OPEN

Clinical Presentation of Patients With Tension Pneumothorax

A Systematic Review

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Objective: To determine whether the reported clinical presentation of tension pneumothorax differs between patients who are breathing unassisted versus receiving assisted ventilation.

Background: Animal studies suggest that the pathophysiology and physical signs of tension pneumothorax differ by subject ventilatory status.

Methods: We searched electronic databases through to October 15, 2013 for observational studies and case reports/series reporting clinical manifestations of tension pneumothorax. Two physicians independently extracted clinical manifestations reported at diagnosis.

Results: We identified 5 cohort studies ($n = 310$ patients) and 156 case series/reports of 183 cases of tension pneumothorax ($n = 86$ breathing unassisted, $n = 97$ receiving assisted ventilation). Hypoxia was reported among 43 (50.0%) cases of tension pneumothorax who were breathing unassisted versus 89 (91.8%) receiving assisted ventilation ($P < 0.001$). Pulmonary dysfunction progressed to respiratory arrest in 9.3% of cases breathing unassisted. As compared to cases who were breathing unassisted, the adjusted odds of hypotension and cardiac arrest were 12.6 (95% confidence interval, 5.8–27.5) and 17.7 (95% confidence interval, 4.0–78.4) times higher among cases receiving assisted ventilation. One cohort study reported that none of the patients with tension pneumothorax who were breathing unassisted versus 39.6% of those receiving assisted ventilation presented without an arterial pulse. In contrast to cases breathing unassisted, the majority (70.4%) of those receiving assisted ventilation who experienced hypotension or cardiac arrest developed these signs within minutes of clinical presentation.

Discussion: The reported clinical presentation of tension pneumothorax depends on the ventilatory status of the patient. This may have implications for improving the diagnosis and treatment of this life-threatening disorder.

Keywords: assisted ventilation, breathing unassisted, clinical manifestations, clinical presentation, diagnosis, management, signs and symptoms, tension pneumothorax

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Tension pneumothorax is an uncommon condition with a high mortality rate most frequently reported to occur in prehospital, emergency department, and intensive care unit (ICU) settings.[1–4] This condition is frequently lethal in injured and ventilated ICU patients without early diagnosis and treatment.[5–7] Although the incidence of tension pneumothorax remains poorly estimated, it may occur in up to 1% to 3% of prehospital, major trauma and ICU patients.[1,3,8–12]

As many authorities recommend urgent thoracic decompression when the diagnosis is first suspected, health care providers are taught to search for classically described clinical manifestations to recognize patients who may have tension pneumothorax.[5,6,13] Although tension pneumothorax is therefore a syndrome diagnosis, available literature sources differ substantially in their descriptions of its clinical presentation.[1] Many of these have been generalized from canine studies of the disorder,[14,15] and do not account for potential differences in pathophysiology and physical signs based on the ventilatory status of the patient (Fig. 1).[1,6,16–21]

As misdiagnosis or inappropriate treatment of tension pneumothorax can have devastating consequences,[6,22–26] a comprehensive description of its clinical presentation may improve patient care.[1] Thus, we conducted a systematic review to determine whether the reported clinical presentation (and resultant management and outcomes) of tension pneumothorax differs between patients who are breathing unassisted (ie, breathing spontaneously and not receiving positive pressure ventilation) versus receiving assisted (ie, positive pressure) ventilation. Our primary objective was to determine whether available clinical data support animal study observations of potentially important differences between subjects of varying ventilatory status in time to, severity, and frequency of presenting hemodynamic complications.[16,17,19] As systematic reviews of case reports and series of other uncommon/emergent conditions have guided clinical practice and future research,[27–31] we synthesized and analyzed data reported by these types of studies alongside a systematic review of observational studies.[1,32–35]

METHODS

A published protocol details our study methods.[1] This protocol was registered in the PROSPERO Register of Systematic Reviews

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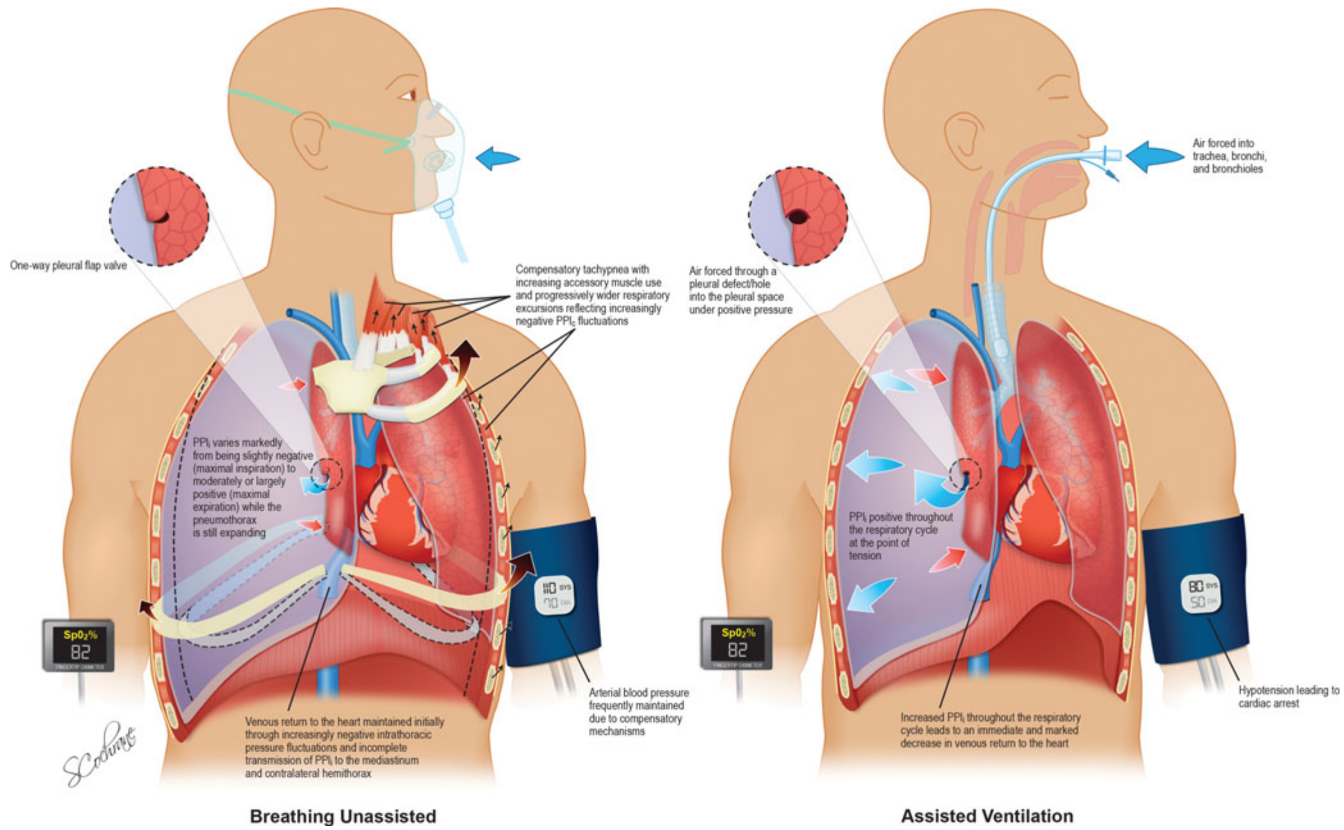

