PhD thesis

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CLINICAL CONSIDERATION OF SOME RARE EMERGENCY THORACIC CASES IN PEDIATRIC SURGERY

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List of full papers related to the subject of the thesis

I. Rieth A, Kovács T, Novák Z, Kapus K, Ottlakán A, Németh T, Furák J

Surgical treatment of awn aspiration causing bronchopleural fistula and bronchiectasis: case reports. BMC Pediatr. 2019 Oct 22;19(1):368. **IF: 1,909**

II. Rieth A., Varga E., Kovács T., Ottlakán A., Németh T., Furák J.

Contemporary management strategies of blunt tracheobronchial injuries. Injury. doi:10.1016/j.injury.2020.07.026 **IF: 2,106**

III. Rieth A, Ottlakán A, Kovács T, Balogh B, Furák J.

The role of an overinflated endotracheal tube in the diagnosis of tracheal injuries. ORV HETIL. 2020;161(25):1063–8. **IF: 0,497**

Contents

ABBREVIATIONS

ATLS – Advanced Trauma Life Support; CT – Computed Tomography; CXR – Chest X-Ray; ECMO – Extracorporeal Membrane Oxygenation; eFAST – Extended Focused Assessment with Sonography in Trauma; ETT – Endotracheal Tube; FB – Foreign Body; MDCT – Multi-slice detector computed tomography; SEMS – Self-Expanding Metallic Stent; TEF – Tracheoesophageal Fistula; TBI – Tracheobronchial Injury

1. Introduction

Emergency pediatric thoracic surgery involves widespread forms of thoracic diseases, includes congenital malformations such as pulmonary sequestration, acquired diseases such as pneumonia, or traumatic injuries such as airway trauma. During our research we studied rare pediatric thoracic disorders having unacquainted official management protocol due to the lack of adequate patient number, thus proper experience. Our aim was to provide comprehensive coverage of diagnostic challenge and the most up-to-date treatment strategies. The main course of the thesis includes discussion of blunt tracheobronchial injuries, and a special type of aspiration.

Tracheobronchial injury (TBI) is noted as an exceptionally uncommon condition in adult population, however the incidence among children even less lower, as its rate is estimated to be 0.7-2.8% (Slimane et al. 1999). It can potentially become a life-threatening condition, and the majority of these patients (30-80%) still die at the scene of the accident (Prokakis et al. 2014). Early diagnosis is essential in reaching improved patient survival. Avoiding airway obstruction and early, successful surgical management are vital for a successful outcome. The lack of typical clinical symptoms and diverseradiological appaerance often lead to delayed diagnosis.

Due to the rare occurrence of TBI, limited experiences and low number of patients, the management of TBI remains highly diversified in different intsitutions, with specific guideline is still lacking. Our aim was to collect current up-to-date informations and recommendations on blunt tracheobronchial injuries of the neck and thorax. Our further purpose was to clarify the drawbacks of diagnostic challenge, and to construct a feasible, easily applicable management algorithm. Furthermore, through our own surgical experience, we would like to highlight the importance of early diagnosis and prompt management. While decisions are often based on clinical suspicion, we would like to present an uncommon, though direct and special radiological sign of TBI, which could help clinicians in reaching improved diagnosis. The overinflated endotracheal tube (ETT) cuff is an easily detectable sign of complete tracheal wall rupture. It can be confirmed even on a chest X-ray (CXR), thus early targeted fiberoscopy can be carried out.

The other main topic of the thesis deals with a special type of foreign body (FB) aspiration. FB inhalation is a well-known entity, which remains a leading cause of

accidental death among children, especially among those younger than 1 year (Blair et al. 2014). It is often difficult to diagnose a non-specific aspiration, and moreover, there are some special forms of foreign bodies, when general protocols are not advised. One of these special types is grass head aspiration, which has specific symptoms, features, and thus requires special management strategy. Literature data is short on grass head aspiration among children, however we present our experience and feasible management algorithm. Our aim was to emphasize the importance the condition, and to highlight the need for minimal resection during surgical treatment.

2. Objectives

Although these are special and rare childhood conditions, no proper guideline in surgical treatment is available. Our aim was to investigate recent studies, and to provide a broad review of literature. Diagnostic difficulties, treatment options and clinical decision-making were analysed for each disease, with the completion of our own practice.

