Pneumothorax and Timing to Safe Air Travel

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INTRODUCTION: Current guidelines regarding the time to flight after an acquired pneumothorax have been generally accepted and in place for years. The majority of these typically advise holding off on air travel until the complete resolution of a pneumothorax. Over the past decade, however, there has been an increase in the amount of literature focusing on this subject and challenging this well-held dogma. A review of these studies has shown that recent evidence contradicts the historical guidelines that many practitioners follow about the safety and timing of flying after pneumothoraces. Based on these studies, air travel with a known pneumothorax is likely safe and can be undertaken much sooner than current guidelines advise.

KEYWORDS: traumatic, tension, hypoxic, commercial, hypobaric.

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With the ever-increasing use of commercial air travel, individuals are traveling away from home more frequently.[3] That increase in travel has spurned a newfound desire to re-examine some of our previous recommendations regarding specific health conditions and flying. Specifically, in the past, a pneumothorax has been deemed an absolute contraindication for flight travel due to the effects of the hypobaric environment and concern for expansion resulting in tension physiology. Numerous societies, including the British Thoracic Society and Aerospace Medical Association (AsMA), previously recommended waiting at least 2 wk from the resolution of a pneumothorax prior to any flight travel, recently updating their recommendation to 7 d.[1,11] A 2011 article published in *Thorax* recommended waiting at least 7 d after the complete resolution of a pneumothorax, and up to 2 wk following a traumatic pneumothorax.[11] However, upon review of the literature, it becomes apparent that these recommendations are based on a few case reports and other weak evidence. As such, numerous authors have noted that further investigation into this field is needed to better understand the natural history of a pneumothorax in flight.[2,7,10]

METHODS

The PUBMED database was queried utilizing search terms "Pneumothorax", "Flight", "Hypobaric", and "Air Travel", resulting in 107 articles. As the goal of this review was to identify post-hospital-discharge air travel following an acquired pneumothorax (surgical or traumatic), studies involving congenital malformations and spontaneous pneumothoraces were excluded. In addition, as a thorough review of the literature was performed in 2013 by Bunch et al., the search was narrowed to original studies, case reports, and case series from 2013 onward.[2] This reduced the number of relevant articles to six, one of which could not be viewed due to access issues. As such, the remaining five articles, with two additional historic articles, are summarized below and in **Table I**.

RESULTS

Theoretical Pathophysiology of a Hypobaric Pneumothorax

To look at the proposed physiology behind a pneumothorax, a study performed in 2013 by Fitz-Clarke et al.[6] used a mathematical model simulating the behavior of pneumothoraces at different altitudes. Using a mathematical model, they determined the theoretical size at which tension physiology would

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Table I. Summary of Studies Discussed.

STUDY	DATE PUBLISHED	NO. OF PATIENTS
Cheatham et al.[5]	1999	12
Tam et al.[13]	2011	176
Majercik et al.[9]	2014	20
Sacco et al.[10]	2014	80
Cassivi et al.[4]	2017	96
Zonies et al.[14]	2018	73
Lafouasse et al.[8]	2021	99

occur. It was determined that a pneumothorax up to 40% in size could be tolerated up to an altitude of 8000 ft (2438 m). This size would not create a large enough mediastinal pressure difference to induce tension physiology. At this size, the authors also concluded that tension physiology would not create enough positive intrathoracic pressure to overcome normal respiratory negative pressure. The apparent limitations of this study are that it is purely theoretical and, therefore, cannot account for some of the nuances of human respiratory mechanics. The model also did not address critical hypoxemia due to lower inspired oxygen partial pressures and pulmonary shunt from lung collapse, which certainly would have an overall effect on patients with pneumothoraces. Still, this paper's findings help explain how patients in later studies with known pneumothoraces seem to have mild to no issues with flight in pressurized cabins. The article mentions that while cabins are pressurized to 8000 feet (2438 m), there is the chance of rapid decompression, which would quickly drop the cabin's pressure to 30000–45000 ft (9144–13,716 m) over a period of seconds. Under these extreme conditions, the risk of lung collapse would drastically increase, but the chance of this event occurring in current commercial aviation is quite rare.[12]

