Chapter

Controversies in Pneumothorax Treatment

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Abstract

Surgical intervention either by video-assisted thoracoscopic surgery (VATS) or open procedure proved its worth in reducing the incidence of recurrence in pneumothorax. However, many controversies surround the management of this common medical condition. Despite advances in knowledge and technology, chest physicians and surgeons could not be more divisive about the management of pneumothorax. There are no two thoracic surgical centres and possibly no two surgeons within the same hospital that agree on the management of the different aspects of pneumothorax. The variability in reported outcomes and the paucity of published multicentre randomised controlled trials (RCT) highlight the need for further studies investigating the best options for pneumostasis and pleurodesis. This chapter aims at discussing some of these controversies and reviews the literature at its current state of evidence.

Keywords: pneumothorax, video-assisted thoracic surgery, thoracotomy, pleurodesis, air leak, surgical emphysema, intercostal drain, COPD

1. Introduction

The Red Indians knew that the North American buffalo had a single pleural cavity. A single arrow to the chest was enough to collapse both lungs and expedite the death of the beast. On the other hand, the elephant is unique insofar as it is the only mammal whose pleural space is obliterated by connective tissue. This natural pleurodesis has been known for over 300 years but only recently explained [1]. Apparently, the elephant is the only mammal that can remain submerged far below the surface of the water while snorkelling. It is intriguing though that the foetal elephant has normal pleural spaces that obliterate later in gestation [2]. Humans are slightly luckier; they enjoy two pleural spaces separated by mediastinal structures; if one lung collapses, the other one sustains life. However, there are reports in the literature of some patients with pleuro-pleural congenital communications, presenting with simultaneous bilateral pneumothoraces, the so-called buffalo chest [3].

Humans collapse their lungs frequently, and the different ways we deal with this common condition match its frequency. There is bound to be differences in opinion, and the multicentre randomised controlled trials (RCT) have not come up with a solid protocol to guide management. There was no general agreement on therapy when Ruckley and McCormac of the Royal Infirmary of Edinburgh described the management of pneumothorax in 1966 [4]. There is no agreement at our present time still, despite the technological advances in our knowledge and the available randomised controlled trials. We could not agree more with Robert Cerfolio et al. on their statement that "although thoracic surgeons are the best trained physicians to manage chest tubes and pleural problems, they often do not speak the same language or recommend similar treatment algorithms even to each other" [5].

2. The physiology of respiration and pneumothorax

The pressure in the pleural space is determined by the difference between the lung elastic recoil and volume changes of the semi-rigid chest wall. The rib cage moves in three dimensions; the girdle handle movement of the ribs increases the anteroposterior and the lateral dimensions of the chest, whereas the piston-pump movement of the diaphragm leads to an increase in the vertical dimension of the chest cavity. The chest and diaphragm movements create a physiological negative pressure within the pleural space that forces the lung to change shape and volume with the respiratory cycle, resulting in inflation and deflation. Neutralising this negative pressure in the pleural space leads to lung collapse, as the elastic structure of the lung favours its collapse (recoil). Pneumothorax or air in the pleural space invariably leads to lung collapse. A thin film of fluid exists between the parietal and visceral pleurae to lubricate the sliding of these two structures, roughly 15 mls in a 70 kg adult person. The fluid is a microvascular filtrate produced by the parietal pleura and is cleared also by the parietal pleural lymphatics, a process similar to that in any other body organ.

3. Epidemiology and pathology of pneumothorax

The term "pneumothorax" was first coined by Itard (1803), but it was Laennec (1819) who described its clinical picture [6]. The term refers to "air in the pleural space". Pneumothorax is a significant global health problem ranking high on the list of common medical conditions, especially in the emergency department. In the United Kingdom (UK), the overall person consulting rate for pneumothorax (primary and secondary combined) was 24 per 100,000 each year for men and 9.8 per 100,000 each year for women. Hospital admissions for pneumothorax as a primary diagnosis occurred at an overall incidence of 16.7 per 100,000 per year for men and 5.8 per 100,000 per year for women. Mortality rates were 1.26 per million per year for men and 0.62 per million per year for women [7].

How does air gain access to the pleural space? Well, there are several mechanisms for this to happen. Communication between atmospheric air and the pleural space can result from trauma, penetrating injuries, impalements, stabs, bullets and ammunition. Fractured ribs puncturing the lung is a common cause for traumatic pneumothorax, recorded in our accident and emergency department (58 patients between January 2007 and 2018). Pneumothorax could also occur spontaneously and unprovoked due to a puncture in the visceral pleura, allowing air to pass from the open alveoli or small bronchi directly into the pleural space. Air can gain access to the pleural space from holes or tears in the aero-digestive system, such as neck stabs to the trachea, or a bronchopleural fistula due to tuberculosis or oesophageal rupture. Iatrogenic pneumothorax is caused by interventional procedures such as central line access, bronchoscopy, oesophagoscopy, insertion of stents, etc. Air in the peritoneal cavity can gain access to the chest through holes (fenestrations) in the diaphragm. This is one of the explanations of catamenial pneumothorax [8, 9]. Pneumothorax following substance abuse and recreational drugs, especially cocaine, cannabis and marijuana, has been associated with bullous disease and pneumothorax. However, many is the time bullae are absent and the pneumothorax is associated with pneumomediastinum or pneumopericardium. In these instances, air leak does not track to the lung surface, but instead it tracks into the connective tissue separating the lung segments and heads towards the hilum. To be comprehensive one should not forget about gas producing organisms which might generate air in the pleural space without any of the above breaches.

One-way valve motion of air from the lung to pleural space is a dreaded complication. It could lead to life-threatening tension pneumothorax. In this complication, not only the ipsilateral lung collapses, but the mounting pressure on the mediastinum pushes the central structures and restricts movement of the contralateral lung. Dislocation of the heart to the contralateral side might reach a critical degree that kinks the vena cavae and severely restricts venous return to the heart. This could result in hyperacute heart failure and death [10]. Cyanosis, sweating, severe tachypnoea, tachycardia and hypotension may indicate the presence of this medical emergency. Diagnosis of tension pneumothorax is clinical, and a needle or chest drain must be inserted, before obtaining a chest X-ray.

4. Classification and treatment

Eighty percent of pneumothoraces are secondary to trauma, and 20% spontaneous without provocation. Two big categories of spontaneous pneumothorax (SP) exist, with bimodal age distribution: primary SP 15–35 years of age and secondary SP +55 years of age. Pneumothorax is distinctly rare among children less than 15 years. Wilcox et al. reported 17 cases in 12 years [11]. Primary SP occurs on a background of normal lungs, whereas secondary SP is associated with diseased lungs, such as emphysema, chronic obstructive pulmonary disease (COPD), lung fibrosis and cystic fibrosis. Secondary SP is strongly related to cigarette smoking and associated with a higher morbidity and mortality compared to primary SP. Primary pneumothorax has been associated with rupture of apical bullae or blebs (**Figure 1**) and has a 54.2% chance of recurring after the first episode [12]. In the UK the male-to-female ratio is 3:1 [7].

