Observational management of penetrating occult pneumothoraces: Outcomes and risk factors for interval tube thoracostomy placement

Genna Beattie, MD, Caitlin M. Cohan, MD, Annie Tang, MD, Joshua Y. Chen, BS,
and **Gregory P. Victorino, MD, FACS**, *Oakland, California*

BACKGROUND: Guidelines for penetrating occult pneumothoraces (OPTXs) are based on blunt injury. Further understanding of penetrating OPTX pathophysiology is needed. In observational management of penetrating OPTX, we hypothesized that specific clinical and radiographic features may be associated with interval tube thoracostomy (TT) placement. Our aims were to (1) describe OPTX occurrence in penetrating chest injury, (2) determine the rate of interval TT placement in observational management and clinical outcomes compared with immediate TT placement, and (3) describe risk factors associated with failure of observational management.

METHODS: Penetrating OPTX patients presenting to our level 1 trauma center from 2004 to 2019 were reviewed. Occult pneumothorax was defined as a pneumothorax on chest computed tomography but not on chest radiograph. Patient groups included immediate TT placement versus observation. Clinical outcomes compared were TT duration and complications, need for additional thoracic procedures, length of stay (LOS), and disposition. Clinical and radiographic factors associated with interval TT placement were determined by multivariable regression.

RESULTS: Of 629 penetrating pneumothorax patients, 103 (16%) presented with OPTX. Thirty-eight patients underwent immediate TT placement, and 65 were observed. Twelve observed patients (18%) needed interval TT placement. Regardless of initial management strategy, TT placement was associated with longer LOS and more chest radiographs. Chest injury complications and outcomes were similar. Factors associated with increased odds of interval TT placement included Chest Abbreviated Injury Scale score of ≥4 (adjusted odds ratio [aOR], 7.38 [95% confidence interval, 1.43–37.95), positive pressure ventilation (aOR, 7.74 [1.07–56.06]), concurrent hemothorax (aOR, 6.17 [1.08–35.24]), and retained bullet fragment (aOR, 11.62 [1.40–96.62]) (all $p < 0.05$).

CONCLUSION: The majority of patients with penetrating OPTX can be successfully observed with improved clinical outcomes (LOS, avoidance of TT complications, reduced radiation). Interval TT intervention was not associated with risk for adverse outcomes. In patients undergoing observation, specific clinical factors (chest injury severity, ventilation) and imaging features (hemothorax, retained bullet) are associated with increased odds for interval TT placement, suggesting need for heightened awareness in these patients. (*J Trauma Acute Care Surg.* 2022;92: 177–184. Copyright © 2021 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Prognostic, level IV.

KEY WORDS: Occult pneumothorax; tube thoracostomy; chest tube; penetrating injury; observation.

With the routine use of thoracoabdominal computed tomography (CT) in the assessment of traumatically injured, identification of occult pneumothorax (OPTX) has become more frequent.[1,2] Recommendations on optimal management remain variable. While Advanced Trauma Life Support supports tube thoracostomy (TT) as the best treatment in almost all traumatic pneumothoraces (PTXs), a growing number of studies advocate for observational management in OPTXs.[3–9] In addition, guidelines from the Eastern Association for the Surgery of Trauma support observation in the hemodynamically normal patient.[10]

In penetrating chest injury, PTXs are present 80% of the time,[11] and it is estimated that 17% of penetrating PTXs are occult in nature.[12] Nevertheless, studies and current management recommendations are based predominately on findings of OPTXs resulting from blunt traumatic injury.[3,10] Further understanding of OPTX presentation and clinical progression in penetrating injury is needed. Moreover, TT when indicated is life-saving; however, with complication rates as high as 22%,[2,13–15] it carries the potential for significant morbidity. In addition, TT management also results in increased hospital resource utilization and cost. Thus, the ability to determine which patients require TT placement and which patients can be safely and successfully observed would be advantageous.

The occurrence of penetrating OPTX and associated clinical outcomes, particularly in patients undergoing observational management, remains unclear. As such, we hypothesized that specific clinical factors and radiographic features may be associated with need for interval TT placement in patients undergoing observational management for penetrating OPTX. The aims of our study were (1) to further describe the occurrence of OPTX in penetrating chest injury, (2) to determine the rate of interval TT placement in patients undergoing observational management and their clinical outcomes compared with immediate TT placement,

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From the Department of Surgery (G.B., C.M.C., A.T., G.P.V.), University of California, San Francisco, East Bay, Oakland; Chemical Sciences Division (J.Y.C.), Lawrence Berkeley National Laboratory, Berkeley, California.

Address for reprints: Genna Beattie, MD, Department of Surgery, University of California, San Francisco, East Bay, 1411 E 31st St, QIC 22134, Oakland, CA 94602; email: gbeattie@alamedahealthsystem.org.