Previous Summary of the Literature

A review article written in 2013 focused on numerous publications that looked at pneumothorax during commercial flight. Bunch et al. found that while there were numerous retrospective studies, only two prospective studies addressed this topic.[2] One of these, based out of Orlando, FL, in 1999, had been used to validate the Aerospace Medical Assocation and British Thoracic Society guidelines of waiting 2 wk after the resolution of a pneumothorax.[5] In that study, 10 patients flew at least 14 d after resolution of a traumatic pneumothorax and did not experience any issues in flight. Two patients flew prior to 14 d, and one had respiratory distress in flight with symptoms suggestive of a recurrent pneumothorax. As such, the recommendation of waiting 2 wk after traumatic pneumothorax seemed appropriate.

Another article cited in that review, however, seemed to provide evidence that air travel prior to 2 wk after pneumothorax would be safe. In a paper by Tam et al., the authors looked at 176 patients who underwent 183 percutaneous transthoracic needle biopsies followed by air travel within 14 d of the procedure.[13] Of those 183 procedures, 65 patients developed a pneumothorax, and only 11 were treated with chest tube insertion. Their indication for tube thoracostomy was either a symptomatic pneumothorax or a pneumothorax larger than 30% in size. Notably, this is significantly larger than many trauma recommendations, which advise chest tube drainage for pneumothoraces greater than 10%. In the Tam study, patients were allowed to fly 24 h after the procedure if they had either no pneumothorax or a stable pneumothorax on imaging. Those patients who received a chest tube were advised to wait 24 h after chest tube removal prior to travel. The patients were contacted 7–10 d after travel and given a questionnaire to examine symptoms. The mean flight time for all patients was 2.5 h, with a range of 0.5–11.5 h. The mean time to air travel after the procedure was 66.7 h, ranging from 3.25–327 h. None of the patients in the survey experienced any severe or life-threatening symptoms that required either in-flight medical care or flight diversion. Only 14 patients surveyed reported either new symptoms or mild worsening of previous symptoms, and none needed to seek medical care at any point for these. The authors then concluded that air travel was safe within 14 d of pneumothorax, and updates to current recommendations were needed.

Up through 2013, these studies appeared to be the best available evidence at the time, though they all noted a significant knowledge gap that needed to be filled. Beginning in 2014, several papers came out addressing this topic and providing much more evidence on the current subject.

Discussion of the New Literature

A study published in 2014 out of the Intermountain Medical Center in Murray, UT, looked specifically at the effects of a hypobaric environment on recent traumatic pneumothoraces.[9] This prospective observational study examined 20 patients with a unilateral traumatic pneumothorax, 16 of whom were treated with chest tube placement and 4 with high-flow oxygen. Those treated with a chest tube were placed into an altitude chamber between 4–48 h after tube removal, with the average time being 19 h. In those patients who did not require a thoracostomy tube, the experiment was performed on post-injury Day 4. The experiment had two phases with 10 patients each. In the first phase, the patients were taken to a simulated altitude of 8400 ft (2560 m), which is the standard pressurization of commercial airliners. As Murray, UT, is at 4500 ft (1372 m) elevation, the second phase of the experiment was to take the patients to 12,650 ft (3856 m) to simulate a change in altitude of at least 8200 ft (2499 m). This would attempt to assess whether those patients who suffered a pneumothorax at sea level could withstand the pressurization of an airline. As humans begin to get hypoxic at this absolute altitude, all the patients were given supplemental oxygen for Phase 2. The patients were kept at these two altitudes for 2 h, during which they were asked about any subjective feelings of cardiopulmonary compromise every 10 min and twice performed vigorous walking for 1 min. At the end of their 2-h "flight", a single chest x-ray was performed, then they were brought back to ambient air pressure. A follow-up chest x-ray was performed 4 h after completion of the study.

