Review Article

Can my patient dive after a first episode of primary spontaneous pneumothorax? A systematic review of the literature

M. Alvarez Villela, MD [1,2], S. Dunworth, MD [1,4], N.P. Harlan, MD [1,5], RE Moon, MD [1,3]

1 Center for Hyperbaric Medicine and Environmental Physiology, Duke University Medical Center, Durham, North Carolina, U.S.

2 Division of Cardiology, Montefiore Medical Center –Albert Einstein College of Medicine, Bronx, New York, U.S.

3 Department of Anesthesiology, Duke University, Durham, North Carolina, U.S.

4 Department of Anesthesiology, Stanford University, Palo Alto, California, U.S.

5 Division of Pulmonary Medicine University of Utah, Salt Lake City, Utah, U.S.

CORRESPONDING AUTHOR: M. Alvarez Villela – *miguel.alvarez.vil@gmail.com*

ABSTRACT

Introduction: Patients with prior primary spontaneous pneumothorax (PSP) frequently seek clearance to dive. Despite wide consensus in precluding compressed-air diving in this population, there is a paucity of data to support this decision. We reviewed the literature reporting the risk of PSP recurrence.

Methods: A literature search was performed in PubMed and Web of Science using predefined terms. Studies published in English reporting the recurrence rate after a first PSP were included.

Results: Forty studies (n=3,904) were included. Risk of PSP recurrence ranged 0-67% (22±15.5%; mean ± SD). Mean follow-up was 36 months, and 63±39% of recurrences occurred during the first year of follow-up.

Elevated height/weight ratio and emphysema-like changes (ELCs) are associated with PSP recurrence. ELCs are present in 59%-89% (vs. 0-15%) of patients with recurrence and can be detected effectively with high-resolution CT scan (sensitivity of 84-88%). Surgical pleurodesis reduces the risk of recurrence substantially (4.0±4% vs. 22±15.5%).

Conclusions: Risk of PSP recurrence seems to decline over time and is associated to certain radiological and clinical risk factors. This could be incremented by the stresses of compressed-air diving. A basis for informed patient-physician discussions regarding future diving is provided in this review.

KEYWORDS: pneumothorax, primary, spontaneous, diving, clearance to dive

BACKGROUND

Spontaneous pneumothorax occurs in patients without antecedent trauma or iatrogenic event. When it occurs in patients who additionally have no apparent underlying lung disease, this phenomenon is termed primary spontaneous pneumothorax (PSP).

The incidence of PSP is age-related, and is estimated to be 7.4/100,000/year in men and 1.2/100,000/year in women, peaking between the ages of 15-34 [1,2].

Diving physicians frequently encounter patients with a history of PSP who wish to dive. Traditionally, the consensus in the hyperbaric medicine field has been to advise against any compressed-air diving since a recurrence under water could lead to serious complications or death. As a result, case series examining this issue are non-existent, and evidence to clearly support or reject this recommendation is lacking in the current literature.

The need for further evidence to help guide clinical practice is illustrated in the American College of Chest Physicians Delphi consensus statement on the management of spontaneous pneumothorax [3]. Fifteen (15) percent of panel members said they would offer surgery to prevent recurrence to individuals with a history of PSP who are at high risk in case of recurrence – such as divers or pilots-, rather than disqualifying them from their activities.

One way to approach this issue is to examine the rate of PSP recurrence in the general population to approximate the general risk in divers, and then contemplate the effect that physiological and mechanical stresses of compressed-air diving may have in increasing that risk.

For this purpose, we conducted a systematic review of the literature on PSP recurrence, seeking to answer pertinent questions including:

1. What is the rate of PSP recurrence in the general population?
2. Can the presence of pulmonary abnormalities such as blebs or bullae predict recurrence?
3. Can blebs or bullae be reliably detected by CT scan imaging?
4. Can pneumothorax recur in patients with radiographically normal lungs?
5. Can surgical treatment of a first episode prevent PSP recurrence?

We then discuss what is known about PSP and diving, specifically what the plausible mechanisms of increased risk during compressed-air diving are.

METHODS

In February 2015 a search was conducted using PubMed and Web of Science, combining the terms "spontaneous AND pneumothorax AND recurrence." The search was limited to studies in adults (19+ years), humans, and work published in the English language.