Addressed questions summarized:

I. to emphasize the difficulties of inflorescence aspiration, and reveal its most important features (Study 1)

II. to define recommended treatment algorithm in the management of grass head aspiration (Study 1)

III. to review best diagnostic and current treatment options for blunt airway injuries (Study 2)

IV. to define the role and practical possibilities of the underestimated sign of overinflated ETT cuff in the diagnosis of tracheal injuries (Study 3)

3.1 A special form of foreign body aspirations – inhalation of grass head

There are some special types of FB aspiration requiring attention, such as grass head aspiration. Grasses *(Poaceae)* are a botanical family of flowering plants (inflorescences) found on almost every field or along the roads. Their heads bear several spikes and bristles, that are responsible for one-way self-propulsion inside the respiratory tract, and are thus responsible for the atypical symptoms and outcomes. Each coughing and respiratory actions make them migrating towards the periphery of the lung. They get deeper and deeper until they reach the chest wall, and able to penetrate to the outside. We demonstrated their special characteristics through our two cases have been observed in recent years. Furthermore, we would like to recommend a management process for faster diagnosis based on our experiences and the revised literature.

3.1.2. Our experiences with grass head aspiration

We had two cases with barley grass aspiration (4-year old and 9-year old boys) resulting in pleuropneumonia and bronchiectasia and requiring surgical management. Despite the fact, that our two cases had improved laboratory markers and symptoms, CT (computed tomography) showed bronchiectasis in Case 1 after six months, while abscess formation was revealed in Case 2 after 32 days. These results suggested the presence of grass head in the respiratory tract. During our first case, extensive pulmonary inflammation required lobectomy, while resection of the rigth 6^{th} segment in our second patient was appropriate due to localised inflammation.

3.1.3. Discussion

Historically, Chevalier Jackson was the first, to cathegorize grass heads into two different types, based on the structure of the head, thus on their behaviour (Jackson, 1952). A small proportion was the so-called “lodging” or “non-extrusive” type, which tends to remain in the respiratory tract, resulting in obstruction or recurrent pneumonitis. However, the majority, called “extrusive” type has the power of changing location, while retrograde movement is blocked by its sharp spikelets. At the moment of aspiration usually only mild symptoms dominate, such as coughing, choking, vomiting or wheezing, however, as the grass head travels deeper these initial symptoms mostly diminish. The following period is characterized by asymptomatic or continously improving physical status. As the grass head easily migrates beyond the reach of bronchoscope, even immediate examination is mostly negative. However, the presence of a bronchial grass head can not be excluded despite negative clinical results or improved inflammatory markers. Nevertheless serious complications may develop after a few days due to migration onto the periphery. According to the literature, the most frequently reported complications caused by grass head migration were: recurrent haemoptysis (Maayan et al. 1993, Diggory et al. 1984), bronchiectasis (Hilman et al. 1980), pneumonitis (Spencer et al. 1981, Jewett et al. 1965), while tension pneumothorax (Kothari et al. 2006), and empyema were also frequently mentioned. Osteomyelitis of the rib (Maayan et al. 1993), consequently developed brain abscess or coexisting acute abdomen (Dindar et al. 1994, Spencer et al. 1981) were unique cases. This type of inflorescences keeps migrating to the periphery of the lung until they finally extrude through the chest wall, causing bronchopleurocutaneous fistula and spontaneus elimination (Kanbur et al. 2015, Karagöz et al. 2006).

With our report a total of 133 children were found in the uptodatee literature. Among the 133 children, 95 probably aspirated an extrusive grass head, compared to 26 non-extrusive type inhalations (we have no valid information about 12 children) (Table 1.). Endoscopical removal was successful in 39 cases (32,2%), including 12 laryngoscopy during the early phase. Of the 133 children, 35 required surgical management (28,9%), while 40 grass heads (33,1%) protruded spontaneously through the chest wall. It is interesting, that 5 spontaneous expectorations (4,1%) were detected, and 2 children (1,7%) died due to 1) abscess in the liver and lung; and 2) widespread empyema and bronchopneumonia (Clery et al. 1959).