During Phase 1 of the experiment, no patient reported any significant symptoms during flight. There were no significant changes in vital signs, and five participants required supplemental oxygen to maintain saturations greater than 88%. Oxygen saturation did not change with exercise. On chest x-ray, the average baseline pneumothorax size was 4.5 mm; at altitude, it was 10 mm. On the follow-up chest x-ray, there was no significant size difference as compared to the baseline chest x-ray done before the flight. Interestingly, patients who started with an O_2 saturation of >93–94% did not require supplemental oxygen, while those in the lower 90s mostly did. These lower saturations can be explained by the fact that many of the patients also had concomitant rib fractures, pulmonary contusions, or laparotomies, which would adversely affect their pulmonary function.

During Phase 2 of the experiment, one patient reported mild transient chest pain during his exercise challenge, which was believed to be secondary to rib fractures. There were no significant changes to the patient's vital signs during the study. Oxygen saturations did drop on average from 96% to 89% during exercise, but oxygen supplementation levels did not change. The average baseline size of the pneumothorax in this group was 3.2 mm; it was 8.7 mm at altitude. Four patients did not have a visible pneumothorax at baseline, but three patients developed one at altitude. No patients developed tension physiology or required any intervention during this experiment. Chest x-ray after the Phase 2 "flight" showed no difference compared to the baseline. The limitation of the study is that it was performed at altitude at the Murray Center and had a small group of subjects. Still, while 25% of the study's participants did require supplemental oxygen at a simulated cruising altitude, there did not appear to be the drastic effects from pneumothorax expansion that one might expect. This also possibly suggests that underlying pulmonary function (as expressed by O_2 saturation) might be more important than the presence of a pneumothorax in decisions about clearing a patient for flight. What would still need to be teased out from this experiment is whether the transient exercise hypoxemia seen in Phase 2 was related to pneumothorax expansion or the absolute altitude to which the patients were exposed.

Another study in 2014 out of Anchorage, AK, performed a retrospective review of 80 patients who sustained a traumatic pneumothorax and were allowed to fly home less than 14 d after injury.[10] Because Alaska is a vast state with minimal infrastructure, the majority of transportation is performed by boat, snowmobile, commercial flight, and bush plane. As such, the Alaskan Native Medical Center, a Level 2 trauma center, has routinely allowed patients to fly home after treatment for traumatic pneumothoraces. In their review, they looked at patients who had a traumatic pneumothorax or hemopneumothorax. They identified 80 patients who met their inclusion criteria, 75 of whom required chest tube drainage and 5 of whom were observed with occult pneumothoraces. The current protocol at the medical center is to obtain a chest x-ray 4 h after tube removal, and, if stable, the patient may be discharged or remain in the hospital. If the patient remains in the hospital, a follow-up chest x-ray is performed 24 h later, and, if stable, the patient may then fly home. If the patient is discharged, they return to clinic 2 d later for a follow-up chest x-ray, and, if stable, they are then allowed to fly home. Of the 75 patients treated with a chest tube, 10 had small residual pneumothoraces at the time of flight. Of the patients included in the study, 77% flew home within 9 d of chest tube removal. What is important to note is that 46 patients flew within 1 wk of chest tube removal, and 14 flew within 2 d. None of the 80 patients who flew encountered any complications. One limitation of the study is that it does not mention the type of air travel (e.g., bush plane or commercial air), flight duration, or cruising altitude. As the majority of bush planes are nonpressurized, and the topography of Alaska includes numerous tall mountain ranges surrounding Anchorage, it is possible that some of these patients were exposed to significant hypobaric conditions during their air travel.

