Management of post-traumatic retained hemothorax: A prospective, observational, multicenter AAST study

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BACKGROUND: The natural history and optimal management of retained hemothorax (RH) after chest tube placement is unknown. The intent of our study was to determine practice patterns used and identify independent predictors of the need for thoracotomy.

METHODS: An American Association for the Surgery of Trauma multicenter prospective observational trial was conducted, enrolling patients with placement of chest tube within 24 hours of trauma admission and RH on subsequent computed tomography of the chest. Demographics, interventions, and outcomes were analyzed. Logistic regression analysis was used to identify the independent predictors of successful intervention for each of the management choices chosen and complications.

RESULTS: RH was identified in 328 patients from 20 centers. Video-assisted thoracoscopy (VATS) was the most commonly used initial procedure in 33.5%, but 26.5% required two and 5.4% required three procedures to clear RH or subsequent empyema. Thoracotomy was ultimately required in 20.4%. The strongest independent predictor of successful observation was estimated volume of RH ≤300 cc (odds ratio [OR], 3.7 [2.0–7.0]; $p < 0.001$). Independent predictors of successful VATS as definitive treatment were absence of an associated diaphragm injury (OR, 4.7 [1.6–13.7]; $p = 0.005$), use of periprocedural antibiotics for thoracostomy placement (OR, 3.3 [1.2–9.0]; $p = 0.023$), and volume of RH ≤900 cc (OR, 3.9 [1.4–13.2]; $p = 0.03$). No relationship between timing of VATS and success rate was identified. Independent predictors of the need for thoracotomy included diaphragm injury (OR, 4.9 [2.4–9.9]; $p < 0.001$), RH >900 cc (OR, 3.2 [1.4–7.5]; $p = 0.007$), and failure to give periprocedural antibiotics for initial chest tube placement (OR 2.3 [1.2–4.6]; $p = 0.015$). The overall empyema and pneumonia rates for RH patients were 26.8% and 19.5%, respectively.

CONCLUSION: RH in trauma is associated with high rates of empyema and pneumonia. VATS can be performed with high success rates, although optimal timing is unknown. Approximately, 25% of patients require at least two procedures to effectively clear RH or subsequent pleural space infections and 20.4% require thoracotomy. (*J Trauma.* 2012;72: 11–24. Copyright © 2012 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: II, prospective comparative study.

KEY WORDS: Hemothorax; trauma; thoracostomy; thoracotomy; empyema.

The true incidence of posttraumatic retained hemothorax (RH) is unknown, but this sequela of thoracic injury is not uncommon. Previously reported to be an independent risk factor for the development of empyema and subsequent adverse outcomes,[1] the recognition and treatment of posttraumatic RH remains a significant problem in trauma care. Although it has been demonstrated that computed tomography (CT) of the chest is superior to plain radiography in the diagnosis of RH,[2] the optimal management after diagnosis remains a matter of debate. The purpose of this study was to determine the current practices and the factors influencing the successful utilization of used interventions in the management of posttraumatic RH and to identify independent predictors of the need for thoracotomy in this setting.

MATERIALS AND METHODS

This was a prospective, observational, multicenter study conducted under the sponsorship of the American Association for the Surgery of Trauma. The study protocol was approved by the American Association for the Surgery of Trauma Multi-Institution Trials Committee and each participating center obtained approval from its institutional review board. Patients with posttraumatic RH over a period of 2 years from 2009 through 2011 were included. Inclusion criteria were placement of a thoracostomy tube within 24 hours of admission for the evacuation of pneumothorax or hemothorax and subsequent CT scan of the chest showing RH after the initial placement of thoracostomy tube. Patients undergoing thoracotomy before placement of tube thoracostomy were not enrolled in the study.