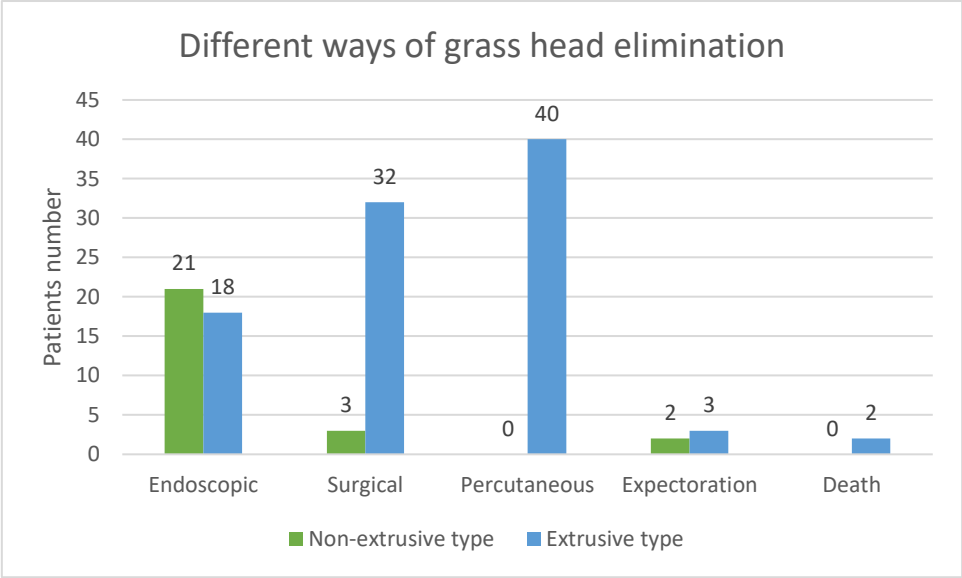

Table 1. Summarized patient number in different outcomes both in the extrusive and the lodging type

Literary data is consistent, that immediate bronchoscopy should be performed in all the cases, however, positive bronchoscopy, or endoscopic removal may only be accomplished prior to deep migration, and in some cases of the lodging type (Nasr et al. 2005).

According to rapid propulsion, the presence of a bronchial floret can not be excluded after negative bronchoscopic result or improved inflammatory markers, thus an asymptomatic child should be followed up thoroughly (CXR or chest ultrasound) to recognise exacerbation in time. If these examinations revealed any possible inflammation site, CT can be a valuable diagnostic tool to localise and identify the foreign body, or to show early complications.

The majority of cases showed (Table 2.), that delayed diagnosis entails serious irreversible sequales (such as residual bronchiectasia or bronchopleurocutaneous fistula). Surgery is opted when signs of localised inflammation can be detected on CXR or CT. According to the literature, lobectomy is the most preferred way during surgical removal. However, in case of fast diagnosis or localized inflammation, segmentectomy should be a considerable choice as a tissue-saving option.

Author	Gender (Female/Male)	Age	Location	Type of elimination	Time between aspiration and elimination	Complications
Nasr et al. (2005)	M	1 y	RLL	Bronchoscopy	5 mo	Pn.
	M	5 y	RLL	Bronchoscopy	6 mo	Pn.
Hilman et al. (1980)	M	7 y	RLL	Lobectomy	1 y	Br.
	M	13 y	RLL	Expectoration	2 mo	Pn.
	M	14 y	RLL	Lobectomy	6 mo	Pn.
	M	14 y	LLL	Percutan	6 mo	Pn., Bpcf.
Maayan et al. (1993)	M	9 y	RLL	Lobectomy	7 y	Haem., Br.
	M	7 mo	RLL	Percutan	9 mo	Ptx., Rib osteomyelitis
	M	0,5 y	RLL	Bronchoscopy	10 mo	Pn. Haem.
Kanbur et al. (2015)	M	13 y	RLL	Percutan	5 mo	Pn.
Karagöz et al. (2006)	M	9 y	RLL	Percutan	2 weeks	Bpcf.
Basok et al. (1997)	M	8 y	LLL	Expectoration	4 y	Haem., Br.
	M	7 y	RLL	Pneumonectomy	3 y	Br. in total right lung
	F	6 y	RLL	Lobectomy (bilat.)	5 y	Br. in both lower lobe
Spencer et al. (1981)	F	4 y	RLL	Bronchoscopy	3 y	Pn.
	M	1,5 y	RLL	Lobectomy	3 mo	Pn.
Choremis et al. (1964)	F	3 y	LLL	Percutan	2 mo	Bpcf.
	M	2,5 y	RLL	Percutan	10 days	Bpcf.
Cavens et al. (1973)	M	5 mo	RLL	Percutan	1,5 mo	Bpcf.
Dudgeon et al. (1980)	M	10 y	LLL	Lobectomy	10 mo	Haem., Atelectasis
	M	4 y	LLL	Lobectomy	3 mo	Pn., Br., Haem.
	M	1,5 y	RLL	Lobectomy	7 mo	Pn.
	F	1,5 y	RLL	Lobectomy	8 mo	Pn., Br.
Godfrey et al. (1957)	M	9 y	RLL	Lobectomy	4 mo	Pn.
	F	16 mo	RLL	Percutan	1,5 mo	Bpcf.
Harries et al. (1967)	F	22 mo	Right side	Percutan	4 mo	Bpcf.
Jewett et al. (1965)	F	7 y	LLL	Lobectomy	6 mo	Br.
	M	1 y	LLL	Bronchoscopy	1,5 mo	Br., Pn. in both lower lobe
	M	20 mo	RLL	Lobectomy	5 mo	Pn.
	M	2,5 y	RLL	Lobectomy	1 y	Pn.
Pattison et al. (1988)	F	17 y	LLL	Wedge resection	4 y	Haem.
Woolley et al. (1955)	M	4 y	RLL	Bronchoscopy	1 y	Br.
	F	18 mo	RLL	Bronchoscopy	3 mo	Pn., Br.
	M	22 mo	RLL	Lobectomy	3 y	Pn.
Diggory et al. (1984)	F	11 y	RLL	Lobectomy	4 y	Haem., Abscess in lobe