The British Thoracic Society (BTS) has published an updated summary of the management of pneumothorax in 2010 [10]. Similar guidelines were published earlier by the American College of Physicians in 2001 [13] and later by the European Task Force in 2015 [14]. Breathlessness and the size of pneumothorax influence the management of SP. There is a general consensus that conservative management should be tried in the first episode, as conservative management of small pneumothoraces has been shown to be safe [10, 15]. Surgery proved that recurrence is less, and video-assisted

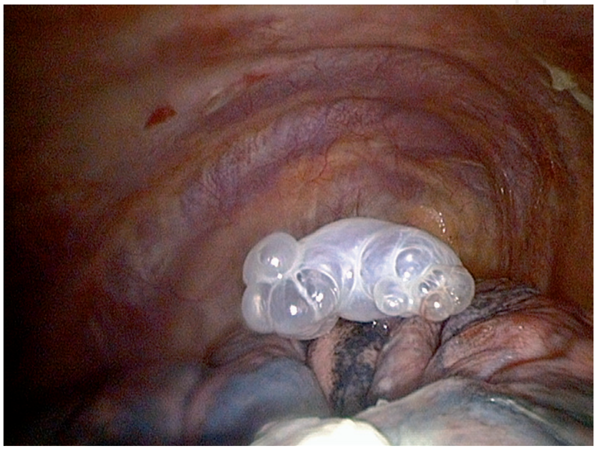

Figure 1.
Single apical bulla, a common cause of primary spontaneous pneumothorax.

thoracoscopic surgery (VATS) has opened the option of treating even the first-time pneumothorax on semi-urgent basis [16–18]. However, there has been no general agreement on the most effective type of surgery or that which is most accepted by patients. Ostensibly such a choice should result in the least incidence of recurrence. Axillary thoracotomy, full posterolateral thoracotomy, limited lateral muscle sparing mini-thoracotomy and triportal, biportal and needlescopic uniportal VATS have all been utilised [10, 18, 19]. A subxiphoid approach has also been tried and reported [20]. These operations have two objectives: firstly, to deal with the source of air leak (pneumostasis) by bullectomy/blebectomy, etc. and, secondly, to obliterate the pleural space leading to permanent adherence of the lung to the chest wall (pleurodesis or symphysis). In essence, we strive to emulate the elephant pleural space and prevent recurrence.

In the 1950s and 1960s, the treatment varied from extremely conservative bed rest only to early insertion of a Malecot catheter through the second intercostal space anteriorly (very painful!) and thoracotomy or bilateral thoracotomies for non-resolving cases [4]. Today's management is nowhere near that, and minimal access surgery or VATS has taken up the management of pneumothorax to a new level [19].

Several randomised and non-randomised trials (RCT) looked into the difference between the optimal surgical techniques in SP [21]. There is no evidence to support the superiority of either VATS or open thoracotomy in the treatment of pneumothorax because the number of randomised trials is sparse and they are underpowered to detect any meaningful difference. Barker et al. published an important meta-analysis of four randomised and 25 non-randomised studies performed in 2007 comparing VATS to open thoracotomy [22]. Complex statistical tests of homogeneity and sensitivity analysis with a hypothetical model biased against open surgery were undertaken. RCT without comparative control groups were excluded. They reported a worrying fourfold increase in the recurrence of pneumothorax following VATS procedure compared to thoracotomy. Their relative risk (RR) favours open surgery; however, postoperative pain could not be assessed since most studies did not report this outcome. Neither did they report on length of hospital stay, due to severe heterogeneity in reporting. A similar previous study by Sedrakyan et al. looking only at the randomised trials did not show this difference [23]. The conclusion is that recurrence following VATS averaged 4.5%, whereas that following mini-thoracotomy was 2.3%. Waller et al. randomised 30 patients to VATS and 30 to open thoracotomy [24]. They concluded that VATS is superior to thoracotomy in the treatment of primary SP but had a higher recurrence rate in secondary SP. Ayed et al. in a randomised trial found VATS superior to thoracotomy but reported higher recurrence rates [25]. A best evidence topic by Vohra et al. reiterated on the superiority of VATS insofar as pain control, less hospital stay and better early lung functions [26]. It stopped short of recommending open thoracotomy for the treatment of this condition, quoting the Barker study. It is hard to imagine that any contemporary surgeon or clinician would recommend open thoracotomy over VATS to their patients, based on this evidence. VATS is the most favoured approach by patients. The Barker study, despite their extensive heterogeneity tests, has lumped together widely heterogeneous approaches to the previously described objectives of pneumostasis and pleurodesis. Great variations exist when it comes to what surgeons do inside the chest, a fact not factorised in the meta-analysis. In our opinion, it should not matter in any way or form how one enters the chest, whereas it matters what one does once inside the chest. Indeed, the Barker study showed that in studies that did the same pleurodesis through two different forms of access, the relative risk (RR) of recurrences in patients undergoing VATS compared with open surgery was similar [22].

With regard to pneumostasis, the practice varies widely between doing nothing (if a bulla is not found) and performing a variety of procedures. These include blind wedge of the lung apex (apicoectomy), ligation of bulla, tying, stitching, stapling, diathermy, applying silver nitrate and lasering among other methods [27–29]. Each of these variants might have a subgroup, for example, stapling with or without buttressing or covering the stapling line to reduce postoperative air leak. Should the treated bulla site (staple line) be covered with bioglue or a sealant agent? Which one? Does a pleural tent work? [30–32]. This choice could be an attractive option for ventilated patients in intensive care and for patients with severe secondary SP [33].

It is conceivable that some clinical importance is attached to the function of the pleura and the preservation of this function is advocated when a single apical bulla is all that explains the pneumothorax. In addition, pleurodesis is not without its complications. It can induce severe postoperative chest pain and increase the risk of bleeding and unscheduled return to theatre. In addition, it poses difficulties with subsequent thoracic surgery, e.g. if lung transplantation will be required later in life. Following this line of thinking, RCT have looked into the difference between bullectomy alone and bullectomy coupled with pleurodesis [34–36]. The general consensus, bar the Korean trial, is that pleurodesis with bullectomy reduces recurrence.

We then come to the second objective of pleurodesis. Several options exist, scratching, abrasion, partial or semitotal pleurectomy and pleural sclerosing agents [37]. Several chemical agents have been described: talc, tetracycline, minocycline, autologous blood, dextrose, etc. [38–41]. The use of chemical pleurodesis is tied to the complication of empyema, which adds insult to injury. The bottom line is that none of these techniques or agents could give a 100% guarantee of freedom from recurrence. Heterogeneity in the methodology of RCT leads to significant differences in outcomes. Nor does the meta-analysis of Barker take into account the human factor of surgical experience and learning curves. It is not useful to lump together trainees at the beginning of their VATS learning curve together with experienced surgeons in this field. Unsupervised trainees are bound to have high recurrence rates, skewing the figures. Familiarity with small details that might avert recurrence is a function of experience. Meticulous examination of the lung surfaces is vital to unveil bullae in other lobes. Seventy percent of postoperative pneumothorax recurrences probably developed because of overlooked bullae and incomplete resection of bullae in the early period of VATS experience [42]. Equally important is to scrutinise the diaphragmatic surface for fenestrations in the child-bearing age of ladies [43]. Identification of the lung margin rosary of blebs and the knowledge of how to deal with them prevent recurrence (**Figure 2**). Detailed knowledge of the stapling devices, their colour code and sizes is mandatory, as well as the realisation that the intersection point of two stapling lines is the weakest link for potential air leak. How many of us perform the bubbling test (underwater testing for air leak before and after pneumostasis)? It seems logical to make sure that there is no air leak by the end of pneumostasis, to ensure the complete expansion of the lung and guarantee pleurodesis (**Figure 3**). Many is the time we found the source of air leak hiding within an azygos lobe (**Figure 4**).