Patients with suspected RH underwent a CT scan after thoracostomy tube placement. RH was defined as a heterogeneous fluid collection with Houndsfield unit readings on CT scan of 35 to 70 and evidence of pleural thickening. The size of the RH was estimated by the CT scan using the method previously validated for estimation of pleural effusions by Mergo et al.[3] (estimate = V (in cc) = $d^2 \cdot X \cdot L$, where d is the greatest depth of hemothorax from the chest wall to lung on any CT image, in centimeters; and L = craniocaudal length in centimeters multiplied by the number of slices X cm thickness of CT cuts). RH was then categorized according to this CT scan estimate into one of three categories (small, ≤300 cc; moderate, 301–900 cc; and large, >900 cc). Patients were managed according to surgeon's discretion with observation, additional thoracostomy tube placement or image-guided percutaneous drainage (IGPD), intrapleural thrombolysis, video-assisted thoracoscopy (VATS), and thoracotomy. A computerized spreadsheet (Microsoft Excel 2003; Microsoft Corporation, Redmond, WA) was generated for this study and included the following variables: age, gender, mechanism of injury, hospital day (HD) of initial thoracostomy tube placement, size of thoracostomy tube, laterality of thoracostomy, use of antibiotics, indication for the initial thoracostomy tube placement, volume of RH, diaphragm injury, rib fractures, Injury Severity Score (ISS), and Abbreviated Injury Scale of the chest and abdomen.

HD of the therapeutic interventions, complications, and hospital course (length of stay in hospital and intensive care unit [ICU]) were reported from each site. In addition, complications including pneumonia and empyema were recorded. For the purpose of our study, empyema was defined by the presence of purulent pleural fluid, pleural fluid below pH below 7.2 with signs of infection or proven bacterial contamination of the pleural space on Gram's stain or culture. For the purpose of standardization in our study, pneumonia was defined as follows: (1) purulent sputum, (2) associated evidence of infection (white blood cells >11,000 or <4,000 or fever >100.4 degrees Farenheit), (3) two or more serial chest radiographs with new or progressive and persistent infiltrate, consolidation or cavitation, and (4) bronchoalveolar lavage or sterile endotracheal specimen with limited number of epithelial cells, at least 2 to 3+ white blood cells and dominant organisms identified on Gram's stain or culture.

Each participating center collected the above data elements on a standardized data collection form, which was faxed or emailed to the principal investigator on completion of data collection. Data were analyzed using the statistical package SPSS for Windows, Version 12.0 (SPSS, Chicago, IL).

Statistical Analysis

The primary objective of the study was to identify the independent predictors of the need for thoracotomy to evacuate RH. Secondary outcomes included the identification of independent predictors for successful utilization of various less invasive management approaches in the treatment of posttraumatic RH. Correlation between CT scan estimation of RH volume and results of operative evacuation by VATS or/and thoracotomy was also examined.

We compared the demographic and clinical characteristics of the patient groups, identifying factors that were significantly different between them at $p < 0.05$. For the univariate analysis, we used the χ^2 test with Yates correction for comparison of categorical risk factors and the Student's t test or the Mann-Whitney test for comparison of continuous risk factors. If any cell was found to have expected five patients or less, the two-sided Fisher's exact test was used. To identify factors independently associated with the need for thoracotomy and the successful intervention for each of the management choices chosen, all potential risk factors that were significant at $p < 0.2$ were entered into a forward logistic regression model. Adjusted OR and 95% confidence intervals (CIs) were derived.

To examine the correlation between CT estimation of RH volume and results of operative evacuations (VATS or/and thoracotomy), we used the scatter plot functions of the statistical package SPSS for Windows, Version 12.0 (SPSS). The Pearson-Moment Correlation Coefficient (r) and the square correlation coefficient (r^2) were calculated.

RESULTS

During the 2-year study period, 328 patients with posttraumatic RH from 20 centers in the United States, Canada, and South America were prospectively enrolled. VATS was the most commonly used initial procedure, performed in 110 patients (33.5%). Thoracotomy was ultimately performed for 73 patients (22.2%). Overall, 101 patients (30.8%) were initially managed with observation. Of these, 83 (82.2%) were successfully managed without the need for any additional therapeutic intervention. One hundred twelve patients (34.1%) required two and 18 patients (5.4%) required at least three procedures to clear the RH or subsequently developed empyema. The various management approaches used to treat posttraumatic RH are shown in Figure 1.