FIGURE 1. Proposed pathophysiology of tension pneumothorax among subjects who are breathing unassisted (ie, breathing spontaneously and not receiving positive pressure ventilation) versus receiving assisted (ie, positive pressure) ventilation. Tension pneumothorax results from air moving through a pleural defect into the intrapleural space, leading to progressive atelectasis, pulmonary arterial shunting, and hypoxemia.[1,16,17,19] In subjects who are breathing unassisted, theory suggests that the pleural defect is a 1-way flap valve that opens during inspiration and closes during expiration, resulting in progressive pneumothorax volumes during respiration. Animal studies suggest that subjects receiving assisted ventilation likely present with sudden hemodynamic and respiratory compromise whereas those breathing unassisted may more often first present with hypoxemia leading to progressive respiratory failure over a more delayed period. Among subjects who are breathing unassisted, several compensatory mechanisms likely prevent hemodynamic compromise during progressive pneumothorax volumes, including increasing respiratory rates and tidal volumes and increasingly negative contralateral chest excursions.[1,6,16,17] Methods by which these compensatory mechanisms may maintain arterial blood pressure during tension pneumothorax include incomplete transmission of pneumothorax-related pressure to the mediastinum and contralateral hemithorax and maintenance of cardiac blood return through a venous siphon effect from increasingly negative contralateral intrathoracic pressures.[1,17] In contrast, among those receiving assisted ventilation (who are likely incapable of mounting a sufficient compensatory response because of sedation and raised inspiratory pressures), increased intrapleural pressure throughout the respiratory cycle produces an immediate and marked decrease in cardiac venous return, which likely frequently leads to hypotension and may result in cardiac arrest.[1,19–21] PPl_i indicates ipsilateral intrapleural pressure; PPl_c, contralateral intrapleural pressure.

(registration number: CRD42013005826) and developed according to recommendations for conducting systematic reviews and meta-analyses.[1,35–37]

Data Sources

With assistance from a medical librarian (H.L.R.), we searched Ovid MEDLINE and EMBASE, PubMed, and the Cochrane Library from their first available dates to October 15, 2013 without restrictions (see our protocol[1] for details regarding database search strategies). To identify additional/ongoing studies, we searched personal files, wrote to colleagues and content experts, and investigated 2 clinical trials registries (ClinicalTrials.gov and www.Controlled-Trials.com). We also used the PubMed "related articles" and Google Scholar "cited by" features and manually searched reference lists of included articles and relevant review papers identified during the search.

Study Selection

Two physicians (D.J.R. and C.B.) independently reviewed titles and abstracts of citations identified by the search and selected articles for full-text review. Potentially relevant non-English language articles were translated into English. We included observational (cohort, case-control, and cross-sectional) studies and case reports and series[38,39] that reported original data on clinical manifestations of tension