Table 2. Without being exhaustive, a collection of the main characteristics of aspirated cases was done, emphasizing the type of elimination and time (y – year, mo – month, RLL – right lower lobe, LLL – left lower lobe, RMB – right main bronchus, LMB – left main bronchus, Pn. – Pneumonitis, Ptx. – Pneumothorax, Br. – Bronchiectasis, Bpfc. – Bronchopleurocutan fistula, Haem. – Haemoptysis)

3.1.4. Conclusion

We conclude that the diagnosis of grass head aspiration often lead to difficulties due to its special features. The presence of bronchial grass head can not be excluded after negative bronchoscopy or improved inflammatory markers, furthermore, an asymptomatic child should be followed up thoroughly to recognise sequalae in time. Regular diagnostic procedures (such as CXR or chest ultrasound) should be carried out in order to localise early inflammation. Chest CT is valuable in identifying the position of the grass head. Surgical intervention is opted when the floret stays peripheral, and only localised inflammation, however should be performed before the appaerance of severe complications (Figure 1.). In case the grass head is found at the site of localized inflammation, anatomical segmentectomy with the removal of the affected bronchus may be preferred. In case of extended inflammation or in obscure conditions, lobectomy may be inevitable.

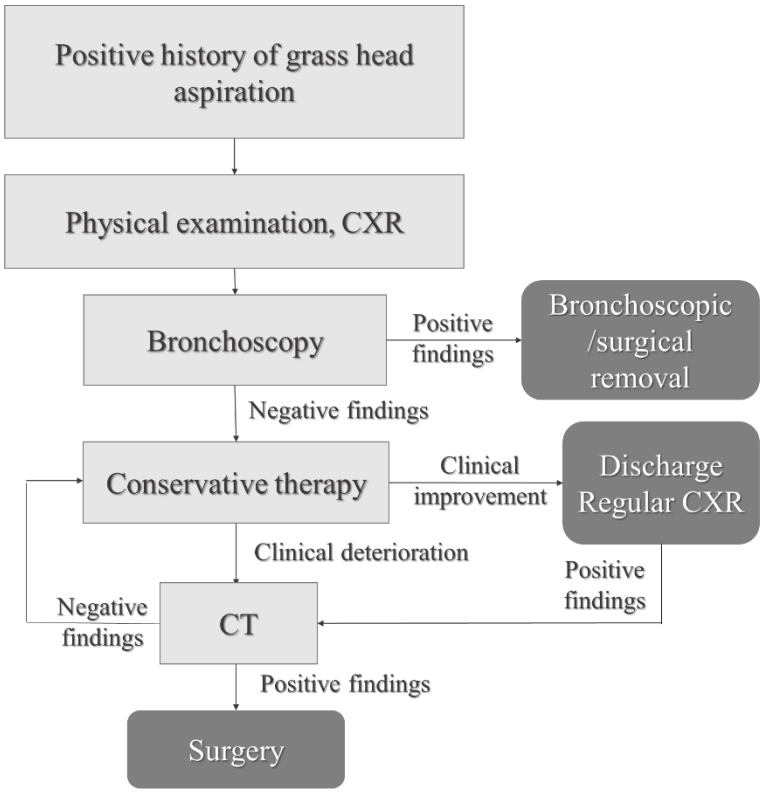

Figure 1. Treatment flowchart of grass head aspiration

3.2 Contemporary diagnostic and treatment options of tracheobronchial injuries

Tracheobronchial injury is an uncommon condition, but can easily become life-threatening. Though the incidence is low among children, the associated mortality rate is known as 8,7-30% (Sidell et al. 2011).

Early diagnosis is essential in patient survival. Avoiding airway obstruction with early, successful surgical management are vital for reaching improved outcome. The lack of typical clinical symptoms and the various radiological signs often delay the diagnosis. In order to reach improved treatment, the possibility of an airway injury should be kept in mind, and one should be aware of tipical symptoms and proper management. Through the presentation of our short case series, contemporary diagnostic and the treatment strategies of the TBI located on the neck and around the bifurcation are discussed.