Included studies [1] were original research and [2] studies that specifically reported the rate of recurrence after a first episode of primary spontaneous pneumothorax (PSP) with a follow-up period of at least one month after receiving any treatment modality.

Studies were excluded if they reported the recurrence rate after more than one PSP episode or after a secondary pneumothorax occurrence – whether spontaneous, iatrogenic or traumatic.

Additionally, a hand search of the references cited in the selected articles was conducted to ensure that all relevant studies were included.

The study selection process was conducted independently by two authors (Dunworth S and Alvarez Villela M), and discrepancies were resolved by discussion between them.

Demographic and clinical data for the included patients are presented as simple means and standard deviations. Where not reported, ranges were calculated from the original study data.

Studies that performed survival analysis, or reported the incidence of recurrence after chest computed tomography (CT) scan examination, or reported recurrences after surgical treatment of a first PSP are given special mention.

RESULTS

In total, 491 studies were reviewed; 40 met criteria for inclusion. Results are summarized in Table 1 and included studies are listed in Table 2. In total, 17 prospective observational studies, 18 retrospective studies, four controlled trials and one cross-sectional study are included.

TABLE 1. Included studies

study design	number of studies
controlled trials	4
prospective observational	17
retrospective	18
cross-sectional	1
TOTAL	40

General Characteristics of PSP Recurrence

Within the selected studies, 3,904 patients with a first episode of PSP were included (Table 3).

The mean probability of PSP recurrence ranged from 0-67% with an average of 22±15.5% (mean ± SD). Follow-up time ranged from one to 120 months with a mean of 36 months.

Sixty-three percent (63±39%) of recurrences, according to 21 studies, occurred during the first year of follow-up. Time to first recurrence, reported by 22 studies, ranged from 2.8 to 107 months, with a mean of 20 months.

The mean age was 28 years (range 16-43), and the prevalence of smokers was 64%.

Predictive value of chest CT scan in PSP recurrence

The prevalence of surgically detected blebs or bullae, also termed emphysema-like changes (ELCs), in patients with PSP ranged from 77%-90% [4-6] and was as high as 100% when histology analysis is included [7]. High-resolution CT scan (HRCT) has a sensitivity of 84%-88% and a specificity of 100% compared with surgery for detecting these ELCs [4,8]. The sensitivity