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and (3) to describe clinical and radiographic risk factors associated with failure of observational management.

METHODS

After institutional review board approval, patients presenting to our level 1 trauma center from January 2004 to July 2019 with penetrating OPTX were reviewed. Occult pneumothorax was identified by query of our trauma registry for all penetrating injury patients with the diagnosis of pneumothorax (PTX). Initial chest radiograph (CXR) and chest CT reads were reviewed to identify patients with OPTX. Occult PTX was defined as a PTX identified on chest CT but not on CXR, with both imaging studies occurring during the patient's initial trauma assessment (CXR preceding chest CT). Included were all trauma patients, 16 years or older, with an OPTX confirmed by staff radiologist formal read. Excluded were patients with overt PTX (radiographically or tension PTX), patients without both CXR and chest CT imaging or available imaging records, patients with placement of a TT before either imaging modality, or patients with a presumed blunt etiology of the OPTX (i.e., extremity stab wound with subsequent fall).

Patients were grouped into those undergoing immediate TT placement versus observational management of their OPTX. Patient demographics and clinical and radiographic features were compared between groups. Observational management was determined based on documented intent of this treatment strategy in the patient's medical record by the trauma team. Occult pneumothorax occurrence was calculated using the total number of patients presenting with a penetrating PTX over the study period.

Demographic and clinical characteristics analyzed included sex, age, injury mechanism (gunshot vs. stab wound), single versus multiple penetrating chest wounds, self-inflicted injury, presenting vitals, Injury Severity Score (ISS), chest Abbreviated Injury Scale (chest AIS) scores, chest injury and non–chest injury diagnoses, operative procedures, intensive care unit (ICU) and hospital length of stay (LOS), positive pressure ventilation requirements, need for emergent operation on admission, complications (chest injury related and otherwise), disposition, 3-month emergency department representation, and readmissions. Data collected on TT placement included date and duration of placement, indication for placement, number of CXRs performed, requirement for subsequent video-assisted thoracoscopy or thoracotomy, and associated TT complications including need for repeat TT placement. Pigtail catheters for the management of acute traumatic PTX were not used at our institution during the study period, and none of the patients in the study received a pigtail catheter as part of their treatment for the OPTX.

Occult pneumothorax was identified based on review of initial trauma evaluation CXR and chest CT imaging. Performance of an extended focused assessment with sonography in trauma examination and findings of PTX were documented for patients in the study but not used in the OPTX definition. Imaging characteristics evaluated on chest CT included OPTX size, laterality (unilateral or bilateral), presence of concomitant hemothorax (HTX), pulmonary contusion, chest wall contusion, rib fractures (ipsilateral and contralateral), subcutaneous emphysema, and retained pulmonary bullet fragments. Size was measured on axial imaging using the radial distance of the largest air collection, in millimeters, between the parietal and visceral pleura/mediastinum in a line perpendicular to the chest wall.[3,16] In the case of bilateral OPTXs, the radiographic data and OPTX-related outcomes were evaluated individually. Clinical outcomes analyzed between groups included TT duration and complications, need for additional thoracic procedures, LOS, disposition, and documented readmissions.

To evaluate clinical and radiographic factors associated with an increased risk for TT placement in patients undergoing observational management, patients within the observation group were stratified into patients with successful observation (without need for TT intervention) versus patients requiring interval TT placement. Radiographic factors were based off of initial chest CT findings. A univariable logistic regression analysis was performed to determine which clinical patient factors and radiographic features were associated with increased odds of requiring interval TT placement. Clinical factors evaluated included age, sex, mechanism of injury, single versus multiple penetrating chest wounds, presenting vital signs, emergent operation on admission, ISS, chest AIS, and positive pressure ventilation. Variables with $p < 0.05$ on univariable analysis (injury mechanism, chest AIS, and positive pressure ventilation) were subsequently included in our multivariable logistic regression analysis. To avoid colinearity with chest AIS, ISS was not included in our multivariable analysis. Radiographic factors evaluated included OPTX size, laterality, concurrent HTX, pulmonary contusion, chest wall contusion, presence of rib fractures, subcutaneous emphysema, and retain bullet fragment(s). Similarly, variables with $p < 0.05$ on univariable analysis (HTX, pulmonary contusion, rib fractures, and retain bullet fragment) were included in our multivariable logistic regression analysis. An α value of <0.05 was used to define statistical significance in the multivariable analysis. To minimize overfit, clinical and radiographic factors were approached separately, allowing us to maintain the generalizability and utility of our findings.