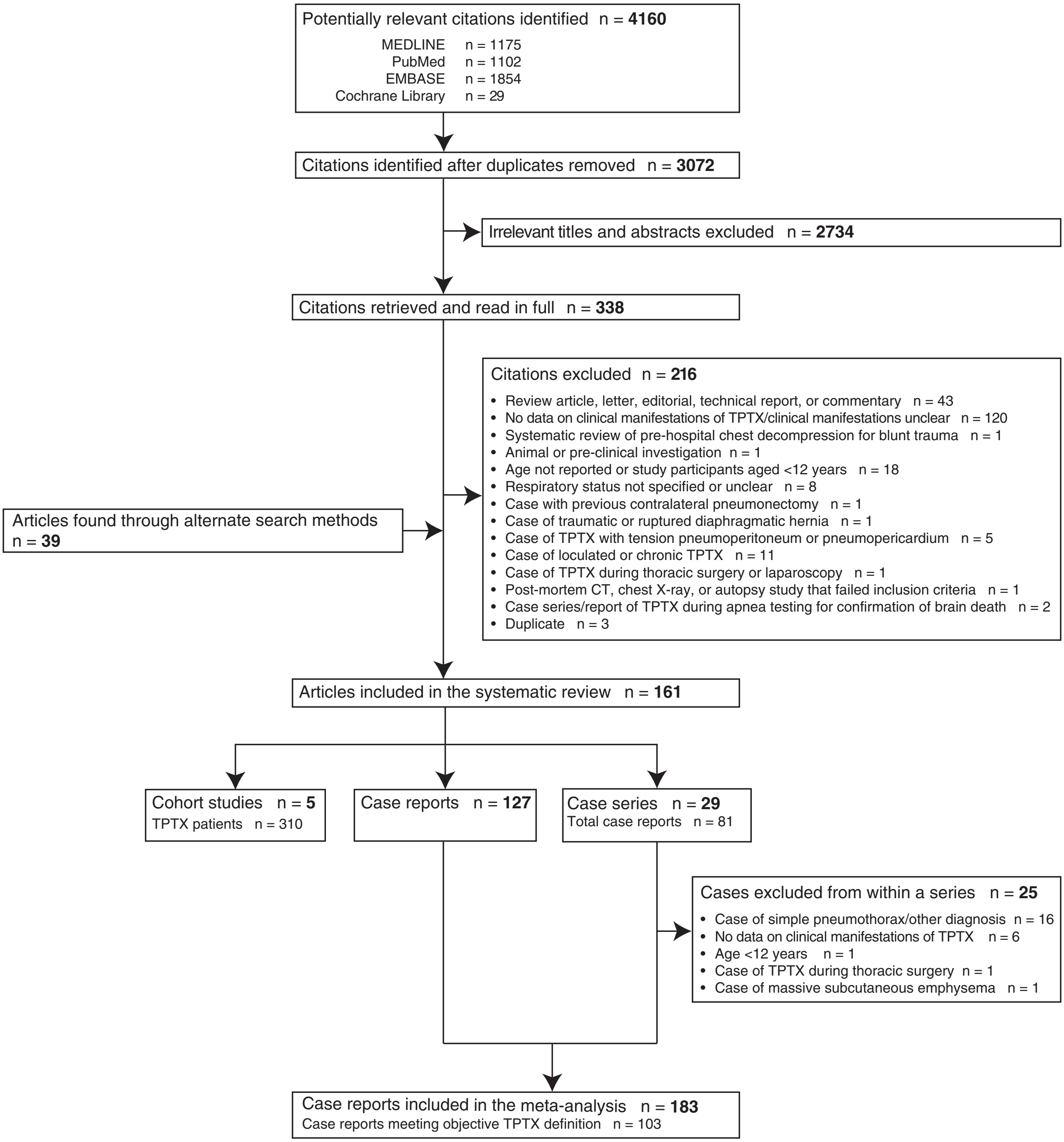

FIGURE 2. Flow of articles through the systematic review. CT indicates computed tomography; TPTX, tension pneumothorax.

pneumothorax. We defined clinical manifestations as patient-level findings gathered during medical interview, physical examination, or through invasive monitoring or treatment equipment or diagnostic studies.[1,40] Studies and reports of fatal cases were included if the condition causing death was attributed by authors to be tension pneumothorax and associated with expulsion of air on thoracic decompression or determined by a pathologist to be present on autopsy.[1] We excluded studies and reports not describing patient ventilatory status and those involving children (defined as age <12 years[41]), as their clinical presentation likely differs from older patients because their mediastinum and thoracic wall are more compliant.[1,5,16] We also excluded studies and reports involving patients with conditions that could misrepresent the more common clinical manifestations of tension pneumothorax.[1]

Disagreements regarding study eligibility were resolved by discussion after the entire article had been reread in full. Inter-investigator agreement was quantified using kappa (κ) statistics,[42] and the κ-statistic interpretation guidelines suggested by Altman.[43]

Data Extraction

Two physicians (D.J.R. and C.B.) independently extracted data from included studies and case reports using a data extraction spreadsheet.[1] Data extracted included study and case characteristics and reported clinical manifestations, initial management, and outcomes of tension pneumothorax.[1] For case reports, the 2 physicians independently categorized times from onset of symptoms, a deterioration in clinical status, or iatrogenic production of a pneumothorax to respiratory decompensation/arrest or hypotension/cardiac arrest according to whether they were described to occur suddenly (approximately 0 to 5 minutes), acutely (approximately >5 to 60 minutes), subacutely (approximately >60 to 180 minutes), or in a more delayed fashion (approximately >180 minutes). Clinical manifestations data were abstracted as proximal as possible to author's descriptions of pretreatment diagnoses of tension pneumothorax. When partial pressure of arterial oxygen (PaO_2) and fraction of inspired oxygen (FiO_2) values were not provided, these were estimated from reported arterial oxygen saturation (SpO_2) values and oxygen delivery device flow rates using conversion tables.[44]

Risk of Bias Assessment

For observational studies, 2 physicians (D.J.R. and C.B.) independently evaluated whether tension pneumothorax diagnoses were supported by radiographic findings/response to thoracic decompression and whether overlap existed between diagnostic criteria and reported clinical manifestations.[1] They also evaluated settings from which patients were recruited to determine whether they were likely representative of the population of tension pneumothorax patients.[1] Finally, they assessed whether reported frequencies of clinical manifestations were precise [(by assessing widths of associated confidence intervals (CIs)] and whether clinical manifestations were sought thoroughly and consistently (by determining methods by which they were gathered and whether this was done similarly across all study patients).[1]

For case reports, the 2 physicians independently determined whether patient presentations satisfied a published tension pneumothorax definition.[1] According to this definition, a tension pneumothorax was defined as one "that results in significant respiratory or hemodynamic compromise that reverses (or at least significantly improves) on thoracic decompression alone."[1,6]

Observational Study Data Synthesis

As included observational studies were limited by clinical heterogeneity, planned observational study meta-analyses[1] were not conducted. Results of these studies were instead described narratively. Exact, 95% CIs surrounding dichotomous clinical manifestations variables reported by observational studies were determined using the Clopper-Pearson method.[45]

Case Reports and Series Data Synthesis and Analysis

We summarized characteristics of reported cases and their described clinical manifestations, management, and outcomes as proportions, medians (with interquartile ranges), and means (with standard deviations). Dichotomous and continuous variables were compared using Fisher exact and Wilcoxon rank sum or matched-pairs signed-ranks tests, respectively.

We estimated unadjusted and adjusted mean differences and odds ratios (ORs) comparing hemodynamic events at tension pneumothorax diagnosis between cases who were breathing unassisted and receiving assisted ventilation. To accommodate for clustering of clinical manifestation variables in case series, we conducted these comparisons using generalized estimating equations with independent correlational data structures.[46] Model covariates for adjusted analyses included age; antihypertensive or vasopressor administration before diagnosis; preexisting shock; history of hypertension, heart failure, or pulmonary disease; and concomitant diagnosis of hemothorax, other pleural effusion, or new pulmonary disease.[1] A separate clustered logistic regression model was used to determine whether subcutaneous emphysema, tracheal deviation, jugular venous distention, ipsilateral percussion hyperresonance, hypoxia, hypotension, respiratory arrest, or cardiac arrest independently predicted ventilatory status across included case reports.

To test the robustness of our findings, we conducted sensitivity analyses in which we recalculated the aforementioned comparisons using only those cases that satisfied the published tension pneumothorax definition.[6] We also explored whether adjusted ORs varied in magnitude or direction among subgroups of cases.[1] We considered 2-sided P values of less than 0.05 significant. Stata MP version 13.1 (Stata Corp., College Station, TX) was used for statistical analyses.

RESULTS

Study Selection

Among 4160 citations identified by the search, we included 5 cohort studies (n = 310 total patients),[12,47–50] 29 case series (median, 2 cases per series; range, 1–5), and 127 case reports in the systematic review (Fig. 2). Inter-investigator agreement on full-text article inclusion was good (κ-statistic, 0.75; 95% CI, 0.68–0.82). We requested supplementary information on study procedures or reported cases from 11 authors, and 10 responded.[3,11,12,48,51–56] After excluding 25 cases that failed inclusion criteria from within included case series, 183 cases were included in the synthesis and analysis of case reports and series data.