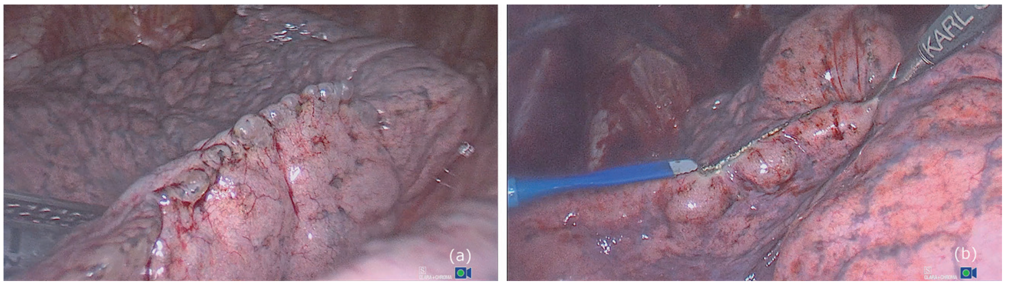

Figure 2.
(a) Rosary of marginal blebs (beads), which can lead to recurrent pneumothorax. (b) Contact diathermy obliterates them and forms a scar at the margin.

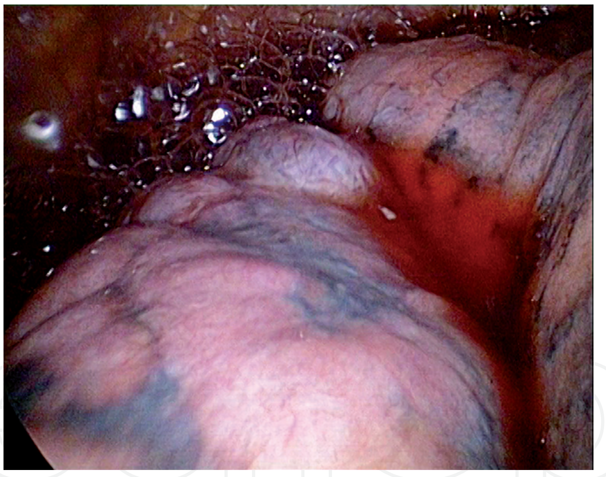

Figure 3.
Bubbling test after stapling an apical bulla. More stapling was needed until the lung was watertight.

Figure 4.
Multiple apical bullae hiding within an azygos lobe.

From the above discussion, it is unreasonable to assign increased recurrence rates to the way we access the chest cavity. Access should never matter. Minimal access surgery has leapt to the forefront of access choices preferred by patients. It has proven to result in less postoperative pain, less usage of analgesics and anti-emetics, early recovery, less stay in hospital and early return to work. Therefore, it is very unlikely to advocate open thoracotomy as a first-choice procedure on the basis of the previously mentioned systematic reviews alone.

5. Controversies surrounding chest drain insertion

Who should and who should not insert a chest drain? There is no consensus on this matter. However, surgical abilities even of a minor order are required to safely insert a chest drain; after all this is a surgical procedure. Therefore, proctored training is mandatory before any trainee is allowed to do it alone. Should one be certified before being allowed to perform this procedure unsupervised? This is debatable. Thoracic surgeons and their trainees are the most experienced to deal with chest drains; however, the idea that surgeons should look after all chest drains in the hospital is ludicrous and logistically unachievable.

The technique of drain insertion keeps changing. The BTS guidelines in 1993 recommend using a trocar (harpoon!); however, deaths had been reported from their use, and subsequently, the BTS changed its recommendations in an updated report in 2010 [10, 44]. Harris et al. reported on current practice and adverse incidents related to chest drains at 148 acute hospitals in the UK between 2003 and 2008 [45]. Thirty-one cases of chest drain misplacement were reported with seven deaths. Misplaced drains were inserted in the liver (10), peritoneal space (6), heart (5), spleen (5), subclavian vessels (2), colon (1), oesophagus (1) and inferior vena cava (1). One of my previous mentors at the University Hospital of Wales, the late Mr. Ian Breckenridge, has previously stated that "I regard trocar systems as potentially lethal weapons, and their misuse has been responsible for the few fatalities that I have seen, when heart, lung and liver have been lacerated" [46]. Similar serious injuries and fatalities were reported elsewhere [47–57]. Trocars are now banned from the UK. It is stating the obvious that the litigation expenses accompanying these cases are exorbitantly costly to the hospital trust and the taxpayer in the UK.

Clinicians differ about the choice of drain type and size [58]. Physicians and interventional radiologist tend to choose small calibre drains (medical drains), such as pigtails, 12F or 14F, whereas surgeons tend to put larger tubes +24F (surgical drains) [10, 59, 60]. Drain kinking, blockage and accidental dislodgment are common complications of small-bore drains (**Figure 5**). Per contra, Riber et al. in a retrospective study concluded that surgical (wide-bore) drains significantly increase the dwell time in primary SP [61]. Although they may be effective in managing pleural infection and less painful than large drains, small-bore drains may be less effective for pleurodesis [58]. The war between chest physicians and chest surgeons around the calibre of the chest drain will continue. Chest physicians have evidence that for air drainage size does not matter and a 16F drain is as good as any. Surgeons see the dysfunctional spectrum of these drains and correct the situation by inserting larger drains.

A persistent air leak with or without re-expansion of the lung is the usual reason for consideration of the use of suction, although there is no evidence for its routine use. The optimal level of suction on the drain is controversial, and so is the optimal time of its removal [62–66]. Data on the actual intrapleural pressure during the use of these systems is lacking [67]. Most of the knowledge is extrapolated from studies after lung resection, and protocols for pneumothorax drain insertion are scanty. It seems that the practice is a personal preference rather than evidence driven. We tend to believe that initial suction will guarantee the full expansion of lung and improves the chances of pleurodesis.