3.2.2. Experiences with unique TBI cases in our practice

We had two children (12-year old girl were passed across by a truck, and a 9-year old boy suffering car accident as a passenger) and an adult patient (got under a bus) with blunt airway injury managing in our institution during recent years. In our adult case (Case 1) CT revealed only a right-sided pneumothorax. The patient had subcutaneous emphysema, and even after chest drainage she was still hypoxic, thus that was which strongly suggested the presence of TBI. In Case 2 (12 year-old girl) respiratory distress, subcutaneous emphysema, blood clot in the larynx were found, and pneumothorax on both sides were managed by chest tubes. CT revealed pneumomediastinum, which together lead to a suspicion of TBI. In the third case (9-year old boy) contusion on the neck was discovered on physical examination. CT showed extremely spreading subcutaneous emphysema and pneumomediastinum as indirect signs, and a real direct sign of TBI was also revealed as the endotracheal tube's cuff was overinflated and present external from the tracheal wall. All our three patients underwent bronchoscopic examination to confirm the diagnosis, and to identify the site of lacerations.

In Case 1 bronchoscopic examination revealed a rupture of the right main bronchus at the level of the carina. We did urgent operation and found a 4-cm long tear on the membranous trachea and a complete transection of the right main bronchus. In the second case bronchoscopy showed deformation in the bifurcation, but its lumen was intact. During operation we found a longitudinal laceration separating the two main bronchi. In the last case CT showed an

overinflated tube cuff and laryngoscopic examination confirmed the suggestion of a laceration at the level of the endotracheal tube's balloon. We found a completely transected trachea between the first and second tracheal rings. All our three patients had primary anastomosis with 3-0 interrupted absorbable sutures without any resection. Two cases with lower airway injury had a pedicle intercostal muscle flap for covering, thus we successfully avoided postoperative dehiscence. Laryngotracheal laceration needed extended mobilisation of the trachea as the separated part were 3 cm apart from each other. Thus flexion in the neck was performed in order to tension-free anastomosis.

3.2.3. Discussion

Tracheobronchial injuries are difficult to diagnose due to the unspecific physical symptoms and radiological appearance. The presence of concomitant injuries can obscure the symptoms of airway lesions and lead to a delayed diagnosis and early fatal outcome.

The most common symptoms are tachypnoea, respiratory distress (59-100%), haemoptysis (14-74%), dyspnoea, stridor, hoarseness or dysphonia. Nevertheless, progressive subcutaneous emphysema is the classic hallmark (35-87%) of TBI (Zhao et al. 2017). Lesion in the lower airway causes pneumothorax in 17%-72% of patients, maintains a massive air-leak through chest drainage and prevents lung re-expansion (Prokakis et al. 2014, Altinok et al. 2014).

Various indirect signs of an airway lesions can be detected by radiologic studies routinely performed in acute emergency settings; however direct, obvious findings rarely occur. Primary survey includes eFAST examination (Extended Focused Assessment with Sonography in Trauma) recommended by 10th edition of ATLS (Claire et al. 2018). It is highly sensitive for detecting the presence of pneumo- or hemothorax. The three typical signs of TBI on CXR are subcutaneous emphysema, pneumothorax and pneumomediastinum (Dominguez et el. 2015, Shemmeri et al. 2018). The endotracheal tube outside of the airways, or an overinflated endotracheal tube cuff are both important radiologic findings (van Rozendaal et al. 2018) requiring more emphasis. Almost the only direct and pathognomic CXR sign of lower airway injury is the "fallen lung sign", which means that complete transection of the bronchi makes the separated lung collapse laterally and posteriorly (Welter et al. 2014).

The following criterion signify the need of an urgent chest multi-slice detector computed tomography (MDCT): 1) hypoxaemia without pneumothorax after endotracheal intubation, 2) massive air leak after tube thoracotomy and persistent pneumothorax, 3) progressive subcutaneous emphysema and pneumomediastinum (Bagga et al. 2020). Unfortunately, the

sensitivity of CT imaging is seen in up to 71-100% (Prokakis et al. 2014). However, a negative CT does not exclude the presence of a TBI. An additional three-dimensional reconstruction, virtual bronchoscopy or contrast esophagogram can also supplement the diagnosis.

Laryngoscopy and bronchoscopy are still the “gold standard” diagnostic tool in the diagnosis of TBI. All patients with suspicion of airway injury should undergo this examination as early as possible.

3.2.4. Modern treatment options of tracheobronchial injuries

According to literature data, in patients suffering from TBI, the most important priority is immediate intubation. Intravenous muscle relaxants should be avoided, since the transected airway is possibly attached and supported only by surrounding muscles It is important, that the tube bypass the injured part and the cuff be inflated distally to avoid further disruption, or even complete transection (Elgendy et al. 2014).

Tracheostomy is rarely necessary. It is recommended in patient with severe maxillofacial trauma, unstable fractures of the face, palpable deformity over the trachea, extreme oedema or haemorrhage. Furthermore, in some young pediatric cases, tracheostomy may be prefered to endotracheal intubation, as intubation can completely obstruct an already damaged and tenuous airway, eventually leading to emergency tracheostomy, but under worse circumstances (Sidell et al. 2011).