The mean age ± standard deviation of patients with RH after trauma was 38.6 years ± 16.1 years, 86.6% (n = 284) were male, and 51.1% (n = 167) sustained penetrating injury. Mean ISS was 20.7 ± 13.0. Overall, 58.1% (n = 186) sustained severe trauma (ISS >15) and 33.8% (n = 108) suffered critical injuries (ISS ≥25). Hemothorax was the most common indication for the initial placement of thoracostomy tube (53.4%, n = 175). Initial thoracostomy tube placement for enrolled patients was conducted in the emergency department for 65.5%, operating room for 26.8%, ICU 3.7%, floor 3.7%, and 1 (0.3%) was placed prehospital. Antibiotics were used periprocedurally for thoracostomy tube placement in 126 patients (40.6%). Diagnosis of RH was documented within 72 hours after initial chest tube placement among 32.0% of patients, increasing to 55.5% by HD 5 and 87.2% by HD 10. Overall range of time from initial thoracostomy tube placement for trauma to diagnosis of RH ranged from 1 day to 30 days. Most of the patients (60.0%, n = 186) had a volume of RH measured on the CT scan ≤300 cc. RH was associated with a diaphragm injury in 46 patients (14.1%) and rib fractures in 177 patients (54.1%). The basic demographics and clinical characteristics of patients with posttraumatic RH are shown in Table 1.

The comparison of demographic and clinical characteristics between patients who were successfully managed with observation and those who required at least one therapeutic intervention are shown in Table 1. Patients who were successfully observed without the need for any therapeutic intervention were more likely to be older (25.3% vs. 15.6%, $p = 0.047$), have a volume of RH ≤300 cc (80.0% vs. 53.6%, $p < 0.001$), sustain rib fractures (63.9% vs. 50.8%, $p = 0.04$), have a higher ISS (24.8 ± 13.0 vs. 19.3 ± 12.7, $p < 0.001$), and higher Abbreviated Injury Scale of the abdomen (30.9% vs. 19.6%, $p = 0.036$). Successfully observed patients were also less likely to have sustained penetrating injury (37.3% vs. 55.7%, $p = 0.004$), to have been initially treated with a smaller (≤34) thoracostomy tube size (40.3% vs. 55.5%, $p = 0.02$), and have hemothorax as the indication for the initial thoracostomy tube placement (37.3% vs. 58.8%, $p = 0.035$). Successful observation was more common among patients who had received periprocedural antibiotics on the initial thoracostomy tube placement (29.6% vs. 44.5%, $p = 0.019$) and did not have concomitant diaphragm injury (6.0% vs. 16.8%, $p = 0.015$). After stepwise regression analysis, the strongest independent predictor of successful observation was estimated volume of RH ≤300 cc (adjusted odds ratio [OR], 3.7; 95% CI, 2.0–7.0; $p < 0.001$; Table 1).

Compared with patients who were unsuccessfully managed with an additional thoracostomy tube or an IGPD after the diagnosis of posttraumatic RH, patients who were successfully treated with these management choices were more likely to have pneumothorax as indication for initial thoracostomy placement (22.2% vs. 9.6%, $p = 0.005$) and less likely to have estimated volume of RH >900 cc (2.4% vs. 13.9%, $p = 0.043$). Successful treatment with additional thoracostomy tube or IGDP was also more common among