Description of Included Cohort Studies and Case Reports

Characteristics of included cohort studies are presented in Table 1. Studies were published between 2005 and 2014. Three exclusively enrolled prehospital trauma patients treated with needle thoracostomy for suspected tension pneumothoraces,[12,48,50] 1 included only injured patients who received prehospital tube thoracostomy,[49] and 1 enrolled ICU patients with both ventilator-associated simple and tension pneumothoraces.[47] Mean patient ages ranged from 31.5 to 67 years. Three studies included patients receiving assisted ventilation,[47–49] whereas only 1 reported separately on patients who were breathing unassisted versus receiving assisted ventilation.[50] The fifth study included 2 groups of patients of which 61% and 87% were receiving assisted ventilation.[12]

Among the 183 included cases, 86 (47.0%) were breathing unassisted and 97 (53.0%) receiving assisted ventilation (see Table in Supplemental Digital Content 1, available at http://links.lww.com/SLA/A690, for details regarding case ventilatory statuses). Most (75.4%) cases were reported after the year 1990. The proportion of reported cases who were breathing unassisted increased across the study search period from a minority of the total reports before 1994 to the majority of them thereafter (see Figure in Supplemental Digital Content 2, available at http://links.lww.com/SLA/A691).

The Table in Supplemental Digital Content 3, available at http://links.lww.com/SLA/A692, provides a bibliography of included case reports/series and characteristics of individual cases. The demographics and medical history of cases were similar between ventilatory status groups (Table 2). Mean age of all cases was 45.5 years (standard deviation, 20.2 years). A total of 3.5% of cases who were breathing unassisted received general anesthesia before diagnosis versus 55.7% receiving assisted ventilation. Bilateral tension pneumothoraces were less frequent among cases breathing unassisted (2.3%) versus receiving assisted ventilation (24.4%).

TABLE 1. Study and Patient Characteristics and Tension Pneumothorax Clinical Manifestations Reported by Cohort Studies Included in the Systematic Review

Source, Country	Design/ Setting	Selection Criteria	Tension PTX Definition	Mean Age, yr	Ventilatory Status		Clinical Manifestation(s) Reported		Data on Simple and Suspected Tension PTXs Combined
					Group	Type	Description	% (95% CI)	
Hsu et al[47] (2014)	Ret cohort/ Taiwan	ICU patients with MV-associated PTX	Mediastinal shift on CXR with hemodynamic compromise	67*	AV (n = 73)	ET intubation and MV	Pao_2/Fio_2 ratio, mean (SD), mm Hg	150 (91)	No
Ball et al[12] (2010)	Ret cohort/ United States	Blunt injured patients who received NT for suspected tension PTX while being transported to hospital via helicopter or ground ambulance	NR	33.5	61% AV (n = 26)	ET intubation and no tracheal intubation	SBP ≤90 mm Hg	17.0 (4.4–34.9)	No
					87% AV (n = 75)	ET intubation and no tracheal intubation	SBP ≤90 mm Hg	28.0 (18.2–39.6)	
Mistry et al[48] (2009)	Ret cohort/ England	Patients with prehospital traumatic cardiac arrest, a hanging mechanism, or penetrating trauma requiring thoracostomy	NR	NR	AV (n = 6)	Bag mask ventilation or ET intubation	Decreased air entry Hyperexpanded chest	50.0 (11.8–88.1) 33.3 (4.3–77.7)	No
Massarutti et al[49] (2006)	Pro cohort/Italy	Anesthetized severe trauma patients rescued by a helicopter medical service and treated with on-scene simple thoracostomy for a PTX/hemo-PTX (91.5%) or hemothorax (5.1%)	Escape of air under pressure and/or immediate resolution of deranged vital signs after thoracostomy	51.6	AV (n = 55)	ET intubation and MV	Decreased air entry S/C emphysema Spo_2, mean (SD),% Spo_2 <90% Unobtainable Spo_2 SBP <90% mm Hg	54.5 (40.6–68.0) 27.3 (16.1–41.0) 86.4 (10.1) 50.9 (37.1–64.6) 7.3 (2.0–17.6) 34.5 (22.2–48.6)	Yes
Davis et al[50] (2005)	Ret cohort/United States	Adult (≥18 yr) major trauma patients who received NT by aeromedical crews for suspected tension PTX	NT insertion guidelines included MOI consistent with development of tension PTX, evidence of thoracic trauma, and physiologic derangement, including hypotension or profound hypoxemia	NR	BU (n = 12)	No ET intubation	Initial Spo_2 ≤90% Initial SBP unobtainable No initial pulse	25.0 (5.5–57.2) 0 (0–26.5) 0 (0–26.5)	No
					AV (n = 63)	ET intubation	Initial Spo_2 ≤90% Initial SBP unobtainable No initial pulse	11.1 (4.6–21.6) 6.3 (1.8–15.5) 39.6 (27.6–52.8)	

*Estimate of age applies to a larger group of patients who also had nontension pneumothoraces.

AV indicates assisted ventilation; BU, breathing unassisted; CXR, chest x-ray; ET, endotracheal; MOI, mechanism of injury; MV, mechanical ventilation; NR, not reported; NT, needle thoracostomy; pro, prospective; PTX, pneumothorax; ret, retrospective; S/C, subcutaneous; SBP, systolic blood pressure.

TABLE 2. Characteristics of Patients With Tension Pneumothorax Reported by Included Case Reports