TABLE 2. List of included studies

Year Publ.	First Author	Study Design	Intervention Comparison	N	Mean Follow-up Time (months)	Overall Mean Recurrence Rate
1993	Abolnik (23)	Retrospective	None	286	107.2 mo	41%
2006	Ayed (48)	RCT	SA vs. CTD	137	24 mo	31% vs. 25%
2013	Casali (17)	Retrospective (Monocenter)	None	176	58 mo	57%
2005	Chan (49)	Retrospective (Monocenter)	None	91	12 mo	15.70%
2008	Chen (29)	Retrospective	SA vs. SA+minocycline instillation	64	13 mo	33.3% vs. 12.9%
2013	Chen (50)	RCT	SA vs. SA+minocycline instillation	214	18 mo	49.1% vs. 29.2%
2008	Chen (26)	Retrospective	CTD vs. VATS	52	19.3 mo	22.7% vs. 3.3%
2003	Chou (5)	Prospective	None	51	38 mo	0.0%
1957	Cliff (51)	Retrospective	None	149	not specified	12%
1946	Cohen (52)	Cross-sectional	None	30	not specified	10%
1967	Cran (53)	Retrospective	None	836	not specified	18.8%
1953	DuBose (54)	Prospective	None	65	not specified	20%
1993	Ferraro (25)	Retrospective	None	239	1 mo	34.2%
2010	Ganesalingam (20)	Retrospective	None	100	57 mo	54%
2000	Hatz (6)	Prospective	None	53	53.2 mo.†	7.5%
2007	Huang (16)	Retrospective	None	231	92 mo	14.30%
1962	Hyde (55)	Retrospective	None	200	not specified	17.5%
2013	Kawaguchi (4)	Prospective observational	None	93	not specified	8%
1998	Kim (10)	Prospective after VATS based on CT	None	61	6 mo.	17.75%
1993	Krasnik (12)	Prospective	Thoracotomy vs. VATS+Tetracycline Inst.	393	not specified	8%
2006	Kuzucu (27)	Retrospective (Monocenter)	Observation vs. CTD vs. VATS	58	25.6 mo	66.8% vs. 21.8% vs. 0%
2011	Laituri (9)	Retrospective	None	34	not specified	13.85%
1991	Lippert (21)	Prospective	None	122	62.4 mo	17%
2003	Margolis (7)	Prospective	None	156	62 mo.†	0.0%
2006	Marquette (56)	Prospective	None	41	10.7 mo	24%
2007	Martinez-Ramos (18)	Prospective	None	55	30.7 mo	24%
2014	Massongo (24)	Prospective	None	60	24 mo	16.70%
1992	Mitlehner (11)	Prospective	None	35	9.6 and 31.7 mo	25%
1948	Myerson (57)	Prospective	None	36	not specified	14.7%
2002	Noppen (58)	RCT	SA vs. CTD	60	not specified	26% vs. 27%
1942	Ornstein (59)	Retrospective	None	58	not specified	30%
2007	Ouanes-Besbes (19)	Retrospective	None	80	34 mo	19%
1939	Perry (60)	Retrospective	None	85	not specified	4.4%
1949	Rottenberg (61)	Prospective	None	97	11.5 mo	20.60%
1997	Sadikot (22)	Prospective	None	153	54 mo	54%
1945	Schneider (62)	Prospective	None	94	not specified	20%
2000	Sihoe (8)	Prospective	VATS	11	59 mo	3.5%
2001	Torresini (28)	Controlled trial (non-randomized)	CTD vs. VATS	64	12 mo	22.8% vs. 2.8%
1986	Voge (63)	Retrospective	None	112	120 mo	28%
2014	Voisin (64)	Retrospective (Monocenter)	None	73	12 mo	22%

† Signals *median* instead of *mean* reported in original study. CTD: chest tube drainage VATS: video-assisted thoracoscopic surgery SA: Simple aspiration

TABLE 3. Summary of included studies

total number of studies	40
total number of patients	5,416
number of patients with a 1st PSP (n)	3,904
mean age (32 studies)	28 y.
prevalence of smokers (20 studies)	64%
mean follow-up time (26 studies)	36 months
follow-up time range	1 – 120 months
time to first recurrence (22 studies; n=2,059)	2.8 – 107 months
mean time to first recurrence (22 studies; n=2,059)	20 months
mean recurrence rate (39 studies; n=3,784)	22% (SD=15.5%)
recurrences within first 12 months (21 studies; n=1,886)	63% (SD=39%)
mean recurrence after surgery for 1st episode (10 studies; n=1,131)*	4.0% (SD=4%)

*Recurrence after different treatment modalities including observation, simple aspiration, chest tube drainage, and surgical bullectomy with or without pleurodesis.

of CT scan techniques with lower resolution can be as low as 36% [9]. Conventional chest radiography has a sensitivity for ELC detection of approximately 15% compared to HRCT, and 60% compared to axial CT scan [10,11].

The role of ELCs in PSP occurrence is not well established but ELCs seem to be more prevalent in patients with PSP, especially among those with recurrence, compared with controls: 59%-89% vs. 0-15% (12-15).

Rates of recurrence in patients with and without CT-scan-detected ELCs were compared in six studies. Findings are summarized in Table 4. Four of these studies used HRCT for assessment of lung parenchyma. Results were variable depending on the study methodology. Recurrence rates were significantly lower in patients without ELCs in three of these studies [8,16,17], but similar or higher in three others [11, 18,19].

The predictive value of conventional chest radiography for recurrence of PSP was reported by Ganesalingam, et al. Although no single radiographic abnormality was found to be an independent predictor of recurrence, the combination of four types of findings – pleural thickening, lung blebs, pleural irregularities and pleural adhesions – had a significantly higher likelihood of recurrence; 12% with no abnormalities vs. 67% with three abnormalities at two years of follow-up [20].

Clinical predictors of recurrence

Certain clinical factors have been associated with higher risk of PSP recurrence.