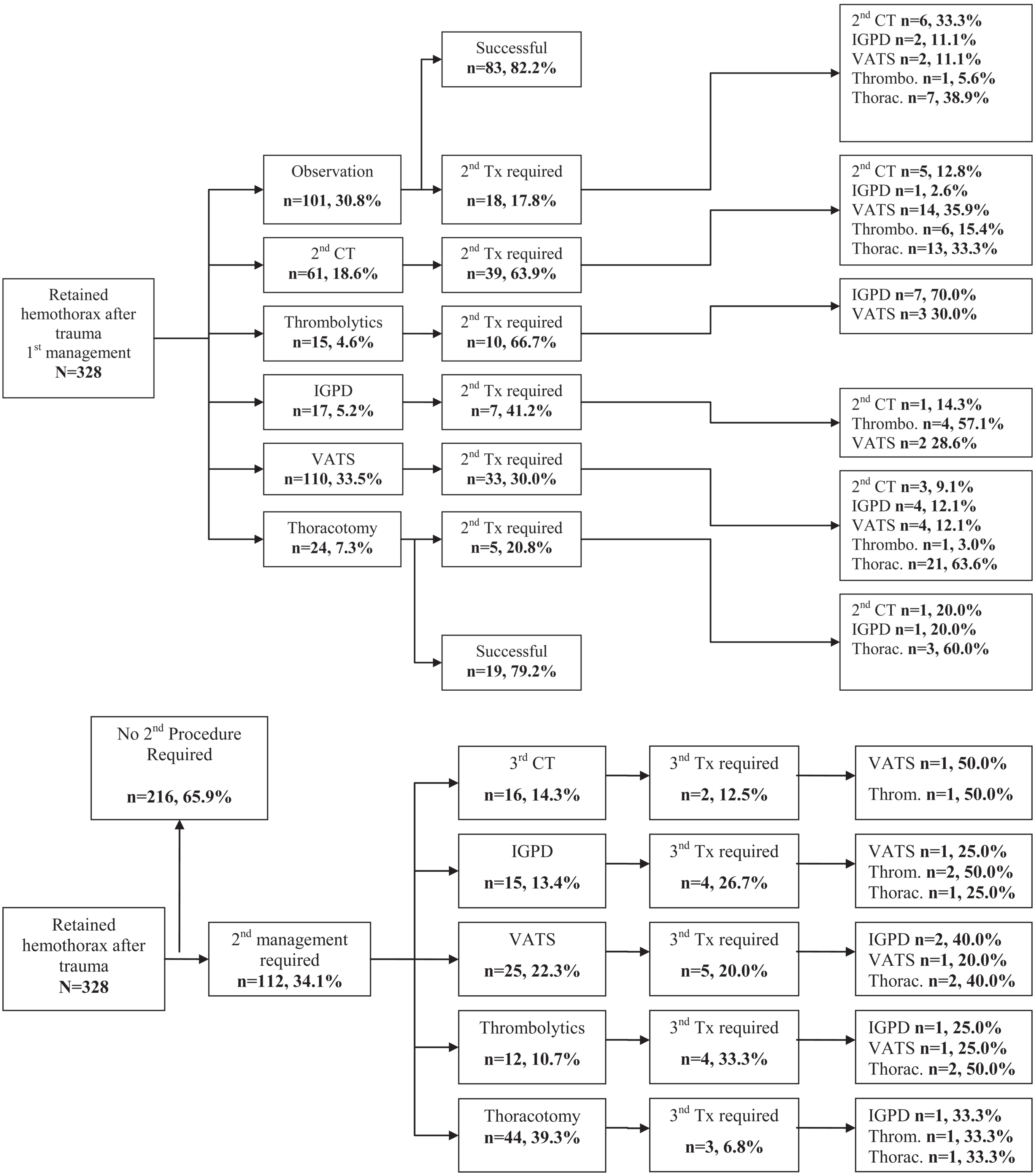

Figure 1. Study outline illustrating the procedures performed for the management of posttraumatic RH after initial thoracostomy tube placement.

TABLE 1. Comparison of the Basic Demographics and Clinical Characteristics Between Patients Who Received Treatment and Those Who Were Successfully Managed With Observation and Independent Predictors of Successful Observation After Stepwise Logistic Regression