Variable—No. (%)	Breathing Unassisted (n = 86)*	Assisted Ventilation (n = 97)*
Demographics		
Age, mean (SD), yr†	42.8 (20.8)	48.1 (19.5)
Male sex	46 (53.5)	44/93 (47.3)
Past medical history		
Chronic lung disease	16 (18.6)	15 (15.5)
Asthma	5 (5.8)	3 (3.1)
COPD	6 (7.0)	13 (13.4)
Other‡	6 (7.0)	2 (2.1)
Heart failure	1 (1.2)	4 (4.1)
Hypertension	4 (4.7)	6 (6.2)
Antihypertensive use	2 (2.3)	2 (2.1)
Present medical history		
Rib fractures	10 (11.6)	12 (12.4)
Flail chest	4 (4.7)	3 (3.1)
Massive chest wall subcutaneous emphysema	0 (0)	1 (1.0)
Newly diagnosed lung disease	19 (22.1)	24 (24.7)
Pulmonary contusion(s)	6 (7.0)	6 (6.2)
Pneumonia/pneumonitis	3 (3.5)	14 (14.4)
Pulmonary edema	1 (1.2)	2 (2.1)
ALI/ARDS	0 (0)	8 (8.3)
Massive hemoptysis	0 (0)	2 (2.1)
Other§	9 (10.5)	0 (0)
Hydro- or hemothorax¶	19 (22.1)	9 (9.3)
Empyema	2 (2.3)	0 (0)
Preexisting hypotension or shock	2 (2.3)	2 (2.1)
Antihypertensive administration before diagnosis	0 (0)	4 (2.2)
Inotrope or vasopressor administration	1 (1.2)	5 (5.2)
Systemic air embolism	0 (0)	2 (2.1)
General anesthesia before diagnosis	3 (3.5)	54 (55.7)
Etiology of tension pneumothorax		
Trauma	17 (19.8)	14 (14.4)
Barotrauma	3 (3.5)	50 (51.6)
Central venous catheter insertion	2 (2.3)	16 (16.5)
Non–central venous catheter-related needle lung injury‖	5 (5.8)	2 (2.1)
Tracheobronchial injury during NG/tracheostomy tube insertion	4 (4.7)	3 (3.1)
Cardiopulmonary resuscitation	0 (0)	1 (1.0)
Thoracostomy tube complications	6 (7.0)	8 (8.2)
Malposition or small tube size	0 (0)	7 (7.2)
Occlusion or kinking	1 (1.2)	1 (1.0)
Pleural suction failure or malfunction	2 (2.3)	0 (0)
Heimlich valve reversal, occlusion, or malfunction	3 (3.5)	0 (0)
Primary spontaneous	14 (16.3)	0 (0)
Secondary spontaneous	21 (24.4)	3 (3.1)
COPD	5 (5.8)	2 (2.1)
Asthma	2 (2.3)	0 (0)
Ruptured hydatid cyst	8 (9.3)	0 (0)
Other	6 (7.0)	1 (1.0)
Gastrointestinal perforation	9 (10.5)	2 (2.1)
Perforated esophagus, duodenum, or gastric ulcer**	7 (8.1)	2 (2.1)
Colonoscopy-related colon or rectal perforation	2 (2.3)	0 (0)
Unclear	9 (10.5)	7 (7.2)
Bilateral tension pneumothorax	2 (2.3)	22/90 (24.4)
Clinical setting tension pneumothorax encountered		
Prehospital	9 (10.5)	0 (0)
Emergency department	45 (52.3)	11 (11.3)
Intensive care unit	4 (4.7)	25 (25.8)
Operating room	3 (3.5)	46 (47.4)
Postanesthesia care unit	1 (1.2)	11 (11.3)
Hospital ward	11 (12.8)	0 (0)
Other in-hospital setting††	4 (4.7)	2 (2.1)
In-hospital setting unclear	9 (11.7)	2 (2.1)

*Denominator of reported responses is given if different than stated in the column heading. The number of responses in a given category may be greater than the category total if responses are not mutually exclusive.

†Age reported among 92 case reports of patients receiving assisted ventilation and all case reports of those breathing unassisted.

‡Other types of chronic lung disease included cystic fibrosis, tuberculosis, sarcoidosis, essential pulmonary hemosiderosis, lung cancer, left upper lobe bronchial atresia, and an unspecified type of previous lung damage.

§Other types of newly diagnosed lung disease included pulmonary hydatid disease and talc-induced pulmonary granulomatosis.

¶Two cases in the breathing unassisted group had a massive hemothorax.

‖These needle lung injuries occurred secondary to liver biopsy, acupuncture, pigtail thoracostomy tube insertion, or instillation of chest wall or intrapleural anesthesia.

**Duodenal perforation was secondary to endoscopic retrograde cholangiography in both cases.

††Other settings included the endoscopy or angiography suite and the diagnostic imaging department.

ALI indicates acute lung injury; ARDS, acute respiratory distress syndrome; COPD, chronic obstructive pulmonary disease; CVC, central venous catheter; NG, nasogastric.

Trauma was a relatively commonly reported cause of tension pneumothorax among all cases (Table 2). However, spontaneous pneumothoraces and gastrointestinal perforation were more frequently described etiologies among cases breathing unassisted whereas barotrauma and attempted central venous catheter insertions were more commonly reported causes among cases receiving assisted ventilation.

Risk of Bias Assessment

An overview of the risk of bias of included cohort studies is shown in Table 3. In all studies, tension pneumothorax diagnoses were partly supported by diagnostic imaging findings and/or the cardiorespiratory response of the patient to thoracic decompression. Described patient presentations or case definitions partly satisfied the published tension pneumothorax definition in 3 cohort studies.[48–50] One study combined some data on clinical manifestations of simple and tension pneumothoraces together.[49]

The 2 physicians independently agreed that clinical conditions of 103 (57.2%) included cases satisfied the published tension pneumothorax definition (κ-statistic, 0.89; 95% CI, 0.82–0.95). Characteristics of these cases were similar when compared with all cases (see Table in Supplemental Digital Content 4, available at http://links.lww.com/SLA/A693).

Reported Clinical Presentation of Tension Pneumothorax

Signs and Symptoms

Tables 1 and 4 summarize signs and symptoms of tension pneumothorax reported by included cohort studies and case reports, respectively. Signs and symptoms reported by all included case reports were similar to those that satisfied the published tension pneumothorax definition (see Table in Supplemental Digital Content 5, available at http://links.lww.com/SLA/A694).

Symptoms and Respiratory Vital Signs

Symptoms reported among case reports of patients breathing unassisted included chest pain (52.3%), dyspnea (38.4%), and shortness of breath (31.4%). Respiratory distress was described in 41.9% of cases breathing unassisted versus 8.3% receiving assisted ventilation.

Many (46.5%) case reports of patients breathing unassisted described tachypnea. Hypoxia or requirement for supplemental oxygen was reported among 43 (50.0%) cases who were breathing unassisted versus 89 (91.8%) receiving assisted ventilation ($P < 0.001$). Hypoxia was also reported among 25.0% of patients breathing unassisted versus 11.1% to 50.9% receiving assisted ventilation across 2 included cohort studies.[49,50] The median PaO_2/FIO_2 ratio among all included case reports was 73.0 (interquartile range, 48.4–152.6). One included cohort study of mechanically ventilated patients with tension pneumothoraces reported a mean PaO_2/FIO_2 ratio of 150.[47] Respiratory arrest occurred in 9.3% of case reports of patients breathing unassisted.