Disruption at the site of the bifurcation may require a double-lumen tube, or selective endobronchial intubation. In a difficult situations finger guidance may be applied, leading the tube through the thoracotomy.

Patients should be transferred to the operating room for reconstruction as soon as possible. Independent of the lesion site, a primary reconstruction should be attempted, with only minimal airway mobilization. For the purpose of a tension-free anastomosis flexion in the neck, opening on the pericardium or division of the inferior pulmonary ligament can be performed. In case of a severe airway disruption protective tissue flap (pleura, pericardium, mediastinal fat, muscle flap) can be used to cover the anastomosis or separate the oesophagus. Severely distorted lung parenchyma requires lung resection occasionally.

In some selected cases conservative treatment can be considered (Figure 2.). Criteria include the following: tear under 2 cm, or one-third of the diameter, clinically stable patient, spontaneous breathing, or minimal ventilatory support, and no sign of mediastinitis, or sepsis (Prokakis et al. 2014, Altinok et al. 2014). Injuries caused by intubation has better prognosis,

because it often produces longitudinal tear on the posterior walls compared with traumatic injuries, which results irregular shaped, horizontal lesions.

These patients need antibiotic therapy and drainage. Self-expanding metallic stent (SEMS) can be used as alternative treatment in patients who have high surgical risk or severe comorbidities (Shemmeri et al. 2018). In case of unstable patients with ventilatory failure, extracorporeal membrane oxygenation (ECMO) is a valuable possibility, since it has already been successfully applied by several authors both in adults and in children (Wada et al. 2019, Ballouhey et al. 2013).

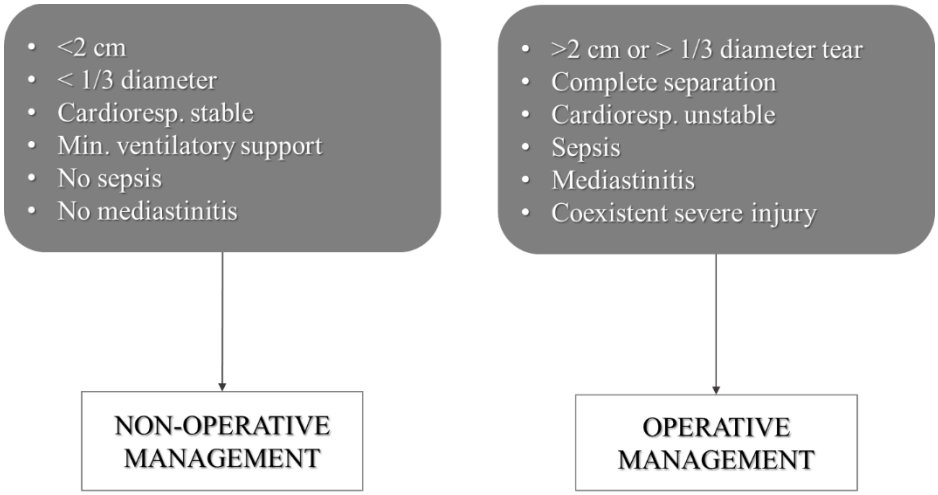

Figure 2. Treatment flowchart of TBI

3.2.5. Summary of the most important current treatment strategies and process

An algorithm for surgical, or non-surgical management of airway injuries is suggested. The most important steps to prompt primary management are summarized according to contemporary literature (Figure 3.).

When patients present at the emergency department, the first step is to consider whether she, or he had a type of trauma which can lead to airway injury (previous flexion-extension, or compression forces, sign of an elevated seat-belt, blood in vomit, or sputum). The most important symptoms we should look for on physical examination include dyspnea, respiratory distress, subcutaneous emphysema, suspected pneumothorax and contusion over the neck and thorax. Stable patients should be referred for prompt MDCT, and if there are signs of tracheobronchial injury (pneumomediastinum, spreading subcutaneous emphysema, persistent

pneumothorax despite tube thoracostomy), then laryngoscopy, or bronchoscopy should be immediately performed in order to localise the site of laceration. When it is necessary, fiberoscope guided intubation can be a feasible option, at least when laryngoscopy/bronchoscopy is applied. We have an opportunity to perform esophagoscopy if a posterior wall disruption is suspected and if diagnosis is unclear. In case an airway injury is confirmed, the patient should be transferred to the operating room as soon as possible. However, in some selected cases when special criteria are fulfilled, conservative therapy can be a valuable alternative choice. These conditions are: tear under 2 cm, or one-third of diameter, clinically stable patient, spontaneous breathing, or minimal ventilatory support, and no sign of mediastinitis, or sepsis. Conservative therapy should be suspended and surgical management should be carried out at any time when the normal healing process, or patient condition is not satisfactory.