Unless otherwise specified, normally distributed continuous statistical tests are reported as mean ± SD, and nonparametric statistical tests as medians with interquartile ranges (IQRs). Categorical statistical tests are reported as proportions. Clinical characteristics and outcome differences were analyzed using paired *t* test and the Mann-Whitney *U* test, as applicable for continuous data. Similarly, for analyzing differences between categorical variables χ^2 analysis and Fisher's exact test were used as appropriate. An α value of <0.05 was used to define statistical significance. Statistical analysis was performed using IBM SPSS Statistics for Windows software (version 25.0; IBM Corp., Armonk, NY).

RESULTS

Over the study period, 8,288 penetrating trauma patients were evaluated at our institution with 1,488 having penetrating thoracic injuries. Of these patients, a total of 629 penetrating PTX patients were identified. Based on the study definition of OPTX, 16% (103 of 629) of patients with penetrating PTX met our criteria for OPTX diagnosis and included in the study group (Fig. 1). Of these patients, 37% (38) underwent immediate TT placement, and 63% (65) underwent a trial of observational management. The patients in these two groups were similar in terms of age, sex, presenting vitals, ISS, chest AIS, isolated thoracic injury, and need for emergent operative intervention

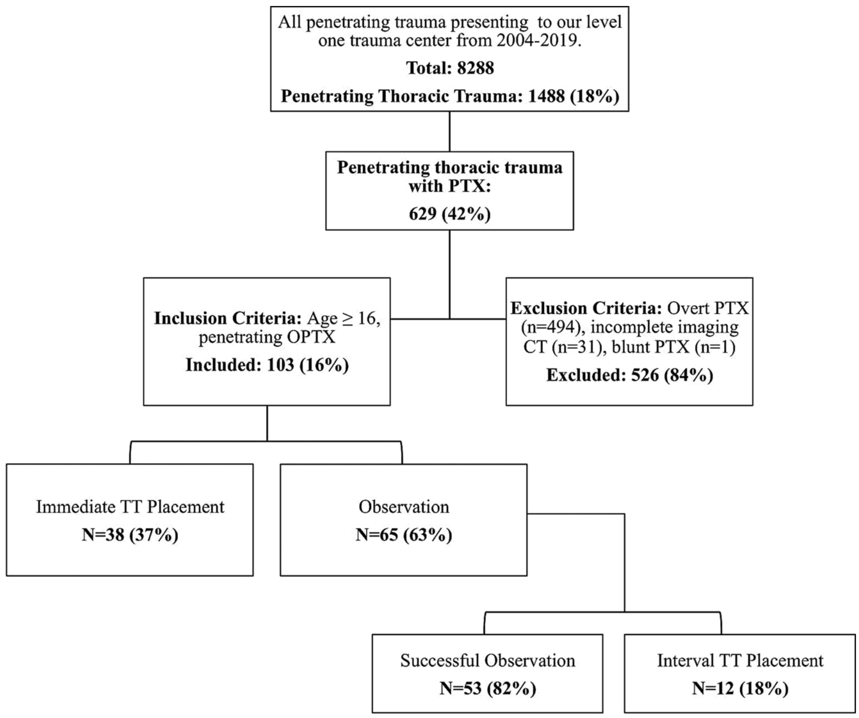

Figure 1. Penetrating OPTX: immediate TT placement versus observation. Flow diagram depicts study design.

(Table 1). Indication for emergent operative intervention included intra-abdominal injury (n = 12), cardiac/aortic injury (n = 2), craniotomy (n = 1), vascular exploration (n = 1), and orthopedic injury (n = 1). Although not statistically significant, OPTX was a result of stab injury for 53% of immediate TT patients compared with nearly 70% of observed patients. In patients with a self-inflicted OPTX injury (n = 7), all were due to stab injuries, and all underwent trial of observational management ($p = 0.048$). More patients with immediate TT placement presented with concurrent HTX on chest CT (93% vs. 46%; $p < 0.001$). Occult PTX size, presence of bilateral PTXs (occult or overt), pulmonary contusion, rib fractures, subcutaneous emphysema, and retained pulmonary bullet fragments were similar between groups (Table 1).

Indications for TT placement in the immediate TT group included OPTX (n = 13), HTX (n = 14), combined OPTX/HTX (n = 9), and after repair of diaphragm injury (n = 4). In the observation group, need for interval TT placement occurred in 12 of the 65 OPTXs evaluated (18%). Indication for interval TT placement included OPTX enlargement (n = 5), OPTX and HTX enlargement (n = 2), and HTX development (n = 5). Occult pneumothorax enlargement was based on CXR or CT imaging with all patients remaining asymptomatic and without clinical signs (change in respiratory status, oxygen requirements or tension PTX physiology).