Head and Chest Examination

Jugular venous distention (7.1%) and contralateral tracheal deviation (9.3%) were uncommonly reported by included case reports and were not described by any of the included cohort studies. As compared with cases who were breathing unassisted, subcutaneous emphysema was noted more often (10.5% vs 30.9%; $P = 0.001$) and contralateral tracheal deviation was noted less often (17.9% vs 2.9%; $P = 0.004$) among cases receiving assisted ventilation. In one included cohort study, subcutaneous emphysema was reported among 27.3% of patients receiving assisted ventilation.[49]

Ipsilateral decreased air entry, percussion hyperresonance, and decreased thoracic excursions/mobility were the most commonly reported chest examination findings among case reports of unilateral tension pneumothoraces. Ipsilateral decreased air entry was also reported among 50.0% to 54.5% of patients receiving assisted ventilation across 2 included cohort studies.[48,49] Hyperresonance to percussion was more commonly described among case reports of patients breathing unassisted versus receiving assisted ventilation (26.7% vs 8.3%; $P = 0.001$).

Cardiovascular Vital Signs

Unadjusted systolic, diastolic, and mean arterial blood pressures were substantially higher among cases who were breathing unassisted versus receiving assisted ventilation (Fig. 3). After adjustment, cases who were breathing unassisted had higher reported systolic (126 mm Hg vs 94 mm Hg; difference = 32 mm Hg; 95% CI, 19.8–45.0 mm Hg; $P < 0.001$) and mean arterial blood pressures (95.0 mm Hg vs 62.8 mm Hg; difference = 32.8 mm Hg; 95% CI, 22.0–43.7 mm Hg; $P < 0.001$) than those receiving assisted ventilation. Moreover, when compared with cases who were breathing unassisted, the adjusted odds of hypotension (defined a priori as a mean arterial pressure $\leq$60 mm Hg[1]) and cardiac arrest were 12.6 (95% CI, 5.8–27.5) and 17.7 (95% CI, 4.0–78.4) times higher among those receiving assisted

TABLE 3. Risk of Bias Assessment for the Cohort Studies Included in the Systematic Review

Source	Tension Pneumothorax Diagnosis Supported by: Response to Thoracic Decompression	Tension Pneumothorax Diagnosis Supported by: Radiography	Condition Described Satisfied Published Tension PTX Definition*	Overlap Between Diagnostic Criteria and Reported Clinical Manifestations	Representative Patient Population	Diagnosis Sought Thoroughly and Consistently
Hsu et al[47] (2014)	Unclear	Yes	No	No	Yes	Unclear
Ball et al[12] (2010)	Yes	Partly	Unclear	Unclear	Yes	Unclear
Mistry et al[48] (2009)	Partly	No	Partly	Unclear	Yes	Unclear
Massarutti et al[49] (2006)	Partly	No	Partly	Unclear	Yes	Unclear
Davis et al[50] (2005)	Yes	No	Partly	No	Yes	Unclear

*According to this definition, a tension PTX is one that results in significant respiratory or hemodynamic compromise that reverses (or at least significantly improves) on thoracic decompression alone.

PTX indicates pneumothorax.

TABLE 4. Clinical Manifestations of Tension Pneumothorax Reported by Included Case Reports

Variable—No. (%)*	Breathing Unassisted (n = 86)†	Assisted Ventilation (n = 97)†	*P*
Symptoms			
Chest pain	45 (52.3)	0 (0)	NA
Dyspnea	33 (38.4)	0 (0)	NA
Shortness of breath	27 (31.4)	0 (0)	NA
Respiratory vital signs			
Respiratory distress	36 (41.9)	8 (8.3)	NA
Tachypnea (RR ≥20/as defined by authors)	40 (46.5)	NA	NA
Bradypnea (RR ≤12/as defined by authors)	1 (1.2)	NA	NA
Hypoxia (Sp_{O_2} <92% or Pa_{O_2} <60 mm Hg on room air/as defined by authors)	9 (10.5)	5 (5.2)	0.27
Requiring supplemental oxygen	34 (39.5)	84 (86.6)	<0.001
Pa_{O_2}/Fi_{O_2} ratio, median (IQR)‡	75.8 (53–215.6)	67.5 (44–127.8)	0.09
Pa_{O_2}/Fi_{O_2} ratio <300	24/31 (77.4)	27/28 (96.4)	0.06
Pa_{O_2}/Fi_{O_2} ratio 200–300	1/24 (4.2)	1/28 (3.6)	>0.99
Pa_{O_2}/Fi_{O_2} ratio 100–200	5/24 (20.8)	9/28 (32.1)	0.53
Pa_{O_2}/Fi_{O_2} ratio <100	18/24 (75.0)	17/28 (60.7)	0.38
Neck and chest examination			
Jugular venous distention	4 (4.7)	9 (9.3)	0.26
Contralateral tracheal deviation	15/84 (17.9)	2/68 (2.9)	0.004
Subcutaneous emphysema	9 (10.5)	30 (30.9)	0.001
Ipsilateral chest signs§			
Thoracic hypoexpansion	3 (3.5)	1 (1.0)	0.34
Thoracic hyperexpansion	2 (2.3)	2 (2.1)	>0.99
Decreased thoracic excursions/mobility	6 (7.0)	12 (12.4)	0.32
Increased thoracic excursions/mobility	0 (0)	0 (0)	NA
Hyperresonance to percussion	23 (26.7)	8 (8.3)	0.001
Decreased air entry on auscultation	50 (58.1)	44 (45.4)	0.10
Contralateral chest signs§			
Thoracic hypoexpansion	0/84 (0)	0/68 (0)	NA
Thoracic hyperexpansion	0/84 (0)	0/68 (0)	NA
Decreased thoracic excursions/mobility	0/84 (0)	1/68 (1.5)	0.45
Increased thoracic excursions/mobility	0/84 (0)	0/68 (0)	NA
Hyperresonance to percussion	0/84 (0)	1/68 (1.5)	0.45
Decreased air entry on auscultation	8/84 (9.5)	6/68 (8.8)	>0.99
Respiratory arrest	8 (9.3)	NA	NA
Cardiovascular vital signs			
Heart rate, median (IQR)¶	116 (98–130)	110 (90–136)	0.78
Tachycardia (heart rate ≥100/as defined by authors)	37 (43.0)	30 (30.9)	0.09
Bradycardia (heart rate ≤60/as defined by authors)	5 (5.8)	8 (8.3)	0.58
Hypotension (MAP ≤60 mm Hg/as defined by authors)	14 (16.3)	64 (66.0)	<0.001
Cardiac arrest	2 (2.3)	28 (28.9)	<0.001
Initial arrest rhythm reported	0 (0)	12/28 (42.9)	NA
Ventricular fibrillation	NA	1/12 (8.3)	NA
Pulseless electrical activity	NA	9/12 (75.0)	NA
Asystole	NA	2/12 (16.7)	NA