Recent introduction of the digital drainage systems seems to offer more physiological and dynamic mobile suction, assisting in enhanced early recovery [68, 69]. Its

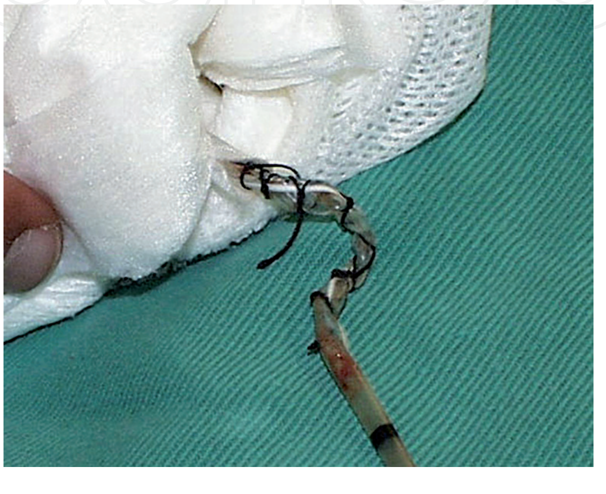

Figure 5.
Dysfunctional medical drain (14F) removed to insert a surgical drain (28F) for pneumothorax. Twisting and overtight anchorage stitch obliterated the drain lumen.

routine use has been recommended by the National Institute for Health and Clinical Excellence (NICE) after VATS pulmonary resections [70]. For how long should we leave the drain? One day, 1 week or more? Some believe (including the author) that if the drain is not serving its purpose, it should be removed. It is our practice to remove the drain the day following the surgery, provided the digital drain registers absence of air leak and the lung is fully expanded on the chest X-ray. The backdrop of such an approach is to accept reinsertion of the drain in a minority of patients when we get it wrong. The patient is allowed home after a normal chest X-ray has followed the drain removal. Others are more conservative and of the opinion that for the pleurodesis to succeed, the drain should remain in situ 3–7 days. We tend to send patients home with a Heimlich valve (flutter bag) if air leak persists more than 3 days and follow them weekly in the outpatient clinic. There are no RCTs to compare drain dwell times, and therefore general rules apply. In the absence of air leak while suction is off, and the lung is fully expanded on the chest X-ray the drain could safely be removed, otherwise; recurrence of pneumothorax is guaranteed.

There is a general consensus that drains should never be clamped [10, 71]. However, some of us do clamp drains and send patients to the radiology department for a chest X-ray, in preparation for removing the drain *despite* the air leak. It must be emphasised that this management should remain selective. This "provocative" approach in removing the drain despite air leak was described before by Kirschner et al. and Cerfolio et al. [72, 73]. If the chest X-ray shows the lung stuck to the chest wall after 2 weeks of tube time, we clamp the tube and send the patient for another X-ray. If the patient is clinically well and there is no change in lung expansion, then the drain is safely removed without bothering to close the drain site, which is usually either infected or has necrotic margins that take stitches badly. A pressure dressing is all that is needed. The stuck lung does not collapse, and the drain site closes in a week or two by secondary intention. The patient has to be reassured about the hissing sound through the drain site, which stops within a week or so.

To complicate matters further, air could entrain back into the chest at the time of drain removal. This usually leads to a small residual pneumothorax, which does not expand on subsequent radiological examination. It is important to realise the difference between erroneous drain removal and recurrence of genuine air leak. The incidence of this complication is technique-dependant and proportional to the experience of the staff member allocated for this task. Instructions given to the patient at the time of removing the drain are crucial. Again RCT about removing chest drains on full inspiration, full expiration, mid inspiration or Valsalva manoeuvre found no statistical difference, and therefore no evidence-based practice could be extrapolated [73, 74]. The rate of absorption of air in the chest is roughly 1–2% of the volume of the hemithorax every 24 hours, and complete re-expansion usually takes 2–7 weeks [75]. However, this might be too late for pleurodesis. By that time the parietal pleura (in the case of pleurectomy) would have healed, and the partially collapsed lung would not stick to the chest wall. Likewise, pleurodesing agents might be diluted or washed away by the reactive effusion, resulting in treatment failure.

From the above discussion, it is safe to conclude and agree with Lim that "No single aspect of postoperative care in general thoracic surgery is subject to more variation than the management of chest drains, … yet almost all thoracic surgeons and institutions manage chest drains differently" [76].

6. Pneumothorax and pregnancy

Spontaneous pneumothorax during pregnancy is rare but not unusual [77, 78]. Notoriously pneumothorax recurs during pregnancy and poses risks to the mother and foetus during labour. In addition, exposure to radiation of the X-rays in the first trimester is tied to foetal deformities and abnormalities. There is no unified evidence-based practice to guide management in this scenario. Historically it was managed by intercostal drainage for the rest of the pregnancy duration, thoracotomy at any stage, premature induction of labour or caesarean section. The clinician must be aware that even in the first trimester, the diaphragm moves cephalad approximately 4 cm. The classical landmarks for drain insertion do not apply.

The most contemporary recommendation of management is a conservative approach. Expectant management is recommended if the mother is not dyspnoeic and there is no foetal distress and the pneumothorax on the chest X-ray is not significant (<2 cm). Symptomatic mothers could have needle aspiration or drain insertion to resolve the pneumothorax. There is no consensus as what to do with non-resolving pneumothorax, but in our centre, we tend to assess the risk in conjunction with the obstetrician's advice and perform a VATS bullectomy and partial parietal pleurectomy. This is safe in the first trimester but should be avoided after that.

With regard to advice to the risk during labour, we adopt the one given by Lal et al. and the BTS guidelines [10, 79]. Elective-assisted delivery (forceps or ventouse extraction) at or near term is recommended, with regional (epidural) anaesthesia. Less maternal effort is required with forceps delivery, which theoretically reduces the chance of recurrence. Close cooperation between the respiratory physician, obstetrician and thoracic surgeon is essential, requiring delivery to be undertaken in a tertiary referral centre with all three specialties under one roof. If a caesarean section is unavoidable, then a spinal anaesthetic is preferable to a general anaesthetic. To avoid desaturation and tension during general anaesthesia, a prophylactic intercostal drain could be considered as a safety measure. It is advisable that the mother should undergo elective VATS procedure after convalescence due to the risk of recurrence in subsequent pregnancies.

7. Pneumothorax and air travel

Commercial air traffic is on the rise. The number of medical emergencies on-board aircraft is increasing as the age-increasing general population becomes more mobile and adventurous. Travellers with respiratory diseases are at particular risk for in-flight events. Exposure to lower atmospheric pressure in a pressurised cabin at high altitude may result in pneumothorax. Gas expansion within enclosed spaces in the human body could expand by 25–30% at the typical cruising altitude of a commercial airline flight, causing significant hypoxia. Patients at risk are those with bullae, cystic lung disease, lymphangioleiomyomatosis (LAM), pulmonary Langerhans cell histiocytosis, cystic pulmonary adenomatoid malformation (CPAM) and cystic bronchiectasis [80].

The currently available guidelines are admittedly based on sparse data and include recommendations to delay air travel for 1–3 weeks after thoracic surgery or resolution of the pneumothorax [80]. No fatalities have been reported due to pneumothorax on-board aviation generally; however, true incidence of specific illnesses associated with air travel has been difficult to assess.

The diagnosis of pneumothorax can be career limiting in the US Air Force. Once an SP has been diagnosed in an individual, he/she will be grounded from further flight duties until either 9 years have elapsed without a recurrence or there has been a bilateral parietal pleurectomy [81].