To evaluate presenting clinical and radiographic risk factors associated with failure of observational management, we subsequently stratified the observed group into patients not requiring interval TT placement (n = 53) and patients requiring interval TT placement (n = 12). On comparison of clinical factors, patients were similar with regard to age, sex, presenting vital signs, and need for emergent operative intervention (Table 3). In the observational group, patients requiring interval TT placement more often had a gunshot injury (67% vs. 23%; $p = 0.0053$), higher ISS (20 [IQR, 12–25] vs. 13 [IQR, 9–16]; $p = 0.028$) and higher chest AIS (3.5 ± 0.8 vs. 3.0 ± 0.6; $p = 0.011$) and were more likely intubated (33% vs. 6%; $p = 0.018$) compared with patients with successful observational management (Table 3). Isolated thoracic injury was more common in patients with successful observational management than in patients requiring interval TT placement, 49% versus 8% ($p = 0.01$, Table 3). In univariable and adjusted analyses of clinical factors for the outcome of interval TT placement, chest AIS score of ≥4 (adjusted odds ratio [aOR], 7.38 [95% confidence interval, 1.43–37.95]; $p = 0.017$) and positive pressure ventilation (aOR, 7.74 [1.07–56.06]; $p = 0.043$) were associated with increased odds of interval TT placement (Table 2). Gunshot injury was associated with increased odds of interval TT placement in univariable analysis, but this association did not remain on adjusted analysis.

On comparison of chest CT imaging, patients requiring interval TT placement more often had concomitant HTX (77% vs. 38%; $p = 0.015$), pulmonary contusion (85% vs. 38%; $p = 0.0042$), rib fracture (54% vs. 22%; $p = 0.036$), and retained pulmonary bullet fragment (67% vs. 15%; $p < 0.001$) than patients with successful observational management (Table 3). Size of OPTX and presence of concomitant chest wall muscle contusion or subcutaneous emphysema was similar between the two groups (Table 3). In univariable and adjusted analyses of initial radiographic factors for the outcome of interval TT placement, concurrent HTX (aOR, 6.17 [1.08–35.24]; $p = 0.041$) and retained pulmonary bullet fragment (aOR, 11.62 [1.40–96.62]; $p = 0.023$) were associated with increased odds of interval TT placement in the observational group (Table 4). Concomitant pulmonary contusion and rib fractures were not associated with increased odds of interval TT placement in patients undergoing observation.

TABLE 1. OPTX Clinical and Imaging Characteristics: Immediate TT Placement Versus Observational Management

Characteristic	Immediate TT (n = 38)	Observation (n = 65)	*p*
Age	33.3 (13.3)	34.2 (12.8)	0.74
Male, n (%)	92 (35)	80 (52)	0.10
Injury type, n (%)			
Gunshot	18 (47)	20 (31)	0.092
Stab	20 (53)	45 (69)	
Chest wound, n (%)			
Single	24 (63)	32 (49)	0.17
Multiple	14 (37)	33 (51)	
Self-inflicted injury, n (%)	0 (0)	7 (11)	**0.036**
SBP, mm Hg	135 (117–150)	136 (111–150)	0.59
PP, mm Hg	52 (40–71)	50 (40–65)	0.63
HR, per min	99 (23.1)	94 (18.0)	0.24
RR, per min	23 (12.7)	21 (3.8)	0.13
Oxygen saturation	98 (2.1)	99 (2.1)	0.61
ISS	15 (10–23)	13 (10–17)	0.22
ISS >15, n (%)	19 (50)	21 (32)	0.075
Chest AIS	3.3 (0.6)	3.1 (0.7)	0.10
Chest AIS ≥ 4, n (%)	12 (32)	14 (22)	0.26
ICU admit, n (%)	6 (16)	10 (15)	0.96
ICU LOS	3 (1–6)	4 (3–11)	0.25
PPV, n (%)	2 (5)	7 (11)	0.34
Total LOS	5 (4–6)	3 (2–5)	**0.0020**
Isolated thoracic injury, n (%)	13 (34)	27 (42)	0.46
eFAST, n (%)	28 (74)	38 (58)	0.2
PTX on eFAST, n (%)	5 (18)	4 (11)	0.38
OR on admit, n (%)	8 (21)	9 (14)	0.34
Mortality, n (%)	1 (3)	1 (2)	0.70
Total no. CXR	7 (5–8)	3 (2–5)	**<0.001**
Chest CT*			
Size OPTX, mm†	10.2 (5.6–17.7)	8.5 (6.0–13.2)	0.40
Bilateral OPTX, n (%)	2 (5)	3 (5)	0.88
HTX, n (%)	37 (93)	31 (46)	**<0.001**
Pulmonary contusion, n (%)	20 (50)	32 (47)	0.77
Chest muscle contusion, n (%)	2 (5)	2 (3)	0.58
Rib fracture, n (%)	15 (38)	19 (28)	0.30
No. fractures	0.5 (0.82)	0.5 (0.99)	0.83
Subcutaneous emphysema, n (%)	21 (53)	37 (54)	0.85
Retained bullet, n (%)	4 (10)	8 (12)	0.78

Data are shown as mean (SD) or median (IQR) unless otherwise noted.
*Bilateral OPTX counted individually (immediate TT, 40; observation, 68).
†Measured by the radial distance of the largest air collection, between the parietal and visceral pleura/mediastinum in a line perpendicular to the chest wall.
eFAST, extended focused assessment with sonography; HR, heart rate; PP, pulse pressure; PPV, positive pressure ventilation; OR, operating room; RR, respiratory rate; SBP, systolic blood pressure.
Bold *p* values are statistically significant.