*Contralateral tracheal deviation and contralateral chest signs analyzed only for those patients with unilateral tension pneumothoraces.
†Denominator of reported responses is given if different than stated in the column heading.
‡The Pa_{O_2}/Fi_{O_2} ratio was able to be computed for 31 and 28 patients who were breathing unassisted versus receiving assisted ventilation, respectively.
§Ipsilateral and contralateral refer to the same versus opposite hemithorax affected by tension pneumothorax, respectively.
¶Heart rate was reported among 41 case reports of patients who were breathing unassisted versus 33 receiving assisted ventilation, respectively.
IQR indicates interquartile range; MAP, mean arterial pressure; NA, not applicable; RR, respiratory rate.

ventilation, with the most commonly reported initial arrest rhythm being pulseless electrical activity (75.0%). These increased odds were robust to a number of sensitivity analyses (see Table in Supplemental Digital Content 6, available at http://links.lww.com/SLA/A695). One included cohort study also reported that none of the included patients with a tension pneumothorax who were breathing unassisted versus 39.6% of those receiving assisted ventilation presented without an arterial pulse.[50]

Clustered logistic regression suggested that contralateral tracheal deviation was independently associated with an increased odds of breathing unassisted (OR, 33.3; 95% CI, 3.0–364.5; $P = 0.004$) whereas hypotension (OR, 8.6; 95% CI, 3.5–31.5; $P < 0.001$) and subcutaneous emphysema (OR, 5.9; 95% CI, 1.9–18.4; $P = 0.002$) were independently associated with an increased odds of having received assisted ventilation.

Disease Evolution

Approximate times to development of hypotension/cardiac arrest could be determined for 20 (90.9%) case reports of patients breathing unassisted versus 54 (72.0%) receiving assisted ventilation. In contrast to cases who were breathing unassisted, the majority (70.4%) of those receiving assisted ventilation who experienced hypotension or cardiac arrest developed these signs within minutes of clinical presentation (Fig. 4).

Initial Investigations

A chest radiograph was obtained before treatment in 55 (64.0%) case reports of patients who were breathing unassisted versus 44 (45.4%) receiving assisted ventilation. A pneumothorax occupying greater than 50% of hemithorax volume (55.8%), contralateral

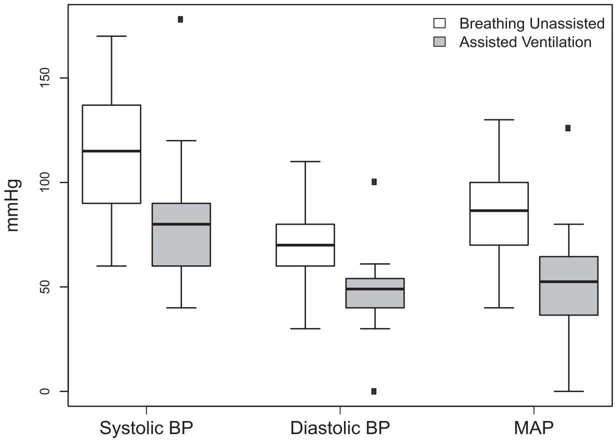

FIGURE 3. Reported arterial blood pressures among case reports of patients with tension pneumothorax stratified by patient ventilatory status. A total of 103 (56.3%), 89 (48.6%), and 96 (52.5%) case reports described systolic, diastolic, and mean arterial blood pressures, respectively, with no difference observed in the frequency of reporting on these variables by case ventilatory status. Blood pressure data were abstracted as proximal as possible to author's descriptions of the pretreatment diagnosis of tension pneumothorax. BP indicates blood pressure; MAP, mean arterial pressure.

mediastinal deviation (57.1%), and ipsilateral hemidiaphragm flattening (22.2%) were the most commonly reported chest radiography findings (see Table in Supplemental Digital Content 7, available at http://links.lww.com/SLA/A696).

Presenting electrocardiographic findings were described by 17 (9.3%) included case reports (see Table in Supplemental Digital Content 7, available at http://links.lww.com/SLA/A696). Commonly reported findings included sinus tachycardia (41.2%), ST segment/T wave changes (41.2%), and decreased voltage (29.4%).

Invasive Cardiopulmonary Measurements

Several case reports of patients receiving assisted ventilation described changes in cardiopulmonary variables between baseline and diagnosis of tension pneumothorax (see Table in Supplemental Digital Content 8, available at http://links.lww.com/SLA/A697). These changes included significant increases in peak inspiratory and central venous pressures, rises in pulmonary vascular resistance, and decreases in cardiac index.

Management and Outcomes

Needle (46.3% vs 36.2%) and tube (46.3% vs 50%) thoracostomy were the most frequently reported initial interventions among cases who were breathing unassisted versus receiving assisted ventilation, respectively. The reported mortality of tension pneumothorax in cases breathing unassisted (6.7%) was substantially lower than that for patients receiving assisted ventilation (22.7%) ($P = 0.003$). One cohort study reported that development of tension pneumothorax among mechanically ventilated patients was associated with a 7.4 (95% CI, 2.2–24.6) times increase in the adjusted hazard of mortality.[47]

DISCUSSION

In this systematic review, after considering findings of animal studies of tension pneumothorax,[14–17,19–21] we synthesized information on the clinical presentation of patients with tension pneumothorax reported by 5 cohort studies and 183 case reports (n = 86 breathing unassisted, n = 97 receiving assisted ventilation). When summarized, these studies highlight a number of reported differences in clinical presentation depending on the ventilatory status of the patient (see Table 5 for a summary). They also highlight how clinicians reportedly diagnose and manage these patients in practice.