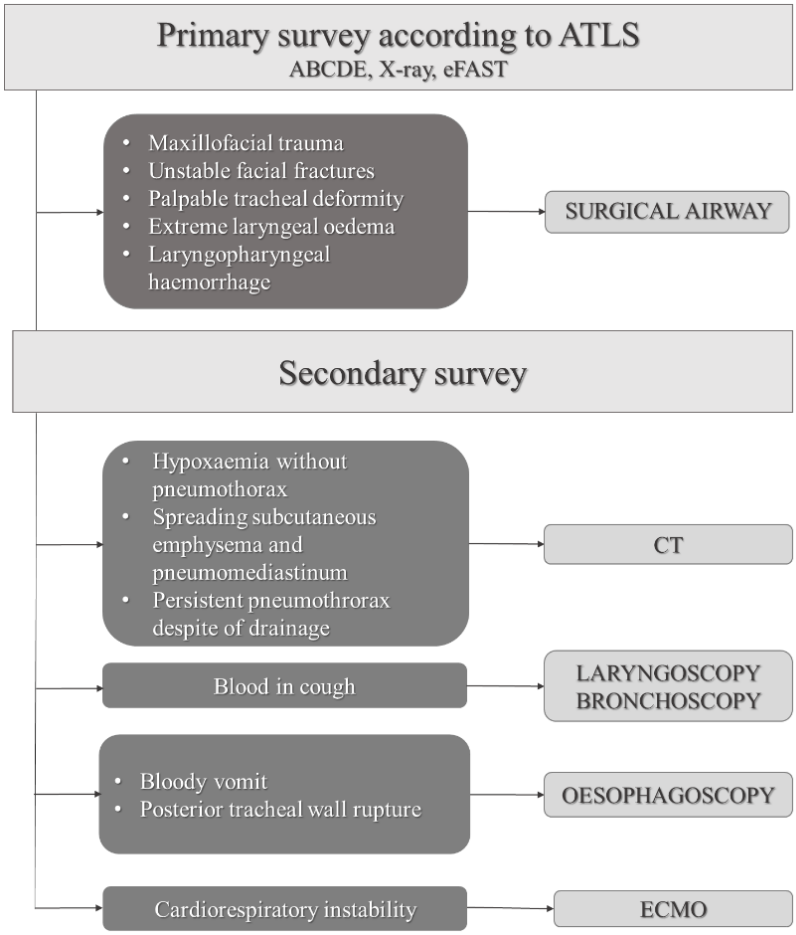

Figure 3. Diagnostic and emergency intervention flowchart

3.3. The role of an overinflated endotracheal tube cuff in the diagnosis of tracheal injuries

In this part, our purpose was to highlight the diagnostic role of a direct radiological sign, the overinflated endotracheal tube's cuff. We studied our patients who had an overdistended endotracheal balloon herniated outside the extratracheal space along the rupture of the tracheal wall. These overinflated balloons were detectable during each of our treated cases on radiographical imaging.

3.3.2. Results and experiences with overinflated balloon sign

We have successfully confirmed this sign in a child, though the same method is able to be used in adult patients, as we did in two cases treated in our institute. The first patient, a 9-year-old boy had an incomplete tracheal lesion occurred during a car accident. This lesion converted into a complete tracheal separation during rapid sequence intubation due to the insufflation of ETT cuff. CT showed an overinflated balloon with deep cervical emphysema (Figure 4.). The cuff had a diameter 2.56 cm, while his tracheal diameter was only 1.03 cm. During urgent surgery we saw the cuff lying between the two separate tracheal parts.

Figure 4. CT of a 9-year old boy: overinflated ETT cuff, and deep cervical emphysema, the tracheal wall can not be detected at the level of the balloon - Courtesy of Affidea Ltd.

Figure 5. Posteriorly herniated cuff showing a complete rupture of pars membranacea in the second patient - Courtesy of Affidea Ltd.

The second patient had also a car accident combined with a difficult intubational situation. ETT cuff had a 3.24 cm diameter on CT, while distal tracheal diameter was 1.53 cm. The ballon had a deformed shape due to the lesion on pars membranacea and due to its herniation inside the esophagus (Figure 5.). The third patient is unique, as her tracheal lesion was diagnosed by CXR after a prolonged intubation (Figure 6.). The hyperinflated ballon had a diameter of 3.5 cm on CXR.

