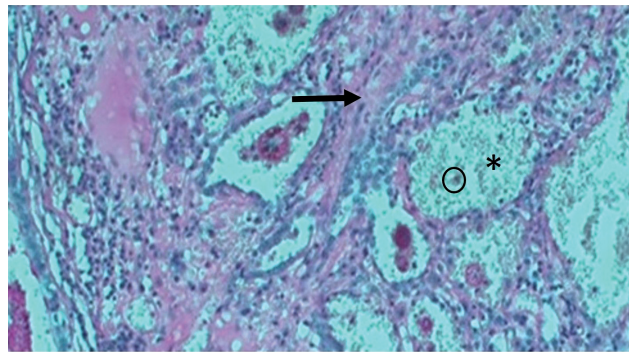

Fig. 3. Histological specimen of resected intralobar pulmonary sequestrum with destructive actinomycotic inflammation, clinically accompanied by haemoptysis. There is a predominantly non-aerated lung parenchyma, thickened collagen-positive alveolar septa (black arrow) (Masson trichrome, Bammed, s.r.o., Czech Republic) and multiple pulmonary interstitium with haemorrhagic purulent inflammation. In the alveoli, there are masses of erythrocytes (*) and foreign PAS-positive material of the nature of actinomycete colonies (black circle) (PAS, Bammed, s.r.o., Czech Republic)

Tab. 2. Arteries nourishing the *sequestra* in our cohort (n = 7).

Artery	Number of patients
Thoracic aorta	5
Intercostal arteries	1
Celiac trunk	1

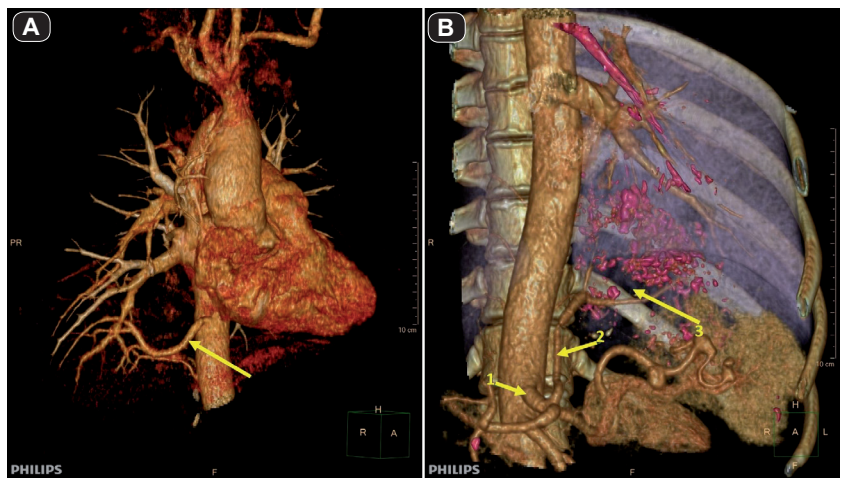

Fig. 4. Intralobar sequestration in the inferior lobe of the right lung with an afferent arteriole arising directly from the aorta (A) and intralobar pulmonary sequestration in the inferior lobe of the left lung with an afferent arteriole arising from the celiac trunk (B) (1-celiac trunk, 2-afferent arteriole, 3-branching of arteries within the sequestration).

Discussion

The incidence of pulmonary sequestration in adulthood is unknown. The available bibliography offers rather limited patient cohorts with PS from a relatively short time period and limited geographical area. Some cases also remain undiagnosed. It is estimated that pulmonary sequestration accounts for 0.15 % to 6.4 % of congenital lung malformations and is found in 1.1 % to 1.8 % of patients undergoing lung resection (16, 17). Some authors ascribe the increase in incidence of PS to the advances in diagnostic methods (18).

Macroscopically, extralobar pulmonary sequestration looks like a wedge-shaped or oval mass of greyish-pink tissue with a smooth or truncated surface. Microscopically, lung parenchyma with dilated bronchioles, alveolar ducts, and alveoli malformed by fibrosis can be seen. In the sequestered tissue, signs of acute inflammation can be seen (9, 19). These findings were also present in our patient with extralobar sequestration in the left pleuropulmonary area (Fig. 1).

Intralobar sequestration exhibits macroscopically pseudotumoral characteristics, appearing either as solid masses or cystic formations. The histological view shows a variety of malformed lung tissue with obvious fibrous remodelling and chronic inflammatory changes. If the bronchial epithelium produces secretions, these accumulate and form cystically dilated spaces filled with liquid-to-gelatinous contents. Chronic inflammatory changes lead to the development of adhesions between the *sequestrum* and surrounding tissues (5, 9). These findings have also been demonstrated in the cases of intralobar pulmonary sequestration reported in our cohort. In the patient with haemoptysis, there were additional signs of active bleeding in the sequestered parenchyma within destructive actinomycotic inflammation environment.

Pulmonary sequestration in adulthood represents the *locus minoris resistentiae* in which natural mechanisms of immunity and blood circulation are impaired. This, in turn, contributes to the development and persistence of infection, bleeding and increases the probability of malignancy (20, 21).

Recurrent unilateral pneumonia in adult patients should raise a suspicion of possible pulmonary sequestration and these patients should undergo CT pulmonary angiography (CTPA pulmonary angiography) as part of the differential diagnosis. In many cases, pulmonary CT angiography reveals an anomalous vascular supply to the sequestered pulmonary tissue, which will be helpful in planning the surgical management. The clarification of anomalous vessels will allow the consideration of their embolization in the preoperative period (22).