Lippert, et al. [21] identified four patient-related factors as independent predictors of recurrence: height/weight ratio >3.2 (cm/kg, adding 0.22 to ratio for men), pulmonary fibrosis on chest radiograph, age 60 or older, and never-smoker status. A prognostic index was constructed based on the presence of these factors classifying patients into four risk groups: PI-1 to PI-4. Recurrence-free survival rates (RFS) in the group with one risk factor were 98±2% at each of one, five and 10 years. Whereas in the group with four risk factors, RFS were 47±19% at one and five years and 31±18% at 10 years.

Other studies mention elevated height or height/weight ratio with variable cutoffs [21-23] female sex [22], relatively smaller size of first pneumothorax, and younger age at first PSP occurrence [24] as factors associated with significantly higher recurrence rates.

Smoking has classically been associated with a higher risk of PSP occurrence, but its role in predicting recurrence seems equivocal. Continued active smoking after a first occurrence was only significantly associated with a higher risk of recurrence in one study [22]. Never-smokers were also found to have a higher risk of recurrence in another study [21].

Recurrence itself was associated with further incidences of recurrence in two studies [23,25].

TABLE 4. Studies with CT chest evaluation after a first PSP occurrence

author	prevalence of ELCs by CT scan	no. of patients	mean f/u time	CT technique	overall recurrence	recurrence with ELC	recurrence without ELC
Casali [17] (2013)	63%	176	58 mo	HRCT	57.0%	ipsilateral 68.1%* contralateral 19%	ipsilateral 6.1%* contralateral 0%
Martinez-Ramos [18] (2007)	47%	55	31 mo	helical CT 3mm slice thickness	24.0%	23%	24%
Ouanes-Besbes [19] (2006)	73%	80	34 mo	HRCT	19.0%	15.5%	27%
Sihoe+ s [8] (2000)	79%	28	59 mo	HRCT	18.0%	ipsilateral 0%+ contralateral-27%*	ipsilateral 33% (1/3) + contralateral-0%*
Huang [16] (2007)	55%	231	92 mo	HRCT	14.30%	contralateral-26%*	contralateral-0%*
Mitlehner [11] (1992)	89%	35	32 mo	axial CT scan 10 mm slice thickness	23%	22.5%	25%

*Statistically significant difference (P<0.005) + All patients underwent VATS with bullectomy + pleurodesis of the affected lung
CT: computed tomography; PSP: primary spontaneous pneumothorax; ipsilateral/contralateral refers to recurrence side relative to side of first PSP occurrence; ELC: emphysema-like changes – includes blebs and bullae

Effect of surgical intervention

Ten studies reported recurrence rates after surgical treatment of a first PSP episode [5-10,12,26-28].

Four of these studies reported recurrence rates comparing conservative management to surgical treatment in different patient groups (Table 5). Overall, the mean recurrence rate was substantially lower in the surgically treated patients than in the general population: 4.0±4% vs. 22±15.5%. The surgical technique used in these studies consisted of video-assisted thoracoscopic surgery (VATS) resection of detected blebs or bullae or, in the absence of these, wedge apical resection followed by pleurodesis using different techniques. In one study, surgery was performed via thoracotomy [12].

TABLE 5. Studies with direct comparison of surgical vs. non-surgical treatment of first PSP

author	year	N	design	recurrence rate: surgical group	recurrence rate: non-surgical group
Krasnik [12]	1993	393	thoracotomy (>2cm blebs) vs. tetracycline pleurodesis (<2cm bullae)	0%+	8%
Torresini [28]	2001	70	chest tube drainage vs. VATS with wedge resection and pleurectomy	2.8%+	22.8%
Kuzucu [27]	2006	90	retrospective review – 3 groups: observation, chest tube, surgery	0%*	66.7% observation* 21.8% chest tube*
Chen [26]	2008	52	chest tube drainage vs. VATS for treatment of PSP after unsuccessful aspiration	3.3%++	22.7%++

+ Level of statistical significance not reported. ++Difference not statistically significant (P=0.07). *Statistically significant (P<0.05).

When do recurrences happen?