Barotrauma during or after scuba diving (also on the rise) can rarely lead to pneumothorax, especially on sudden ascent not allowing time for equilibrium. The data is sparse, and there is no solid recommendation about this sport in the literature. Snorkelling sport up to a depth of 10 m does not seem to increase the risk of pneumothorax.

8. Genetics and pneumothorax

A lot of work needs to be done in the field of spontaneous pneumothorax that runs in families. Genetic profiling in patients presenting with pneumothorax might be indicated, in the hope of finding defective genes that expose conditions such as Marfan, Ehler Danlos and Birt-Hogg-Dubé syndromes [82]. These have one thing in common, defective connective tissue. Patients may or may not have pre-existing lung cysts before their pneumothoraces, which can be bilateral and recurrent. Risk stratification of other siblings needs to be calculated and predicted [83]. The importance of this subject is realised by frequent flyers, pilots, airhostesses and scuba divers. They need to know the risk and whether prophylactic procedures would be a wise thing to go for. By the same token patients who are expected to require lung transplantation at one stage in their life, such as cystic fibrosis patients, require special consideration of treatment. Pleurodesis seems to render transplantation a difficult task, but this is not a prohibitive contraindication. It might be prudent to discuss the case with a lung transplantation centre before embarking on such treatment [84].

9. Complications of pneumothorax treatment

Getting the treatment of pneumothorax right is of paramount importance. The decision of which procedure to go for might not be crucial to fit patients but might endanger the lives of compromised patients. Patients with cardio-pulmonary compromise, severe COPD and emphysema might have very little cardiopulmonary reserve, so much so they tolerate lung collapse poorly. Air leak is known to be a killer after lung volume reduction surgery for severe COPD patients. Assessment for general anaesthesia is essential for compromised patients. Consideration of alternative local or spinal/extrapleural analgesia might be required.

Insertion of intercostal tubes under non-sterile conditions leads to infection and empyema with formation of a thick rind over the visceral pleura, trapping the lung in a collapsed position. Lung re-expansion is formidable in this scenario. Formal thoracotomy and lung decortication might be required to re-inflate the lung and prevent chronic empyema with a permanently infected cavity. We never push an intercostal drain few centimetres into the chest (as possibly suggested by the chest X-ray). Pushing a bit of the unsterile part of the tube inside the chest leads to empyema. It is, however, safe to shorten a drain by pulling it out and re-anchor it with a fresh stitch.

Severe surgical (subcutaneous) emphysema could complicate insertion of a chest drain. The clinician should be aware of the position of the last lateral holes of the tube, which should always be inside the bony chest (**Figure 6**). Until the advent of the digital systems, which tell us exactly how much air is leaking, quantifying air leak visually was a subjective bias. No leak, countable bubbles, and coalesced bubbles were the measures of air leak in the underwater seal systems. This subjective assessment leads to days of unnecessary drain dwell time. Urgency of this complication is highlighted in ventilated patients in the intensive care. Insertion of a second large intercostal drain, subcutaneous cannulae and subcutaneous small-bore drains on suction has all been tried with varying success. It should be noted that fixed wall suction in these cases might lead to tension pneumothorax and the drain must be on gravity mode without suction. Information about how to deal with surgical emphysema is very sparse, and the management of severe air leak and surgical emphysema is controversial.

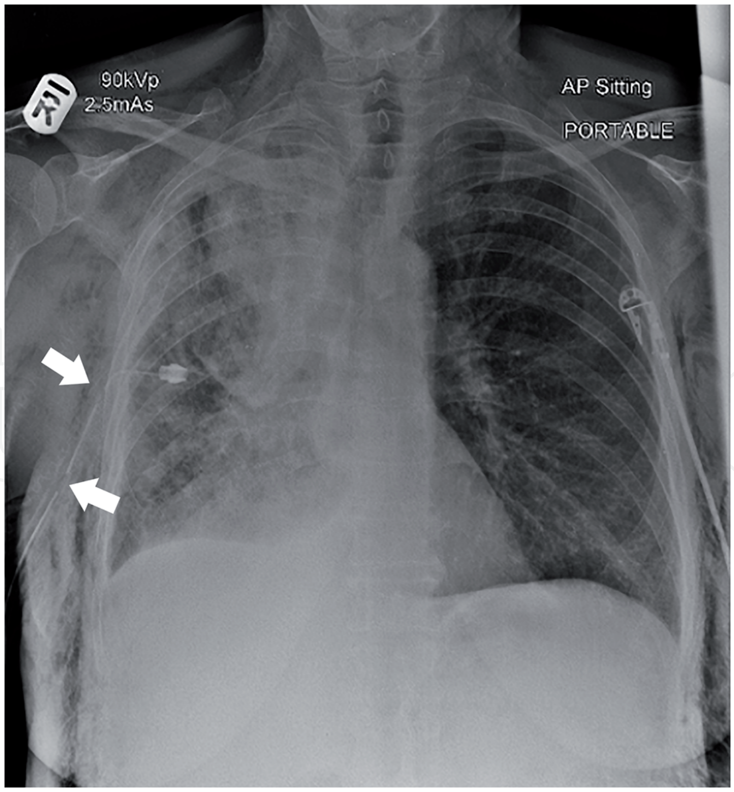

Figure 6.
Lateral holes of the intercostal drain are outside the chest, a common cause for surgical emphysema.

Should the need arise for a second drain to replace a dysfunctional one due to, e.g. blockage or kinking, the second drain should not be introduced at the site of the removed first one to reduce the risk of empyema. A fresh stab wound is better in the long run.

And last but not the least is the question of pain and analgesia which should be carefully worked out before and after surgical procedures or ward bedside pleurodesis. Talc pleurodesis is known to cause severe pain that can result in cardiac arrest, and it is, therefore, prudent to pre-empt it by administration of opioid analgesia before introducing the talcum powder or slurry [85]. The question of whether postoperative non-steroidal analgesia (NSAID) is detrimental to pleurodesis is not resolved. RCT have shown a negative predictive effect of such drugs to pleurodesis and increased incidence of recurrence. Therefore, it is best to avoid them in the immediate postoperative period [86, 87].

10. The future

There is a trend for single-port VATS procedures under sedation/epidural anaesthesia [88]. The so-called tubeless surgery has a lot to commend, avoiding the risk of general anaesthesia, early recovery and discharge from hospital. However, they have the inherent caveat of suitability for selected patients. Understanding of the technique and cooperation in case of conversion to general anaesthesia is mandatory.

Advances in diagnostic techniques have increasingly allowed the identification of lung abnormalities in patients previously labelled as having a primary spontaneous pneumothorax. This allowed different managements from that of simple pneumothorax. A good example of this is demonstrated in secondary SP. The choices for lung reduction surgery and the advent of valves have revolutionised the options for this category of severe COPD [89]. Bronchial valves have been used to treat prolonged air leak, especially in ventilated patients in the intensive care, with large air leaks and inflated lungs [90, 91]. In future we might see expansion of the use of "easily removable" and temporary bronchial valves especially in the subgroup of patients who are high risk for surgical intervention.