Clinical outcomes of ICU LOS and mortality were similar between patients undergoing immediate TT placement compared with observational management (Table 1). Compared with observed patients, median hospital LOS and median number of CXRs were higher in the immediate TT group (5 days [IQR, 4–6 days] vs. 3 days [IQR, 2–5 days]; $p = 0.002$ and 7 CXRs [IQR, 5–8 CXRs] vs. 3 CXRs [IQR, 2–5 CXRs]; $p < 0.001$, respectively). However, between patients undergoing immediate TT placement and those in the observation group requiring interval TT placement, median hospital LOS and number of inpatient CXRs were similar (5 days [IQR, 4–6 days] vs. 7 days [IQR, 4–9 days] and 7 CXRs [IQR, 5–8 CXRs] vs. 9 CXRs [IQR, 6–11 CXRs], respectively; both $p = 0.10$). Tube thoracostomy dwell time was similar in patients undergoing immediate versus interval TT placement (4 ± 1.5 days vs. 4 ± 1.6 days, $p = 0.95$). On average, interval TT placement in observed patients occurred on hospital day 2 with a range from hospital day 1 to day 4. A single patient death occurred in each group. Mortality was due to hemorrhage shock in the immediate TT group and nonsurvivable brain injury in the observation group.

No patient, in either group, required a subsequent thoracotomy or thoracoscopic procedure on the side of their OPTX. In the immediate TT placement group, there were three inpatient OPTX-related complications: one patient required TT reinsertion for extrapleural placement, one patient required a repeat TT for PTX recurrence after planned removal, and one patient left against medical advice with the TT still in place (this patient represented the next day and after 24 hours of monitoring had an uneventful TT removal). In the observation group, no patients required reinsertion or repeat TT placement. One patient in the observation group developed pneumonia requiring ICU management.

Lastly, within 3 months after discharge, 1 of 37 patients (3%) in the immediate TT group and 3 of 64 patients (5%) in the observation group represented for reasons related to their

TABLE 2. Clinical Predictors of Interval TT Placement

A. Univariable Logistic Regression: Clinical Factors Associated With Need for TT Placement in Observation Group

Variable	Odds Ratio	95% CI	*p*
Age	0.97	0.92–1.03	0.29
Sex (male)	0.65	0.13–3.35	0.61
Multiple chest wounds	1.13	0.34–3.78	0.85
Self-inflicted injury	0.68	0.08–6.20	0.73
SBP, mm Hg	0.99	0.96–1.01	0.39
PP, mm Hg	0.99	0.96–1.03	0.69
HR, per min	0.97	0.93–1.00	0.07
RR, per min	0.96	0.81–1.14	0.67
OR on admit	3.05	0.74–12.61	0.12
Gunshot injury	7.27	1.92–27.54	**0.004**
ISS >15	4.27	1.20–15.12	**0.025**
Chest AIS ≥4	5.04	1.34–18.91	**0.017**
PPV	7.99	1.76–36.12	**0.007**

B. Multivariable Logistic Regression: Clinical Predictors of Need for TT Placement in Observation Group

Variable*	Odds Ratio	95% CI	*p*
Gunshot injury	3.08	0.62–15.24	0.17
Chest AIS ≥4	7.38	1.43–37.95	**0.017**
PPV	7.74	1.07–56.06	**0.043**

$\chi^2 = 17.46$; $p < 0.001$. Hosmer and Lemeshow $\chi^2 = 2.82$; $p = 0.42$. AUROC, 0.80 (95% CI, 0.64–0.96); $p = 0.001$.
*To avoid colinearity with chest AIS, ISS was not included.
AUROC, area under the receiver operating characteristic curve; CI, confidence interval; HR, heart rate; OR, operating room; PP, pulse pressure; PPV, positive pressure ventilation; RR, respiratory rate; SBP, systolic blood pressure.
Bold *p* values are statistically significant.