Five studies performed survival-type analysis and can provide a more precise idea of timing of recurrence. In the study by Lippert, et al. [21] mentioned above, the risk of recurrence was dictated by the presence of four clinical risk factors. Recurrence-free survival (RFS) remained relatively stable at one, five and 10 years (98±2%) in patients with only one risk factor, but declined over time in patients with four risk factors (47±19%, 47±19% and 31±18%). When considering all risk groups, the overall RFS was 85% at one year, 82% at two years and 82% at three years. The total follow-up time in this study was 10 years; no recurrences were observed in any of the four risk groups after eight years.

A retrospective analysis of 64 patients by Chen, et al. [29], which compared simple aspiration to simple aspiration plus intrapleural minocycline instillation for pleurodesis after a first PSP, found an RFS of 66.7% in the simple aspiration group and 87% in the minocycline instillation group at one year. No additional recurrences were seen after two years. Another retrospective study performed by this same group compared the RFS after simple chest tube drainage (CTD) and after VATS with bleb resection or blind apical stapling, plus pleural abrasion for pleurodesis. RFS for the CTD group was 80%, 77.3% and 77.3% at one, two and three years, and 96.7% at each of those three time points for patients in the VATS intervention group [29].

Two of the studies examining the predictive value of CT scan reported recurrence-free survival data. Casali, et al. reported an RFS that varied substantially depending on the appearance of lung parenchyma on HRCT: 95%, 95% and 93% at one, two and three years respectively for patients without blebs; 62.5%, 56.5%, 36% for patients with blebs; and 50%, 30% and 22% for patients with "high-grade" blebs as defined by a custom severity grading system created by the authors [17]. Martinez-Ramos, et al. reported a recurrence-free survival of 80% that remained stable at one, two and three years for patients without blebs; and of 90%, 78% and 78% for patients with blebs, using helical CT scan for detection. The prevalence of ELCs was lower than in other reports, and the percentage of smokers was not specified in this study. Also, despite no difference in RFS between groups, most of the recurrences in the patients with ELCs occurred within the first six months of follow-up [18].

DISCUSSION

Summary

The recurrence rate after a first episode of PSP is close to 22±15.5%, with a majority of recurrences (63±39%) occurring in the first 12 months of follow-up. The studies reporting survival-type analysis support this time-related incidence of recurrence in most series, with RFS rates dropping early in the follow-up period but stabilizing thereafter [17,18,21,26,29]. To this effect, no recurrences are reported after eight years in the study with the longest follow-up period [21].

Predicting the risk and timing of recurrence is of paramount importance in "returning to dive" decision-making. Several clinical, radiological and therapeutic factors seem to be associated with this risk. Clinical risk factors associated with higher recurrence include elevated body height/weight ratio as the most consistently identified one, although its quantitative definition varies among studies [21-23]. Also, one recurrence is associated with further recurrences [23,25]. Other clinical factors were less consistently identified as predictors of recurrence.

Regarding radiological factors; nearly all patients with PSP have blebs or bullae when examined surgically [4-7]. High-resolution CT scans perform well in the identification of these lesions, with a sensitivity of 84%-88% compared with surgery [4,8,10]. In three of the four studies using HRCT to examine the lung parenchyma, ELCs were associated with a significantly higher risk of recurrence [8,16,17]. Non-high resolution CT scans [9] and conventional chest radiographs [11] are less sensitive and have a lower predictive value. However, recurrences even in the absence of blebs in HRCT was still as high as 27% and 33% in two studies [8,19]. It is important to note that there is evidence that the pathophysiology of spontaneous pneumothorax may in most cases be related to factors other than ELCs [30].

Therapeutic options such as surgical resection of the lung apex or of visualized emphysematous changes plus pleurodesis using different techniques, via VATS or thoracotomy, seem to reduce the risk of recurrence substantially, from 22% to nearly 4% [5-10,12,26-28].

Xe-133 single-photon emission washout scanning is commonly used for detection of emphysema that may not be yet manifest in pulmonary function testing or other imaging modalities [31]. However, no data relating abnormal studies on this modality to the risk of pneumothorax are available in the literature, and the value of this imaging technique in clearance-to-dive evaluations is unknown.