	Total (N = 328)	Successful Observation (n = 83)	Intervention (n = 245)	*p*
Mean age ± SD	38.6 ± 16.2	42.0 ± 17.8	37.4 ± 15.4	0.027
Age (55 yr)	18.0% (59/327)	25.3% (21/83)	15.6% (38/244)	0.047
Male	86.6% (284/328)	85.5% (71/83)	86.9% (213/245)	0.747
Mechanism of injury—penetrating	51.1% (167/327)	37.3% (31/83)	55.7% (136/244)	0.004
Initial CT placement				
HD (mean ± SD)	1.2 ± 0.9	1.1 ± 0.4	1.3 ± 1.1	0.118
Size^2 (34)	51.8% (162/313)	40.3% (31/77)	55.5% (131/236)	0.020
Side				
Left	52.1% (171/328)	59.0% (49/83)	49.8% (122/245)	0.145
Right	42.7% (140/328)	37.4% (31/83)	44.5% (109/245)	0.256
Both	5.2% (17/328)	3.6% (3/83)	5.7% (14/245)	0.456
Indication				
HTX	53.4% (175/328)	37.3% (31/83)	58.8% (144/245)	0.035
PTX	14.0% (46/328)	21.7% (18/83)	11.4% (28/245)	<0.001
Both	31.7% (104/328)	41.0% (34/83)	28.6% (70/245)	0.036
Other	0.9% (3/328)	0.0% (0/83)	1.2% (3/245)	0.321
Antibiotics used	40.6% (126/310)	29.6% (24/81)	44.5% (102/229)	0.019
Volume of retained HTX (cc)				
3 00	60.0% (186/310)	80.0% (60/75)	53.6% (126/235)	<0.001
301–900	30.3% (94/310)	16.0% (12/75)	34.9% (82/235)	0.002
>900	9.7% (30/310)	4.0% (3/75)	11.5% (27/235)	0.039
Diaphragmatic injury	14.1% (46/327)	6.0% (5/83)	16.8% (41/244)	0.015
Rib fractures	54.1% (177/327)	63.9% (53/83)	50.8% (124/244)	0.040
ISS (mean ± SD)	20.7 ± 13.0	24.8 ± 13.0	19.3 ± 12.7	0.001
ISS (16–24)	58.1% (186/320)	73.2% (60/82)	52.9% (126/238)	0.001
ISS (≥25)	33.8% (120/320)	50.0% (41/82)	28.2% (67/238)	<0.001
AIS chest (≥3)	95.6% (302/316)	98.8% (80/81)	94.5% (222/235)	0.105
AIS abdomen (≥3)	22.5% (71/316)	30.9% (25/81)	19.6% (46/235)	0.036

Independent Predictors of the Successful Observation in Patients With Retained Hemothorax After Stepwise Logistic Regression

Step	Variables	Adjusted OR (95% CI)*	Adjusted *p**	r^2
1	Volume of retained hemothorax 300 cc	3.7 (2.0–7.0)	<0.001	0.067
2	PTX as an indication for the initial CT	2.7 (1.5–4.8)	0.001	0.105
3	Placement of a left side CT initially	2.1 (1.2–3.8)	0.013	0.125

SD, standard deviation; PTX, pneumothorax; AIS, Abbreviated Injury Scale; HTX, hemothorax; CT, chest tube.

The *p* values for categorical variables were derived from χ^2 test or Fisher's exact test; *p* values for continuous variables were derived from Student's *t* test or Mann-Whitney *U* test. For multivariate analysis, all variables with a *p* value of <0.2 on univariate comparison were entered into the logistic regression model: age, mechanism of injury (penetrating), left-sided chest tube, hemothorax, pneumothorax, both hemothorax and pneumothorax, antibiotic use, volume of retained HTX (<300, 300, and >900), rib fractures, chest AIS score >3, abdomen AIS score >3, ISS, hospital day of placement of first chest tube, C-statistic (area under the curve) for model: 0.62 (0.46–0.79), standard error = 0.08, $p = 0.104$. Hosmer and Lemeshow test (Goodness of fit) = 0.827.

patients without a diaphragm injury (8.9% vs. 24.7%, $p = 0.026$) and in those patients who received these interventions within 5 days of hospitalization (47.7% vs. 65.7%, $p = 0.047$). The comparison of the basic demographics and clinical characteristics between the two groups are shown in Table 2. After forward regression analysis, pneumothorax as initial indication for thoracostomy tube (adjusted OR, 3.7; 95% CI, 1.5–9.1; $p = 0.004$) and CT-estimated volume of RH ≤300 cc (adjusted OR, 3.4; 95% CI, 1.3, 8.9; $p = 0.013$) were independent risk factors of successful management with an additional thoracostomy tube placement or IGPD (Table 2).

Patients who were successfully treated with VATS, without the need for any additional therapeutic intervention, were more likely to have been given antibiotics on the initial thoracostomy tube placement (58.6% vs. 33.3%, $p = 0.02$) and less likely to have sustained an associated diaphragm injury (14.2% vs. 32.3%, $p = 0.022$). The comparison of basic demographics and clinical characteristics between the two groups are shown in Table 3. After forward logistic regression analysis, independent predictors of successful VATS as definitive treatment were absence of an associated diaphragm injury (adjusted OR, 4.7; 95% CI, 1.6, 13.7; $p = 0.005$), use of periprocedural antibiotics for initial