TABLE 3. Observed OPTX Clinical and Imaging Characteristics: Successful Observation Versus Interval TT Placement

Characteristic	Successful Observation (n = 53)	Interval TT (n = 12)	*p*
Age	34.8 (12.5)	31.5 (14.3)	0.42
Male n (%)	41 (77)	10 (83)	1.00
Injury type, n (%)			
Gunshot	12 (23)	8 (67)	**0.0053**
Stab	41 (77)	4 (33)	
Chest wound, n (%)			
Single	27 (51)	5 (42)	0.75
Multiple	26 (42)	7 (58)	
Self-inflicted injury, n (%)	6 (11)	1 (8)	1.00
SBP, mm Hg	138 (114–150)	130 (106–151)	0.47
PP, mm Hg	51 (40–65)	46 (32–66)	0.51
HR, per min	95 (17.5)	87 (19.1)	0.15
RR, per min	21 (3.9)	20 (3.6)	0.77
Oxygen saturation	98 (2.3)	99.5 (0.8)	0.083
ISS	13 (9–16)	20 (12–25)	**0.028**
ISS >15, n (%)	14 (26)	7 (58)	**0.033**
Chest AIS	3.0 (0.6)	3.5 (0.8)	**0.011**
Chest AIS ≥4, n (%)	8 (15)	6 (50)	**0.008**
ICU admit, n (%)	5 (9)	5 (42)	**0.014**
ICU LOS	4 (3–11)	4 (2–16)	0.92
PPV, n (%)	3 (6)	4 (33)	**0.018**
Total LOS	3 (2–4)	7 (4–9)	**<0.001**
Isolated thoracic injury, n (%)	26 (49)	1 (8)	**0.010**
eFAST, n (%)	30 (57)	8 (67)	0.75
PTX on eFAST, n (%)	3 (10)	1 (13)	1.00
OR on admit, n (%)	6 (11)	3 (25)	0.35
Mortality, n (%)	0 (0)	1 (8)	0.19
Total no. CXR	3 (2–3)	9 (6–11)	**<0.001**
Chest CT*			
Size OPTX, mm†	8.7 (6.0–14.6)	7.7 (4.2–10.7)	0.43
Bilateral OPTX, n (%)	2 (4)	1 (8)	**0.46**
HTX, n (%)	21 (38)	10 (77)	**0.015**
Pulmonary contusion, n (%)	21 (38)	11 (85)	**0.0042**
Chest muscle contusion, n (%)	2 (4)	0 (0)	1.00
Rib fracture, n (%)	12 (22)	7 (54)	**0.036**
No. fractures	1.6 (1.0)	2 (1.3)	0.43
Subcutaneous emphysema, n (%)	32 (58)	5 (38)	0.23
Retained bullet, n (%)	2 (4)	6 (46)	**<0.001**

Data are shown as mean (SD) or median (IQR) unless otherwise noted.
*Bilateral OPTX counted individually (successful, 55; interval TT, 13).
†Measured by the radial distance of the largest air collection, between the parietal and visceral pleura/mediastinum in a line perpendicular to the chest wall.
eFAST, extended focused assessment with sonography; HR, heart rate; OR, operating room; PP, pulse pressure; PPV, positive pressure ventilation; RR, respiratory rate; SBP, systolic blood pressure.
Bold *p* values are statistically significant.

thoracic injury. In the immediate TT placement group, this was the patient who left against medical advice with TT in place. In the observation group, one patient represented with a chest wall hematoma from a subscapular artery bleed on the opposite side as their OPTX requiring embolization. Two patients represented with shortness of breath, and both were discharged from the emergency department after clinical evaluation revealed no abnormal findings.

DISCUSSION

Trauma surgeons frequently encounter the challenge of managing OPTXs resulting from penetrating injury. Nevertheless, current guidelines are based on analyses dedicated predominately to blunt OPTX, leaving the optimal management of penetrating OPTX uncertain. In this study, we further investigated OPTX in penetrating injury, in particular, the rate of interval TT placement in OPTX patients undergoing observational management and their clinical outcomes compared with patients with immediate TT placement. Lastly, we describe clinical and radiographic factors associated with need for interval TT placement. We hypothesized that, in patients undergoing observational management for penetrating OPTX, specific clinical factors and radiographic features on chest CT would be associated with need for interval TT placement.

We found that OPTX occurred in 16% of penetrating PTXs with 18% of patients undergoing observational management requiring interval TT placement. In addition, in the observation group, we found specific clinical factors, chest AIS score of ≥4 and positive pressure ventilation, as well as initial chest CT findings of HTX and retained pulmonary bullet fragment to be associated with increased odds of interval TT placement. Immediate and observation with interval TT placement were associated with longer hospital LOS and greater number of CXRs. However, chest injury complications and outcomes were similar regardless of either management strategy—immediate TT placement or observation.