As the cost of VATS surgery comes down, as well as capacity increases in tertiary referral hospitals, we will see more of the operative treatment for first episode of spontaneous pneumothorax, on a semi-urgent basis (1–2 days from start of episode). Better risk stratification will identify those at high risk of recurrence and put them forward for early operation.

The economic reality of reducing cost and the technological advances might team up to drive change. It is possible to see scenarios whereby pneumothorax is treated as a day case. Patients are discharged home on the same operative day, with a chest drain in situ. They would be asked to enter the reading of air flow from the digital device daily. The information is transmitted by a social media application such as WhatsApp to the hospital which instructs the patient to call in for removal of the drain. Better still, the visiting district nurse could pay the patient a visit at home to remove the drain without the need for readmission. Fiction? Perhaps not!

Currently robotic surgery is too expensive for this type of surgery, and we have not come across any meaningful publications in this regard. However, when robotic expenses come down in due course, we might see a surge in the use of the robot.

11. Conclusion

Many controversies surround the management of pneumothorax. Surgical intervention either by VATS or open procedure leads to less incidence of recurrence. The variability in reported outcomes and the paucity of published multicentre randomised controlled trials highlight the need for further studies to investigate the best options for pneumostasis and pleurodesis.

Conflict of interest

I have previously received honoraria for providing educational material, presentations and lectures for Ethicon (Johnson & Johnson), Medtronic-Covidien and Karl Storz.

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References

[1] West JB. Snorkel breathing in the elephant explains the unique anatomy of its pleura. Respiration Physiology. 2001;**126**(1):1-8

[2] Eales NB. XI—The anatomy of a Fœtal African elephant, Elephas africanus (Loxodonta africana). Part III. The contents of the thorax and abdomen, and the skeleton. Earth and Environmental Science Transactions of the Royal Society of Edinburgh. 1929;**56**(1):203-246

[3] Hartin DJ, Kendall R, Boyle AA, Atkinson PRT. Case of the month: Buffalo chest: A case of bilateral pneumothoraces due to pleuropleural communication. Emergency Medicine Journal. 2006;**23**(6):483-486

[4] Ruckley CV, McCormack RJM. The management of spontaneous pneumothorax. Thorax. 1966;**21**: 139-144

[5] Cerfolio RJ, Bryant AS. The management of chest tubes after pulmonary resection. Thoracic Surgery Clinics. 2010;**20**(3):399-405

[6] Laennec RTH. Traité du Diagnostic des Maladies des Poumons et du Coeur. Tome Second, Paris: Brosson and Chaudé; 1819. p. 4

[7] Gupta D, Hansell A, Nichols T, et al. Epidemiology of pneumothorax in England. Thorax. 2000;**55**:666-671

[8] Alifano M, Jablonski C, Kadiri H, Falcoz P, Gompel A, Camilleri-Broet S, et al. Catamenial and noncatamenial, endometriosis-related or nonendometriosis-related pneumothorax referred for surgery. American Journal of Respiratory and Critical Care Medicine. 2007;**176**:1048-1053

[9] Korom S, Canyurt H, Missbach A, et al. Catamenial pneumothorax revisited: Clinical approach and systematic review of the literature. The Journal of Thoracic and Cardiovascular Surgery. 2004;**128**:502-508

[10] MacDuff A, Arnold A, Harvey J. Management of spontaneous pneumothorax: British Thoracic Society pleural disease guideline 2010. Thorax. 2010;**65**:ii18-ii31

[11] Wilcox DT, Glick PL, Kramanoukian HL, et al. Spontaneous pneumothorax: A single institution 12-year experience in patients under 16 years of age. Journal of Pediatric Surgery. 1995;**30**:1452-1454

[12] Sadikot RT, Greene T, Meadows K, Arnold AG. Recurrence of primary spontaneous pneumothorax. Thorax. 1997;**52**(9):805-809

[13] Baumann MH, Strange C, Heffner JE, et al. AACP pneumothorax consensus group. Management of spontaneous pneumothorax: An American College of Chest Physicians Delphi consensus statement. Chest. 2001;**119**:590-602

[14] Tschopp JM, Bintcliffe O, Astoul P, Canalis E, Driesen P, Janssen J, et al. ERS task force statement: Diagnosis and treatment of primary spontaneous pneumothorax. The European Respiratory Journal. 2015;**46**(2):321-335

[15] Stradling P, Poole G. Conservative management of spontaneous pneumothorax. Thorax. 1966;**21**: 145-149

[16] Torresini G, Vaccarili M, Divisi D, Crisci R. Is video-assisted thoracic surgery justified at first spontaneous pneumothorax? European Journal of Cardio-Thoracic Surgery. 2001;**20**(1):42-45

[17] Schramel FM, Sutedja TG, Braber JC, Van Mourik JC, Postmus PE.

Cost effectiveness of video-assisted thoracoscopic surgery versus conservative treatment for first time or recurrent spontaneous pneumothorax. The European Respiratory Journal. 1996;**9**:1821-1825

[18] Al-Mourgi M, Alshehri F. Video-assisted thoracoscopic surgery for the treatment of first-time spontaneous pneumothorax versus conservative treatment. International Journal of Health Sciences. 2015;**9**(4):428-432

[19] Ooi A, Ling Z. Uniportal video assisted thoracoscopic surgery bullectomy and double pleurodesis for primary spontaneous pneumothorax. Journal of Visceral Surgery. 2016;**26**(2):17

[20] Li L, Tian H, Yue W, Li S, Gao C, Si L. Subxiphoid vs intercostal single-incision video-assisted thoracoscopic surgery for spontaneous pneumothorax: A randomised controlled trial. International Journal of Surgery. 2016;**30**:99-103

[21] Sudduth CL, Shinnick JK, Geng Z, McCracken CE, Clifton MS, Raval MV. Optimal surgical technique in spontaneous pneumothorax: A systematic review and meta-analysis. The Journal of Surgical Research. 2017;**210**:32-46

[22] Barker A, Maratos EC, Edmonds L, et al. Recurrence rates of video-assisted thoracoscopic versus open surgery in the prevention of recurrent pneumothorax: A systematic review of randomised and non-randomised trials. Lancet. 2007;**370**:329-335

[23] Sedrakyan A, van der Meulen J, Lewsey J, Treasure T. Video assisted thoracic surgery for treatment of pneumothorax and lung resections: Systematic review of randomised clinical trials. British Medical Journal. 2004;**329**(7473):1008

[24] Waller DA, Forty J, Morritt GN. Video-assisted thoracoscopic surgery versus thoracotomy for spontaneous pneumothorax. The Annals of Thoracic Surgery. 1994;**58**:372-376

[25] Ayed AK, Al-Din HJ. Video-assisted thoracoscopy versus thoracotomy for primary spontaneous pneumothorax: A randomized controlled trial. Medical Principles and Practice. 2000;**9**:113-118