A retrospective study published in May 2017 out of the Mayo Clinic looked at air travel after recent anatomic pulmonary resection.[4] In the study, 96 individuals were identified who flew home after having either an open or VATS lobectomy between 2005–2012. These individuals completed a survey about their travel and were compared to 721 patients who traveled by ground to determine if flying increased post-op complications. The only significant differences between the two groups were that more men flew home than women and the distance traveled to home was longer for those who flew. The mean hospital length of stay for both groups was around 5.8 d, and the median interval from discharge to air travel was 2 d. Of the 96 patients who flew home, 64 had evidence of a pneumothorax on a pre-dismissal chest x-ray. The median distance flown was 1783 km, which, at an average cruising speed of $926\,km \cdot h^{-1}$ would mean that the average flight lasted around 2 h. For both groups, there were 64 post-dismissal significant complications, 8 of which occurred in air travelers and 56 occurred in those traveling by ground. On analysis, there were no statistically significant differences between the two groups in regard to complications. In those who flew, two patients developed a pneumothorax as a complication, which we can only assume meant that it went on to require drainage. In the ground travel group, two patients also developed a pneumothorax, and the *P*-value approached significance between these groups at 0.07. Two patients in the group that flew also reported severe dyspnea, though there was no crossover with those who developed a pneumothorax as a complication. The remaining complications were related to deep vein thrombosis/pulmonary embolism, pneumonia, empyema, chest tube site drainage, severe pain, and major cardiac arrhythmia. Unfortunately, the article does not specifically address in-flight diversion or medical emergencies. This was, however, addressed in their questionnaire and would likely have been a published outcome if it occurred. Another limitation is that some patients were surveyed over 10 yr after their surgery and travel, which could introduce a recall bias. Still, this is a large cohort of patients who traveled with known pneumothoraces and did not experience any life-threatening in-flight complications.

An additional study out of the French Caribbean also looked at early air travel (EAT) following thoracic surgery.[8]

The researchers ultimately looked at 306 patients, 99 of whom underwent a transthoracic procedure involving post-op tube drainage, followed by air travel. Air travel was performed on commercial airlines and ranged from 40 min to 3 h with a maximum cabin altitude of 2400 m (7874 ft). Upon landing, all patients received a chest x-ray at a local clinic to confirm the absence or presence of a pneumothorax. The mean time between surgery and EAT was 7.2 d, with a median of 6 d. The mean interval between drainage removal and EAT was 3.3 d, with a median of 2 d. Of the 99 patients who flew, only 1 developed chest pain with confirmation of a pneumothorax 15 d after his flight; interestingly, his radiograph immediately after landing was normal. From this, the authors published an incidence of 1% for EAT-related complications and advocated for reducing published wait times for air transport.

Finally, a retrospective study by Zonies et al. in 2018 looked at military patients flown from Germany to the United States shortly following chest tube removal.[14] From 2008–2012, the study examined 73 patients who underwent military air transport from Landstuhl Regional Medical Center to either San Antonio Military Medical Center or Walter Reed National Naval Medical Center. These patients were all U.S. military members treated with tube thoracostomies following traumatic pneumothoraces, with subsequent chest tube removal prior to transport. The patients were flown at pressure levels between 5000–8000 ft (1524–2438 m) for an average of 11 h with onboard monitoring and medical staff available. The median duration of tube thoracostomy prior to transport was 4 d, and the median time to flight after removal was 2.5 d. Notably, 40% of patients transported were mechanically ventilated during transport, which would be unusual in a civilian setting but is relatively commonplace for military casualty evacuation. Of the entire study population, only five patients experienced a medical concern based on reviewed documentation; four ventilated patients had ventilator-related issues, and the last nonventilated patient had mild respiratory discomfort without any distress. All patients had close radiological follow-up after arrival, and no patients experienced a recurrent pneumothorax after flight, radiographically or clinically, in the 30-d follow-up. One caveat from the authors was that their recommendation for clearance to fly 72 h after chest tube removal is based on complete radiological and anatomic pneumothorax resolution, which is a stricter standard than previously cited studies.

DISCUSSION

It is easy to understand why recommendations for air travel following development of a pneumothorax have been as conservative as they are. Should a tension pneumothorax develop in flight, death could follow in a matter of minutes. In theory, this would occur through one of two possible mechanisms. The first, a stable pneumothorax expands, per Boyle's law, when exposed to a hypobaric environment, eventually causing enough intrathoracic pressure to impede venous return to the heart.[6] The second mechanism, and the most concerning, would involve a recent lung injury (surgical or traumatic) that has previously sealed against the pleura suddenly breaking free after gas expansion, causing a recurrent air leak progressing to tension physiology. While both mechanisms make sense conceptually, neither seems to be borne out from the recent literature.