Over our study period, we detected a 16% occurrence of OPTX in penetrating PTX patients. The frequency of OPTX in penetrating injury is not well described. A single prior study examining 25 OPTXs in 146 penetrating traumatic PTX patients found a 17% OPTX occurrence.[12] Our study further expands

TABLE 4. Radiographic Predictors of Interval TT Placement

A. Univariable Logistic Regression: Radiographic Features Associated With Need for TT Placement in Observation Group

Variable	Odds Ratio	95% CI	*p*
Bilateral OPTX	1.82	0.31–10.62	0.51
Size, mm	0.54	0.14–2.08	0.37
HTX	5.40	1.33–21.89	**0.018**
Pulmonary contusion	8.91	1.80–14.12	**0.007**
Chest wall contusion	0	0–Infintity	1.00
Rib fractures	4.18	1.18–14.80	**0.027**
Subcutaneous emphysema	0.45	0.13–1.55	0.21
Retained bullet	22.71	3.82–135.22	**0.001**

B. Multivariable Logistic Regression: Radiographic Predictors of Need for TT Placement in Observation Group

Variable	Odds Ratio	95% CI	*p*
HTX	6.17	1.08–35.24	**0.041**
Pulmonary contusion	4.30	0.70–26.50	0.12
Rib fractures	1.70	0.35–8.28	0.51
Retained bullet	11.62	1.40–96.62	**0.023**

$\chi^2 = 23.34$; $p < 0.001$. Hosmer and Lemeshow $\chi^2 = 4.01$; $p = 0.55$. AUROC, 0.84 (95% CI, 0.70–0.99); $p < 0.001$.
AUROC, area under the receiver operating characteristic curve; CI, confidence interval.
Bold *p* values are statistically significant.

and lends support that nearly one fifth of PTXs in penetrating chest injury result in OPTX, reenforcing the need for optimal management strategies.

In patients undergoing initial observational management, 18% required interval TT placement. Radiographic OPTX enlargement was a clinical factor in 58% of these interval placements. Prior studies have demonstrated that 6% to 11%[2,3,17] of patients initially observed ultimately require TT placement. These studies however were either based predominantly, if not solely, on blunt traumatic OPTX. We suspect our study's higher rate of interval TT placement directly correlates to the penetrating nature of these injures—extrinsic penetration of the thoracic cavity compared with compression and deceleration forces from blunt impact. While a retrospective South African review of small stab injury PTXs (defined as less than 2 cm on CXR) reported a 3% incidence of interval TT placement,[18] this study examined uncomplicated PTXs, the majority from a single stab wound. In our study, the inclusion of both stab and gunshot OPTXs with a greater severity of thoracic injury likely contributed to our higher interval TT rate. Thus, our findings suggest that, compared with observational management for blunt OPTX, penetrating OPTX may have a higher rate of interval TT placement.

Despite a potential higher rate for interval TT placement in penetrating compared with blunt OPTX, more than 80% of patients in our observational group were successfully managed without need for TT. Importantly, in patients requiring interval TT placement, complications were not increased, including compromises in respiratory status or need for additional interventions related to retained HTX or infection. Our findings suggest that observational management may be beneficial over immediate TT placement in the stable penetrating OPTX patient. Furthermore, with observational management when TT placement is required, it could ideally occur in a more controlled, nonemergent setting with the goal of reducing patient morbidity and TT complications in these high risk patients.[19]

Avoidance of unnecessary TT placement is essential given complication rates upward of 22%[2,13–15,20] and the significant morbidity derived from these complications. Likewise, patients with TT placement are exposed to longer hospital and ICU LOS and the complications associated with longer hospitalization.[3,20,21] We also found longer hospital duration in patients undergoing immediate TT placement compared with observed patients despite similar injury severity and chest AIS scores, and need for emergent operative intervention. Moreover, on subgroup analysis of patients in the observation group requiring interval TT placement hospital, LOS was also increased, similar to the immediate TT group, indicating the presence of TT to be a contributing factor in our longer LOS parameters. In addition, patients who required both immediate and interval TT placement were exposed to an increased number of CXRs and thus the corresponding increases in cost, resource utilization, and radiation exposure.

Identification of risk factors associated with interval TT placement can help to optimize observational OPTX management by heightening clinical awareness of patients in need of closer monitoring. Presently, there are no accurate scoring systems to predict which patients will need insertion of a TT for OPTX,[10] and current published risk factors are focused almost exclusively on blunt OPTX. We found that observed patients requiring interval TT placement had higher chest injury scores compared with patients not requiring TT placement, specifically, chest AIS score of ≥4 (aOR, 7.38). A recent multicenter study assessing the safety of observation in blunt OPTX found injury severity to not be a factor associated with failed observational management.[3] However, severity of chest injury was not examined in this study, and as blunt traumatic injury often results in multiple injuries, ISSs are not necessarily reflective of chest injury severity and may account for this study's findings.