[26] Vohra HA, Adamson L, Weeden DF. Does video-assisted thoracoscopic pleurectomy result in better outcomes than open pleurectomy for primary spontaneous pneumothorax? Interactive Cardiovascular and Thoracic Surgery. 2008;**7**:673-677

[27] LoCicero J, Hartz RS, Frederikson JW, et al. New applications of laser in pulmonary surgery (hemostasis and sealing of air leaks). The Annals of Thoracic Surgery. 1985;**40**:546-550

[28] Marcheix B, Brouchet L, Renaud C, et al. Videothoracoscopic silver nitrate pleurodesis for primary spontaneous pneumothorax: An alternative to pleurectomy and pleural abrasion? European Journal of Cardio-Thoracic Surgery. 2007;**31**(6):1106-1109. DOI: 10.1016/j.ejcts.2007.03.017

[29] Potaris K, Mihos P, Gakidis I. Experience with an albumin-glutaraldehyde tissue adhesive in sealing air leaks after bullectomy. The Heart Surgery Forum. 2003;**6**(5):429-433

[30] Matar AF, Hill JG, Duncan W, et al. Use of biological glue to control pulmonary air leaks. Thorax. 1990;**45**:670-674

[31] Hong KP, Kim DK, Kang KH. Staple line coverage with a polyglycolic acid patch and fibrin glue without pleural abrasion after thoracoscopic bullectomy for primary spontaneous pneumothorax. Korean Journal of

Thoracic and Cardiovascular Surgery. 2016;**49**(2):85-91

[32] Lee S, Kim HR, Cho S, Huh DM, Lee EB, Ryu KM, et al. Korean pneumothorax study group. Staple line coverage after bullectomy for primary spontaneous pneumothorax: A randomized trial. The Annals of Thoracic Surgery. 2014;**98**(6):2005-2011

[33] Nicotera SP, Decamp MM. Special situations: Air leak after lung volume reduction surgery and in ventilated patients. Thoracic Surgery Clinics. 2010;**20**(3):427-434

[34] Ferguson LJ, Imrie CW, Hutchison J. Excision of bullae without pleurectomy in patients with spontaneous pneumothorax. The British Journal of Surgery. 1981;**68**:214-216

[35] Horio H, Nomori H, Kobayashi R, Naruke T, Suemasu K. Impact of additional pleurodesis in video-assisted thoracoscopic bullectomy for primary spontaneous pneumothorax. Surgical Endoscopy. 2002;**16**(4):630-634

[36] Nakanishi K. Long-term effect of a thoracoscopic stapled bullectomy alone for preventing the recurrence of primary spontaneous pneumothorax. Surgery Today. 2009;**39**(7):553-557

[37] Min X, Huang Y, Yang Y, Chen Y, Cui J, Wang C, et al. Mechanical pleurodesis does not reduce recurrence of spontaneous pneumothorax: A randomized trial. The Annals of Thoracic Surgery. 2014;**98**(5):1790-1796

[38] Chung WJ, Jo W, Lee SH, Son HS, Kim KT. Effects of additional pleurodesis with dextrose and talc-dextrose solution after video assisted thoracoscopic procedures for primary spontaneous pneumothorax. Journal of Korean Medical Science. 2008;**23**(2):284-287

[39] Hallifax RJ, Yousuf A, Jones HE, et al. Effectiveness of chemical pleurodesis in spontaneous pneumothorax recurrence prevention: A systematic review. Thorax. 2017;**72**:1121-1131

[40] Shackcloth MJ, Poullis M, Jackson M, Soorae A, Page RD. Intrapleural instillation of autologous blood in the treatment of prolonged air leak after lobectomy: A prospective randomized controlled trial. The Annals of Thoracic Surgery. 2006;**82**(3):1052-1056

[41] Milanez JR, Vargas FS, Filomeno LT, et al. Intrapleural talc for prevention of recurrent pneumothorax. Chest. 1994;**106**:1162-1165

[42] Haraguchi S, Koizumi K, Hioki M, Orii K, Kinoshita H, Endo N, et al. Postoperative recurrences of pneumothorax in video-assisted thoracoscopic surgery for primary spontaneous pneumothorax in young patients. Journal of Nippon Medical School. 2008;**75**(2):91-95

[43] Cowl CT, Dunn WF, Deschamps C. Visualisations of diaphragmatic fenestration associated with catamenial pneumothorax. The Annals of Thoracic Surgery. 1999;**68**:1413-1414

[44] Miller AC, Harvey JE. Guidelines for management of spontaneous pneumothorax. Standards of care committee, British Thoracic Society. British Medical Journal. 1993;**307**:114-116

[45] Harris A, O'Driscoll BR, Turkington PM. Survey of major complications of intercostal chest drain insertion in the UK. Postgraduate Medical Journal. 2010;**86**:68-72

[46] Breckenridge IM. Risk management of chest drains. Clinical Risk. 2001;**7**:91-93

[47] Haggie JA. Management of pneumothorax. Chest drain trocar unsafe and unnecessary. British Medical

Journal. 1993;**307**:443. DOI: 10.1136/bmj.307.6901.443

[48] Kwiatt M, Tarbox A, Seamon MJ, et al. Thoracostomy tubes: A comprehensive review of complications and related topics. International Journal of Critical Illness and Injury Science. 2014;**4**(2):143-155

[49] Tait P, Waheed U, Bell S. Successful removal of malpositioned chest drain within the liver by embolization of the transhepatic track. Cardiovascular and Interventional Radiology. 2009;**32**:825-827

[50] Osinowo O, Softah AL, Eid Zahrani M. Ectopic chest tube insertions: Diagnosis and strategies for prevention. The African Journal of Medical Sciences. 2002;**31**:67-70

[51] Nahum E, Ben-Ari J, Schonfeld T, Horev G. Acute diaphragmatic paralysis caused by chest-tube trauma to phrenic nerve. Pediatric Radiology. 2001;**31**:444-446

[52] Taub PJ, Lajam F, Kim U. Erosion into the subclavian artery by a chest tube. The Journal of Trauma. 1999;**47**:972-974

[53] Knyazer B et al. Horner's syndrome secondary to chest tube insertion for pneumothorax. Asian Journal of Ophthalmology. 2008;**10**:27-29

[54] Etoch SW, Bar-Natan MF, Miller FB, Richardson JD. Tube thoracostomy. Factors related to complications. Archives of Surgery. 1995;**130**:521-525. Discussion 525-6

[55] Banagale RC, Outerbridge EW, Aranda JV. Lung perforation: A complication of chest tube insertion in neonatal pneumothorax. The Journal of Pediatrics. 1979;**94**:973-975

[56] Icoz G, Kara E, Ilkgül O, Yetgin S, Tunçyürek P, Korkut MA. Perforation of the stomach due to chest tube complication in a patient with iatrogenic diaphragmatic rupture. Acta Chirurgica Belgica. 2003;**103**:423-424

[57] Johnson JF, Wright DR. Chest tube perforation of esophagus following repair of esophageal atresia. Journal of Pediatric Surgery. 1990;**25**:1227-1230