For the first mechanism, from the mathematical model presented earlier, one can see that a very large (>40%) pneumothorax would be required to cause significant hemodynamic compromise.[5] The Tam et al. study probably best addresses this mechanism in practice, as they allowed patients with up to a 30% stable pneumothorax to fly, noting no significant in-flight complications.[13] One would likely be hard-pressed to find practitioners who would not intervene on a pneumothorax greater than 30%, with most pneumothoraces treated with observation falling into the occult to small (10%) range. Interestingly, the study out of Utah actually quantified the gas expansion on radiographs in their hypobaric chamber, indeed showing that, per Boyle's law, the thoracic cavity acts as a closed system in practice.[9] However, with all their pneumothoraces falling in the <1 cm range (∼10%), these would be classified as small and not be expected to enlarge enough to cause tension physiology. Given all of this evidence, it would seem reasonable to conclude that the first mechanism should not impede patient air travel, but most physicians would probably agree the second mechanism is the one of most concern.

Upon reading the air travel recommendations from the British Thoracic Society, one can infer that this second mechanism is the one they are considering the most. This becomes evident in that those patients who have undergone a thoracotomy and mechanical pleurodesis do not have restrictions on air travel, as they note that the rate of recurrence is extremely low.[11] In this class of patients, it is clear that the increased scarring of the pleura to the lung gives these experts the reassurance that a previously closed air leak will not reopen. Yet, in the studies examined here, none of the patients underwent any form of pleurodesis, and yet, there does not appear to be any definitive evidence of recurrences. Should a recurrence have occurred, one would expect to see an enlarged pneumothorax on subsequent imaging following their flight. In the Zonies et al., Majercik et al., and Lafouasse et al. papers, all of which had close radiological follow-up after decompression, no enlargement or recurrence of a pneumothorax was seen, which would argue against the occurrence of this second mechanism.[8,9,14] It is important to note that in the Mayo Clinic post-lobectomy study, there was a 2% (two patients) postflight pneumothorax complication rate versus a 0.2% rate in the ground-travel group that almost approached a significant difference. It is difficult to determine if this increased complication rate was secondary to the flight or surgery itself, and likely closer examination would be needed to tease this out in this patient population. Overall, even if those two complicated pneumothoraces were secondary to hypobaric re-expansion, the risk of this happening appears extremely low, and none progressed to a life-threatening condition while airborne.

With this evidence, it does seem like the concern of a recurrent air leak is likely overestimated.

One interesting observation that came from this review was the relationship between hypobaric oxygen saturation and the setting of a pneumothorax. While only one of the studies examined the patients' oxygen saturation while flying, those results were thought-provoking. Based on the study out of Utah, the authors reached an important conclusion: the patients who were saturating <93% before flight might encounter issues with hypoxemia when flying. This paper specifically looked at trauma patients, some with concomitant rib fractures and pulmonary contusions which might have also been responsible for the hypoxia. Further investigation into the oxygen saturation during actual flight with a pneumothorax would seem prudent. Another issue that is not adequately elucidated in any of these studies is how a patient with previous lung disease or lobectomy would fare, from an oxygenation perspective, when flying with a known pneumothorax. As their pulmonary reserve could be significantly lower than that of a healthy patient, the combination of pneumothorax expansion and environmental hypoxia may be too great to be tolerated. Another important note is that all the patients in these studies had an acquired pneumothorax related to trauma or an iatrogenic procedure. Those patients who develop spontaneous pneumothoraces have a significantly different natural history, as there is ample evidence from the military that they are more prone to recurrent pneumothoraces. These results should not be applied to that patient population as the underlying pathophysiology is different.

While the current recommendations from many major medical societies are that flight travel should be delayed until 1–2 wk after complete resolution of a pneumothorax, the best currently available evidence seems to disagree. Based on the evidence presented in this review, the current recommendations of waiting 1–2 wk after the resolution of a pneumothorax appears to be overly conservative. The recommendations of the Alaskan Native Medical Center, which gives flight clearance if a repeat chest x-ray 24–48 h after chest tube removal is stable seems like a reasonable approach to this question. However, these recommendations would be most appropriate for those otherwise healthy patients with adequate pulmonary reserve. For those patients with trouble oxygenating following their trauma or surgery, a different form of transportation may be beneficial. Further studies into the effects of pneumothoraces in the setting of underlying pulmonary disease would be needed before adjusting recommendations for that patient population.

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