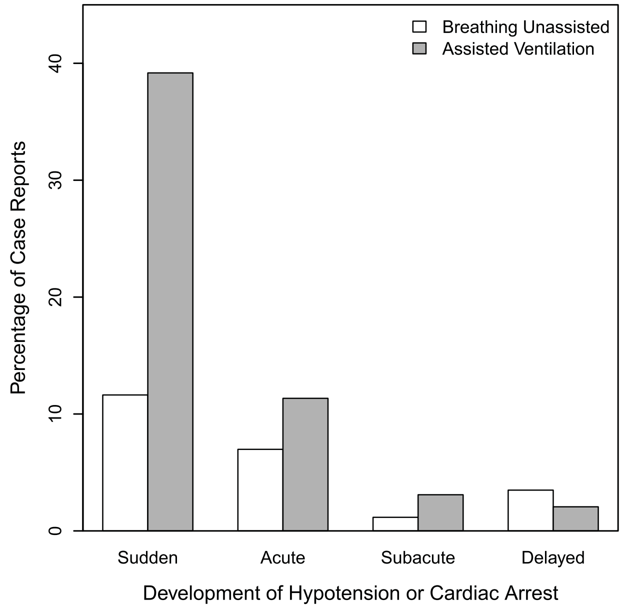

FIGURE 4. Percentage of case reports of patients with tension pneumothorax who presented with sudden, acute, subacute, and delayed hypotension or cardiac arrest. Sudden was defined as approximately 0 to 5 minutes, acute as more than 5 to 60 minutes, subacute as more than 60 to 180 minutes, and delayed as more than 180 minutes.

Cases who were breathing unassisted were frequently reported to present with shortness of breath, dyspnea, tachypnea, respiratory distress, hypoxemia, and ipsilateral decreased air entry and percussion hyperresonance. Pulmonary dysfunction progressed to respiratory arrest in 9% of cases breathing unassisted. Hypotension and cardiac arrest were reported among only 16% and 2% of included cases who were breathing unassisted, respectively, and among none of the 12 breathing unassisted patients in one included cohort study.[50] When these outcomes did occur, more than half of the cases seemed to develop them in a relatively delayed fashion, and nearly two-thirds of clinicians obtained a chest radiograph before performing thoracic decompression. Despite this, half of the cases were managed first with needle thoracostomy.

Hypoxemia, subcutaneous emphysema, and ipsilateral decreased air entry were also commonly described among case reports and cohort studies of patients receiving assisted ventilation. However, the clinical presentation of these patients differed substantially from those who were breathing unassisted, potentially as a result of their requirement for ventilatory support and/or greater illness severity. Similar to animal study findings (Fig. 1), when compared with case reports of patients who were breathing unassisted, hypotension and cardiac arrest were significantly more commonly reported to be present at the time of tension pneumothorax diagnosis. These outcomes were also frequently described to occur within minutes of a sudden clinical deterioration (eg, a decrease in SpO_2) or an iatrogenic creation of a pneumothorax. Interestingly, however, half of the cases receiving assisted ventilation underwent chest radiography before

TABLE 5. Semiquantitative Summary of Reported Signs and Symptoms of Tension Pneumothorax Stratified by Patient Ventilatory Status*

Variable	Breathing Unassisted	Assisted Ventilation
Symptoms		
Chest pain	****	
Shortness of breath	***	
Dyspnea	***	
Respiratory distress	***	*
Vital signs		
Hypoxia/requiring supplemental oxygen	***	****
Tachypnea	****	
Tachycardia	***	***
Hypotension	*	****
Sudden onset of hypotension	*	***
More delayed onset of hypotension	***	*
Neck and chest examination findings		
Jugular venous distention	*	*
Contralateral tracheal deviation	**	*
Subcutaneous emphysema	*	***
Decreased air entry	****	****
Percussion hyperresonance	***	*
Thoracic hypoexpansion	*	*
Respiratory arrest	*	
Cardiac arrest	*	***

*Where *, **, *** and **** indicate that the sign or symptom was reported among approximately 0% to 15%, 15% to 30%, 30% to 45%, or >45% of included observational studies or case reports/series.

thoracic decompression and half were initially managed with tube thoracostomy.

Our findings may have implications for improving the diagnosis and treatment of tension pneumothorax. In contrast to classical medical teaching, contralateral tracheal deviation and jugular venous distention are uncommonly reported clinical manifestations of tension pneumothorax. Tension pneumothorax may have to be considered in patients who are breathing unassisted who present with predominantly respiratory signs and symptoms. As those who are breathing unassisted have seldom been reported to present with sudden hemodynamic compromise, it may be appropriate to obtain a chest radiograph in a monitored setting to confirm the diagnosis and lateralize the disease instead of performing urgent thoracic decompression for patients who are not in extremis.[5,6,13] Thoracic ultrasonography may be superior to chest radiography for this purpose, as it has a sensitivity of approximately 80% to 90% for detection of pneumothoraces (versus approximately 50% for supine chest radiography) and can be performed rapidly at the bedside.[57,58] Conversely, clinicians should be prepared to perform urgent thoracic decompression without chest radiographic confirmation in patients suspected of a tension pneumothorax who are receiving assisted ventilation, as these patients have frequently been reported to present with sudden hemodynamic compromise and/or cardiac arrest.

Our synthesis and analysis of case reports/series data has several potential limitations. Our estimates of the frequency of clinical manifestations of tension pneumothorax may have been influenced by underreporting of relatively common presentations of tension pneumothorax or overreporting of presentations that manifested more unusual or interesting clinical features.[1,59] However, as we can think of no reason why under- or overreporting would depend on case ventilatory status, it seems unlikely that selection bias would have influenced our between-group comparisons. Furthermore, although some of the included case reports could be argued not to represent tension pneumothorax, our findings were robust to sensitivity analyses that included only cases satisfying a published definition. Similarly, as we included case reports of patients with less common etiologies of tension pneumothorax (eg, gastrointestinal perforation), the validity of combining all cases together may be questioned.[1] Despite this, we are unsure why patients with a less common etiology would present with different clinical manifestations when compared to those with more common etiologies.[1,16,17,19–21] Finally, although some may argue that our findings may be due to unmeasured confounding,[59] this seems unlikely given that any unmeasured confounder that could account for the observed magnitude of the association between ventilatory status and hypotension/cardiac arrest would have to be very strongly associated with patient ventilatory status and highly predictive of hypotension and cardiac arrest. Thus, as our findings are consistent with results from animal studies,[16,17,19–21] we believe them to be clinically important.

CONCLUSIONS

The reported clinical presentation of tension pneumothorax depends on the ventilatory status of the patient. This may have implications for improving the diagnosis and treatment of this uncommon yet catastrophic clinical condition.

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