The tissue microenvironment affected by recurrent inflammation, hypoxia, and weakened immune barrier mechanisms, can be colonized by a variety of pathogens. One our case of ILS was colonized by anaerobic capnophilic actinomycetes. The treatment of such infections is complicated due to impaired penetration of antibiotics into the affected tissue. In addition, destructive inflammation may damage blood vessels to an extent allowing for subsequent bleeding into the sequestration or its surroundings. In such a case, the bleeding leads to haemoptysis, haemothorax, or haemoperitoneum. Cases of intra-abdominal pulmonary sequestrations complicated by haemoperitoneum were published by Laje et al (8). Moreover, our asymptomatic patients showed histological signs of recurrent inflammations. Latent inflammation can lead to an accumulation of damaged tissue that eventually results in life-threatening complications.

The spectrum of possible morphological abnormalities in pulmonary sequestration is large (18). Various combinations of afferent and efferent vessels are known. In our patients, the extralobar and intralobar *sequestra*, in one and four cases, respectively, were supplied by direct branches from the thoracic section of the aorta. The direct branches of the aorta enter up to 71 % of the sequestered tissue. The two intralobar *sequestra* were accessed by vessels from more peripheral arteries, namely from the intercostal arteries and coeliac trunk (Fig. 3). A similar case of sequestration with an afferent vessel from the coeliac trunk was published by Arenas et al (23). In the case of an intrathoracically localized sequestration involving a vessel entering the diaphragm from the abdominal aorta or its branches, it is particularly beneficial to know its origin and be aware of its course before the surgery (24). Van Langenhove et al reported a case of intralobar *sequestrum* supplied by an afferent vessel running from the right coronary artery (25). There is also a variability in the venous drainage of pulmonary sequestrations. In cases of extralobar sequestration, the veins mostly drain into the systemic venous system. There are also known cases of their drainage into the pulmonary veins or the portal venous system of the liver. The veins of intralobar *sequestra* most often drain into the pulmonary venous system.

The vascular system of the pulmonary *sequestra* can cause vascular shunts by their inclusion in the bloodstream of a subject. Chatelain et al reported a patient with secondary dilated cardiomyopathy induced by a left-to-left shunt through the sequestration vessels. This shunt led to a volumetric overload of the left ventricle. The patient's condition significantly improved after the surgical removal of the *sequestrum* (26). We did not observe any secondary cardiac damage in our patients. However, the vascular supply may have played an important role in the development of haemoptysis in a patient with intralobar *sequestrum* in the middle lobe of the right lung, which was entered by numerous afferent vessels running from nearby intercostal arteries. These vessels supplied excessive amounts of blood from high-pressure systemic arteries to the sequestered parenchyma, which, in combination with destructive actinomycotic inflammation, led to intense bleeding (27).

Pulmonary sequestrations may have an association with a derivative of the foregut from which their anomalous bud was formed (19). We did not observe such an association in any case in our cohort. When a connection of the sequestered tissue with the oesophagus, stomach or even with the bronchial system of the functional lung is present, the patent fistula may represent a gateway for the entry of infection into the sequestered tissue.

Asymptomatic cases of pulmonary sequestration are incidentally detected in adulthood as a result of radiological examination performed due to other diseases, preventive examinations or preoperative examinations prior to the planned surgery of another known disease.

Symptomatic sequestrations can manifest in the form of an exhaustive array of diverse complications. The most reported complications of extralobar pulmonary sequestration in adulthood are pleural empyema, haemothorax, and haemoperitoneum. Intralobar pulmonary sequestration is often accompanied by recurrent unilateral pneumonia or haemoptysis. Several authors described cases of coincidence of pulmonary sequestration with pulmonary malignancies (28).

The surgical management of pulmonary sequestration in prospective patients with adequate functional reserve represents a condition *sine qua non* in preventing its complications. The most common surgical procedures are anatomical resections, namely lobectomies and segmental lung resections. Video-assisted thoracoscopic resections are also successfully used. The solution for extralobar sequestrations lies in straightforward surgical extirpation. The authors reporting on surgical management of pulmonary sequestrations have consistently achieved very good postoperative results (29, 30).

Pulmonary sequestration is a rare congenital bronchopulmonary anomaly of foregut found in adulthood. It most often occurs in the thoracic region. Because the aboral border of the foregut is located underneath the diaphragm, the pulmonary sequestration can also develop in the abdominal region. The altered tissue microenvironment provides the basis for a wide variety of complications. Anomalous vessels represent a potential source of severe bleeding, especially if they are damaged by destructive inflammatory changes. Our paper reports 7 cases of pulmonary sequestration diagnosed over seven years. In our study, the most serious complication was haemoptysis, in a case of an intralobar sequestration of the middle lobe of the right lung affected by destructive actinomycotic inflammation, which was vascularly supplied by numerous anomalous branches of nearby intercostal arteries. The case required urgent surgery. In the other six cases, the sequestrations were surgically resected during the period when they were asymptomatic, and their sputum was confirmed negative upon microbiological examination. The surgical resection of pulmonary sequestration represents an essential prerequisite in the prevention of its possible complications and is indicated in all prospective patients with adequate functional reserves.

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