[58] Hallifax RJ, Psallidas I, Rahman NM. Chest drain size: The debate continues. Current Pulmonology Reports. 2017;**6**(1):26-29

[59] Fang M, Liu G, Luo G, Wu T. Does pigtail catheters relieve pneumothorax? A PRISMA-compliant systematic review and meta-analysis. Medicine. 2018;**97**(47):89

[60] Filosso PL, Sandri A, Guerrera F, Ferraris A, Marchisio F, Bora G, et al. When size matters: Changing opinion in the management of pleural space-the rise of small-bore pleural catheters. Journal of Thoracic Disease. 2016;**8**(7):E503-E510

[61] Riber SS, Riber LP, Olesen WH, Licht PB. The influence of chest tube size and position in primary spontaneous pneumothorax. Journal of Thoracic Disease. 2017;**9**(2):327-332

[62] Sharma TN, Agrihotri SP, Jain NK, et al. Intercostal tube thoracostomy in pneumothorax: Factors influencing re-expansion of lung. The Indian Journal of Chest Diseases & Allied Sciences. 1988;**30**:32-35

[63] Reed MF, Lyons JM, Luchette FA, et al. Preliminary report of a prospective, randomized trial of underwater seal for spontaneous and iatrogenic pneumothorax. Journal of the American College of Surgeons. 2007;**204**:84-90

[64] Blair Marshall M, Deeb ME, Bleier J, Kucharczuk JC, Friedberg JS, Kaiser LR, et al. Suction vs water

seal after pulmonary resection. Chest. 2002;**121**(3):831-835

[65] Cerfolio RJ, Bass C, Katholi CR. Prospective randomized trial compares suction versus water seal for air leaks. The Annals of Thoracic Surgery. 2001;**71**(5):1613-1617

[66] SY S, DY Y. Catheter drainage of spontaneous pneumothorax: Suction or no suction, early or late removal? Thorax. 1982;**37**:46-48

[67] Aguayo E, Cameron R, Dobaria V, Ou R, Iyengar A, Sanaiha Y, et al. Assessment of differential pressures in chest drainage systems: Is what you see what you get? The Journal of Surgical Research. 2018;**232**:464-469

[68] Pompili C, Detterbeck F, Papagiannopoulos K, Sihoe A, Vachlas K, Maxfield MW, et al. Multicenter international randomized comparison of objective and subjective outcomes between electronic and traditional chest drainage systems. The Annals of Thoracic Surgery. 2014;**98**(2):490-496

[69] Gilbert S, McGuire AL, Maghera S, Sundaresan SR, Seely AJ, Maziak DE, et al. Randomized trial of digital versus analog pleural drainage in patients with or without a pulmonary air leak after lung resection. The Journal of Thoracic and Cardiovascular Surgery. 2015;**150**:1243-1249

[70] Thopaz+ Portable Digital System for Managing Chest Drains. NICE. 2018. Available from: https://www.nice.org.uk/guidance/MTG37/chapter/1-Recommendations [Accessed: November 11, 2018]

[71] Wong PS. Management of pneumothorax. Never clamp a chest drain. British Medical Journal. 1993;**307**:443

[72] Kirschner PA. "Provocative clamping" and removal of chest tubes despite persistent air leak. The Annals of Thoracic Surgery. 1992;**53**:740-741

[73] Cerfolio RJ, Minnich DJ, Bryant AS. The removal of chest tubes despite an air leak or a pneumothorax. The Annals of Thoracic Surgery. 2009;**87**:1690-1694

[74] Bell RL, Ovadia P, Abdullah F, Spector S, Rabinovici R. Chest tube removal: End-inspiration or end-expiration? The Journal of Trauma. 2001;**50**(4):674-677

[75] Novoa NM, Jiménez MF, Varela G. When to remove a chest tube. Thoracic Surgery Clinics. 2017;**27**(1):41-46

[76] Lim E. The devil is in the details: Managing chest drains and interpreting negative randomized trial data. The Journal of Thoracic and Cardiovascular Surgery. 2015;**150**:1252-1253

[77] Traoré A, Doumiri M, Bensghir M, Haimeur C, Tazi AS. Management of spontaneous pneumothorax during pregnancy: A case report and review of literature. Revue de Pneumologie Clinique. 2015;**71**(5):306-308

[78] Terndrup TE, Bosco SF, McLean ER. Spontaneous pneumothorax complicating pregnancy: Case report and review of the literature. The Journal of Emergency Medicine. 1989;**7**:245-248

[79] Lal A, Anderson G, Cowen M, et al. Pneumothorax and pregnancy. Chest. 2007;**132**:1044-1048

[80] Hu X, Cowl CT, Baqir M, Ryu MJ. Air travel and pneumothorax. Chest. 2014;**145**(4):688-694

[81] Voge VM, Anthracite R. Spontaneous pneumothorax in the USAF aircrew population: A retrospective study. Aviation, Space, and Environmental Medicine. 1986;**57**:939-949

[82] Gupta N, Sunwoo BY, Kotloff RM. Birt-Hogg-Dubé syndrome. Clinics in Chest Medicine. 2016;**37**(3):475-486

[83] Viveiro C, Rocha P, Carvalho C, et al. Spontaneous pneumothorax as manifestation of Marfan syndrome. BMJ Case Reports. 2013;**2013**:pii: bcr2013201697

[84] Weill D. Lung transplantation: Indications and contraindications. Journal of Thoracic Disease. 2018;**10**(7):4574-4587

[85] Tschopp JM, Boutin C, Astoul P, Janssen JP, Grandin S, Bolliger CT, et al. Talcage by medical thoracoscopy for primary spontaneous pneumothorax is more cost-effective than drainage: A randomised study. The European Respiratory Journal. 2002;**20**:1003-1009

[86] Ben-Nun A, Golan N, Faibishenko I, Simansky D, Soudack M. Nonsteroidal anti-inflammatory medications: Efficient and safe treatment following video-assisted pleurodesis for spontaneous pneumothorax. World Journal of Surgery. 2011;**35**(11):2563-2567

[87] Lardinois D, Vogt P, Yang L, Hegyi I, Baslam M, Weder W. Non-steroidal anti-inflammatory drugs decrease the quality of pleurodesis after mechanical pleural abrasion. European Journal of Cardio-Thoracic Surgery. 2004;**25**(5):865-871

[88] Pompeo E, Tacconi F, Mineo D, Mineo TC. The role of awake video-assisted thoracoscopic surgery in spontaneous pneumothorax. The Journal of Thoracic and Cardiovascular Surgery. 2007;**133**(3):786-790

[89] Kemp SV, Herth FJF, Shah PL. Bullectomy: A waste of space or room for improvement? Respiration. 2016;**92**:218-219

[90] Keshishyan S, Revelo AE, Epelbaum O. Bronchoscopic management of prolonged air leak. Journal of Thoracic Disease. 2017;**9**(Suppl 10):S1034-S1046

[91] Wood DE, Cerfolio RJ, Gonzalez X, Springmeyer SC. Bronchoscopic management of prolonged air leak. Clinics in Chest Medicine. 2010;**31**(1):127-133