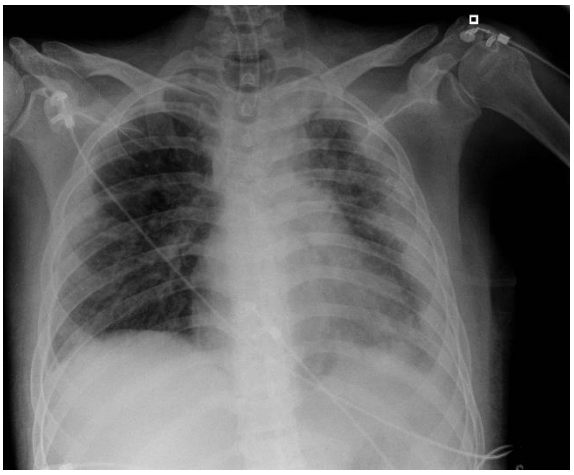

Figure 6. Overinflated ETT cuff seen on chest X-ray of the third patient.

Courtesy of Affidea Ltd.

3.3.3. Discussion

While blunt thoracic or neck trauma remains the most frequent cause of tracheobronchial lesions, a difficult intubation, or prolonged intubation associated with nasogastric tube insertion are also significant causative factors.

Traumatic tracheal injury followed by intubation is a major factor of complete tracheal laceration. Inflation of the endotracheal balloon at the level of the lesion may convert a partial injury to a complete disruption involving each layer of the wall, or even to complete transection resulting in two separate tracheal segments. In addition, a difficult intubation without trauma may also be responsible for tracheal damage.

Most cases happen during rapid sequence intubation, when an abrupt movement, or excessively inflated cuff with high pressure causes tracheal rupture. The most frequent predictive factors are several intubational attempts, repositioning of ETT without deflation of the cuff, cough during intubation, improper sized tube, abrupt movement of the head, or neck during intubation (Fan et al. 2004). Children are also often involved in postintubational injuries,

due to structural and physiological differences. For instance, funnel-shaped pediatric cricoid lumen, highly cartilaginous larynx, or weaker and more flexible wall.

Another significant cause is long-term intubation combined with nasogastric tube insertion, which can easily lead to tracheoesophageal fistula. The main cause is a high pressure ETT cuff, which maintains consistent tension on the tracheal wall, consequently causing local damage in blood supply, ischaemia, necrosis, and may finally lead to fistula formation.

The abovementioned mechanisms are the main reasons of tracheal injury, where the ETT cuff may potentially become overdistended and herniated through the tracheal wall. A partially herniated balloon may have a distorted shape instead of ball-shaped: it can be a Mickey-mouse or dumbbell mold, which can be easily detected (Chen et al. 2001).

This sign rarely occurs but adequately shows the exact level of the lesion, and suggests complete tracheal wall ruption. This overinflated cuff may be detectable even on CXR in some cases.

3.3.4. Summary the possibilities of overinflated balloon-sign

In summary, neck or thoracic blunt trauma and difficult intubation suggest the presence of a tracheal injury, especially in presence of subcutaneous emphysema. We should bear the possibility of tracheoesophageal fistula in mind during long-term intubation. On some case the only diagnostic sign is the overinflated balloon-sign seen on CXR or CT, thus early fiberoscopy can be carried out.

4. Summary and key results

I. We emphasized the difficulties of inflorescence aspiration, and revealed its most significant characteristics (Study 1). One of the most important point is that a negative bronchoscopic result and improved inflammatory markers do not exclude the presence of bronchial grass head, thus an asymptomatic child should be followed up thoroughly to recognise late complications in time. Regular diagnostic steps (such as chest ultrasound, or X-ray) should be performed to localise early inflammation. Chest CT is a useful tool to confirm diagnosis and identify the position of the foreign body. Its use is strongly recommended if pheripheral changes are noted on radiologic examinations.

II. Surgical removal is opted when the grass head stayes peripheral, and localised inflammation evolves, but prior to severe complications. Our aim was to enhance the importance of segmentectomy as a tissue-saving option, which has special relevance in children. When grass head is found in a completely localized inflammation site or abscess, anatomical segmentectomy with the removal of the affected bronchus may be the preferred choice. In case of extended inflammation and abscess, or in obscure conditions, lobectomy may be required. We also offer an achievable algorithm to define recommended treatment steps in the management of grass head aspiration, and to facilitate decision making (Study 1).

III. An algorithm for surgical or non-surgical management of blunt airway injury has been recommended. The most important steps of prompt primary management according to contemporary literature was summarized (Study 2.)..

IV. We defined the role of overinflated balloon sign, which may be the only radiological change in some TBI cases. It is a clearly visible, direct sign of tracheal injury, which can lead us to an early and definitive diagnosis. The balloon is able to show the exact location of the lesion, according which, targeted fiberoscopy can be performed. Although overinflated ballon seen in tracheobronchial injuries is not a new radiological concept, it is extremely underestimated and underreported. More emphasis should be placed on this sign during diagnostic procedures, and both radiologists and traumatologists should be aware of its role to achieve early

diagnosis and prompt treatment. Medical staff should be trained to avoid postintubation airway injury caused by a hyperinflated cuff.

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