Our study also found positive pressure ventilation a risk factor for interval TT placement in penetrating OPTX (aOR, 7.74), with 4 of the 11 (36%) intubated observational management patients requiring TT insertion. Observational management of OPTX in patients requiring positive pressure ventilation is controversial with systematic reviews remaining indeterminate.[5,22] While the majority of studies demonstrate that frequency of interval TT placement is higher in patients maintained on positive pressure ventilation, ranging from 14% to 53%, it is not associated with adverse outcomes.[3,6,7,23,24] Similarly, in our study, interval TT placement in ventilated OPTX patients did not correlate with poorer outcomes. These findings support that OPTX from penetrating injury can be safely observed, regardless of ventilation status, with the awareness ventilated patients may be at higher risk for interval TT placement.

In addition to these clinical factors, the radiographic presence of HTX and retained pulmonary bullet fragment were both independently associated with risk for interval TT placement. In blunt OPTX concurrent, HTX has been associated with the need for interval TT placement,[3] and even without a visible HXT on presentation, approximately 12% may ultimately need interval TT placement owing to HXT development.[16] In our study, HTX evacuation was successful in all interval TT placements with no patient requiring further intervention.

Unique to penetrating OPTX, we found retained pulmonary bullet fragment on initial chest CT to be independently associated with risk for interval TT placement (aOR, 11.62). To our knowledge, this is the first study able to identify this association. We hypothesize that a retained bullet remnant may signify increased risk for ongoing air leak or hemorrhage from the parenchymal injury. As such, in the acute setting, these patients may warrant closer monitoring for progression of their chest injury.

Our study did not find an association between size of OPTX and risk for interval TT placement. Prior research has demonstrated a PTX measuring 35 mm and below, using the radial distance from the parietal and visceral pleura/mediastinum in a line perpendicular to the chest wall, as a safe cutoff value for observation with a positive predictive value of 91% to 96%.[16,25] In our observed patients, using the same measurement guidelines, OPTX sizes were all under this cutoff, ranging from 3 to 29 mm. Thus, our findings support that an OPTX size of less than 35 mm is safe to observe in penetrating OPTX.

Recently, studies have demonstrated that pigtail catheters may be comparable with standard TT evacuation of traumatic PTX [26,27] and HTX,[28,29] with the use of pigtail catheters significantly reducing patient pain and discomfort.[27] While our study did not evaluate pigtail management in OPTX, current research suggests that they may serve as a viable and more comfortable option when interval TT placement is required. Importantly, these same studies also demonstrated similar failure and complication rates between standard TT drainage and pigtail catheter drainage;[26–29] thus, avoidance of these invasive procedures when unnecessary remains the goal.

While our study found that presence of a higher chest AIS, need for positive pressure ventilation, concurrent HTX, and retained bullet fragment were risk factors associated with need for interval TT placement in penetrating OPTX patients, not all patients with these risk factors will require interval TT placement. Importantly, our study demonstrated that a trial of observational management despite need for interval TT placement did not result in increased morbidity or pulmonary complications and provided improved clinical outcomes. Thus, identification of patients at high risk for interval TT placement is important to ensure appropriate monitoring and risk assessment; however, given the known morbidity of TT placement, avoidance of unnecessary TT placement should also be emphasized. Therefore, we do not advocate for immediate TT placement but rather close clinical monitoring in patients at increased risk.

Our study has several limitations. As a retrospective study, it relies on previously collected data not specifically intended to address our study hypothesis and, as such, does not allow for determination of causation. Also, we had to rely on medical record documentation to determine reason for TT placement and associated complications. In addition, at our institution, the decision to place an immediate TT rather than observe a patient is based on provider discretion introducing a source of potential selection bias. While there were no protocol changes with regard to observational management or immediate TT placement for OPTXs over the study period, it is possible that individual attending surgeon practice may have changed, favoring either increased observation or immediate TT placement. Our study did not exclude patients with concurrent HTX, which makes for a more heterogeneous study population; however, we feel that including all patients presenting with penetrating OPTX regardless of other concomitant lung injuries is more representative and thus more relevant to actual trauma care. Lastly, our study included only patients with radiographic OPTX. Patients with small but nonoccult PTXs were excluded from the study, and it is unclear whether our results can be generalized to this patient population.

CONCLUSION

Little is known regarding the progression of OPTX in penetrating injury. Our findings suggest that the majority of patients with penetrating OPTX can be successfully observed with improved clinical outcomes (LOS, avoidance of TT-related complications, reduced radiation exposure) without incurring increased risk for adverse outcomes. In patients undergoing observation, specific clinical factors (chest AIS, positive pressure ventilation) and CT features (HTX, retained bullet fragment) are associated with increased odds for interval TT placement, suggesting need for heightened awareness in patients with these findings.

AUTHORSHIP

G.B., C.M.C., and G.P.V. contributed in the literature search, study design, data collection, data analysis, data interpretation, and manuscript preparation. A.T. and J.C. contributed in the literature search, study design, data collection, data analysis, and data interpretation.

DISCLOSURE

The authors declare no conflicts of interest.

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