Pneumothorax and compressed-air diving

Pneumothorax while diving is rare, and is normally thought to result from pulmonary barotrauma (PBT). PBT occurs due to air entrapment, leading to alveolar rupture and potentially AGE, pneumomediastinum or, much less frequently, pneumothorax. Although breath-holding during ascent is a well-known mechanism for PBT, many of the reported cases of barotrauma have occurred at depth, or do not seem to be associated with a closed glottis during lung expansion [32]. When a pneumothorax occurs at depth there is a greater risk of expansion and tension pneumothorax upon ascent. The conditions leading to PBT in such cases could be obstructive airway disease with regional differences in the degree of air entrapment, and/or parenchymal diseases that lead to regional differences in lung tissue compliance [33].

Rupture of pulmonary structures is not caused by pressure per se, but rather overstretching of pulmonary parenchyma. This can indeed happen due to gas expansion during ascent from a dive. During normal breathing, ventilation is relatively homogeneous (uniform time constants); however, in the presence of lung disease different lung regions have substantially different ventilatory time constants [34]. At interfaces between regions with different time constants, excess strain could cause alveolar rupture. This phenomenon is most likely, at least partly, responsible for pneumothorax occurring in lung disease [35,36]. Inter-regional ventilatory inhomogeneity would be augmented during diving, where the breathing gas density and thus airways resistance are increased. While at depth, airway resistance and alveolar pressure rise due to increased density of breathing gases [37,38]. In the presence of local fragility in the lung parenchyma, such as those seen with ELCs or air-trapping due to bronchoconstriction, this could conceivably result in PBT without a change in surrounding ambient pressure.

Along these lines, several studies and case reports seeking to identify factors associated with higher risk of PBT while diving have found that the presence of blebs, bullae or airway reactivity can increase the risk of these events [32,39-47]. These studies, while performed in divers who have experienced PBT, were generally limited by the lack of pre-event imaging or lung function testing as well as by the lack of a control population composed of divers [32,40,41,43,45].

The study by Tetzlaff, et al. overcomes many of these limitations. In this report, 15 divers with PBT, of whom the majority (10/15) had pre-injury plain chest radiograph, and all subjects had pre-injury pulmonary function testing. The findings in these subjects were compared with 15 cases of decompression sickness (DCS) referred to their center for treatment. There was only one pneumothorax occurrence in the PBT group, while the majority of patients suffered from AGE (13/15). Non-high-resolution CT scan was performed in 12 PBT cases after the injury, and five were found to have blebs not detected in pre- or post-injury plain chest radiograph. In contrast, four of the DCS cases underwent CT scan imaging after their injury: All were normal. Pulmonary function testing showed a statistically significant lower value in peak expiratory flow (PEF) 50% and PEF 25% in pre-injury testing of the PBT group, indicating that obstructive airway disease may have a higher prevalence among these subjects [39].

Although these studies are suggestive of an association between ELCs and obstructive airway disease with PBT – and this remains a physiologically plausible association – the number of studied divers is extremely small, and conclusive evidence for a causal association is still lacking.

CONCLUSION

Pneumothorax while diving is a rare but potentially life-threatening condition. Currently, a history of primary spontaneous pneumothorax (PSP) is widely considered as an absolute contraindication to further diving. Although the risk of pneumothorax recurrence is associated with certain clinical and radiological factors, this risk remains present even in the absence of these factors. The mechanical and physiological stressors associated with compressed-air diving can increase this risk further, as compared to the general population.

Offering surgery to reduce the risk of a new pneumothorax might not be effective in divers since it will reduce the risk of pneumothorax but not protect against PBT, which may result in serious complications such as pneumomediastinum or arterial gas embolism.

Moreover, PBT can theoretically occur in the absence of a closed glottis ascent due to increased gas density, leading to high airway resistance at depth. The association between obstructive airway disease and ELCs with PBT remains inconclusive but is suggested by the current evidence.

Given that a pneumothorax at depth can result in a fatality, the current practice of generally advising against further diving is probably sound. The evidence available does not suggest with confidence a specific time limit on such a recommendation.

A thorough physician-patient discussion should be undertaken in each case. This review can provide evidence to facilitate that discussion and allow the patient to make an informed decision. If a patient without identifiable clinical risk factors, who has a normal chest HRCT, and has not had a recurrence after many years, elects to dive given his lower risk profile, he or she should be strongly warned that his or her risk of a pneumothorax or PBT is still higher than that of the general population, and that such an occurrence underwater could be fatal.

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