TABLE 2. Comparison of the Basic Demographics and Clinical Characteristics in Patients Treated With an Additional CT/IGPD and Independent Predictors of Successful Additional CT/IGDP After Stepwise Logistic Regression

	Total (N = 118)	Successful CT/IGPD (n = 45)	Unsuccessful CT/IGPD (n = 73)	p
Mean age ± SD	37.1 ± 1.4	38.5 ± 16.4	36.2 ± 15.0	0.428
Age^3 (55 yr)	14.4% (17/118)	15.6% (7/45)	13.7% (10/73)	0.780
Male	84.7% (100/118)	82.2% (37/45)	86.3% (63/73)	0.364
Mechanism of Injury—penetrating	49.2% (58/118)	42.2% (19/45)	53.4% (39/73)	0.160
Initial chest tube placement				
HD (mean ± SD)	1.2 ± 0.1	1.1 ± 0.3	1.2 ± 0.9	0.548
Size^2 (34)	37.2% (42/113)	39.5% (17/43)	35.7% (25/70)	0.683
Side				
Left	48.3% (57/118)	42.2% (19/45)	52.1% (38/73)	0.198
Right	44.9% (53/118)	51.1% (23/45)	41.1% (30/73)	0.192
Both	6.8% (8/118)	6.7% (3/45)	6.8% (5/73)	0.640
Indication				
HTX	57.6% (68/118)	42.2% (19/45)	67.1% (49/73)	0.098
PTX	14.4% (17/118)	22.2% (10/45)	9.6% (7/73)	0.005
Both	27.1% (32/118)	35.6% (16/45)	21.9% (16/73)	0.106
Other	0.8% (1/118)	0.0% (0/45)	1.4% (1/73)	0.110
Antibiotics used	38.8% (40/103)	28.9% (13/45)	46.6% (27/58)	0.068
Volume of retained hemothorax (cc)				
^{2}3 00	61.9% (70/113)	68.3% (28/41)	58.3% (42/72)	0.199
301–900	28.3% (32/113)	29.3% (12/41)	27.8% (20/72)	0.516
>900	9.7% (11/113)	2.4% (1/41)	13.9% (10/72)	0.043
Diaphragmatic injury	18.6% (22/118)	8.9% (4/45)	24.7% (18/73)	0.026
Rib fractures	53.4% (63/118)	57.8% (26/45)	50.7% (37/73)	0.288
HD of CT/IGPD				
>5 d	58.6% (44/67)	47.7% (21/44)	65.7% (44/67)	0.047
Size of CT/IGPD				
^{2}34	57.0% (61/107)	62.5% (25/40)	53.7% (36/67)	0.375
ISS (mean ± SD)	21.1 ± 1.2	23.3 ± 14.2	19.8 ± 11.2	0.145
ISS (>15)	61.2% (71/116)	68.2% (30/44)	56.9% (41/72)	0.157
ISS^3 (25)	32.8% (38/126)	40.9% (18/44)	27.8% (20/72)	0.144
AIS chest^3 (3)	96.6% (112/116)	93.0% (40/43)	98.6% (72/73)	0.143
AIS abdomen^3 (3)	28.4% (33/116)	27.9% (12/43)	28.8% (21/73)	0.921

Independent Predictors of the Successful Additional CT/IGPD in Patients With Retained Hemothorax After Stepwise Logistic Regression

Step	Variable	Adjusted OR (95% CI)*	Adjusted p*	r^2
1	PTX as an indication for the initial CT placement	3.7 (1.5–9.1)	0.004	0.094
2	Volume of retained HTX^2 300 cc	3.4 (1.3–8.9)	0.013	0.158

SD, standard deviation; PTX, pneumothorax; AIS, Abbreviated Injury Scale; HTX, hemothorax; CT, chest tube.

The p values for categorical variables were derived from χ^2 test or Fisher's exact test; p values for continuous variables were derived from Student's t test or Mann-Whitney U test. For multivariate analysis, all variables with a p value of <0.2 on univariate comparison were entered into the logistic regression model: hemothorax, both hemothorax and pneumothorax, other chest tube indication, antibiotic use, ISS, diaphragm injury, chest tube placement > day 5, left-sided chest tube, right-sided chest tube, mechanism of injury (penetrating), volume of retained hemothorax (<300), ISS C-statistic (area under the curve) for model: 0.50 (0.43–0.79), standard error = 0.04, p = 0.989. Hosmer and Lemeshow test (Goodness of fit) = not applicable.

thoracostomy placement (adjusted OR, 3.3; 95% CI, 1.2, 9.0; $p = 0.023$), and volume of RH ≤900 cc (adjusted OR, 3.9; 95% CI, 1.4–13.2; $p < 0.03$; Table 3). Despite examining a variety of intervals for the timing of VATS from both the time of admission and the time of diagnosis (including 24, 48, and 72 hours; 5 and 7 days), no association between timing and successful utilization as definitive procedure was noted on either univariate or multivariate analysis.

Patients who underwent thoracotomy were more likely to have been initially managed with bilateral thoracostomy tubes (13.4% vs. 3.1%, $p = 0.001$), have had a CT-estimated volume of RH >900 cc (18.2% vs. 7.4%, $p = 0.008$), and have sustained diaphragm injury (29.9% vs. 10.0%, $p = 0.001$). The comparison of demographic and clinical characteristics between the two groups is shown in Table 4. After stepwise regression analysis, the presence of diaphragm in-

TABLE 3. Comparison of the Basic Demographics and Clinical Characteristics Between Patients Who Were Successfully Managed With VATS and Those Who Were Not Independent Predictors of Successful VATS After Stepwise Logistic Regression

	Total (N = 138)	Successful VATS (n = 107)	Unsuccessful VATS (n = 31)	p
Mean age ± SD	35.6 ± 15.5	35.1 ± 15.1	37.4 ± 16.9	0.468
Age^3 (55 yr)	12.4% (17/137)	12.3% (13/106)	12.9% (4/31)	0.924
Male	87.0% (120/138)	88.8% (95/107)	80.6% (25/31)	0.236
Mechanism of injury—penetrating	67.4% (93/138)	68.2% (73/107)	64.5% (20/31)	0.698
Initial chest tube placement				
HD (mean ± SD)	1.3 ± 1.2	1.4 ± 1.4	1.1 ± 0.3	0.375
Size^2 (34)	66.2% (88/133)	66.7% (68/102)	64.5% (20/31)	0.825
Side				
Left	50.7% (70/138)	54.2% (58/107)	38.7% (12/31)	0.129
Right	46.4% (64/138)	43.9% (47/107)	54.8% (17/31)	0.283
Both	2.9% (4/138)	1.9% (2/107)	6.5% (2/31)	0.181
Indication				
HTX	63.0% (87/138)	63.6% (68/107)	61.3% (19/31)	0.846
PTX	6.5% (9/138)	6.5% (7/107)	6.5% (2/31)	0.744
Both	29.7% (41/138)	29.0% (31/107)	32.3% (10/31)	0.339
Other	0.7% (1/138)	0.9% (1/107)	0.0% (0/131)	0.724
Antibiotics used	53.2% (67/126)	58.6% (58/99)	33.3% (9/27)	0.020
Volume of retained hemothorax (cc)				
^{2}300	50.8% (67/132)	52.9% (54/102)	43.3% (13/30)	0.355
301–900	36.4% (48/132)	37.3% (38/102)	33.3% (10/30)	0.695
>900	12.9% (17/132)	9.8% (10/102)	23.3% (7/30)	0.052
Diaphragmatic injury	18.2% (25/137)	14.2% (15/106)	32.3% (10/31)	0.022
Rib fractures	41.6% (57/137)	40.6% (43/106)	45.2% (14/31)	0.648
HD of VATS				
>5 d	51.1% (67/131)	47.5% (48/101)	63.3% (19/30)	0.128
ISS (mean ± SD)	16.6 ± 11.4	15.7 ± 10.1	19.8 ± 14.7	0.078
ISS (16–24)	44.4% (60/135)	42.3% (44/104)	51.6% (16/31)	0.360
ISS^3 (25)	19.3% (26/135)	16.3% (17/104)	29.0% (9/31)	0.116
AIS chest^3 (3)	94.7% (124/131)	95.0% (95/100)	93.5% (29/31)	0.754
AIS abdomen^3 (3)	13.7% (18/131)	12.0% (12/100)	19.4% (6/31)	0.299

Independent Predictors of the Successful VATS in Patients With Retained Hemothorax After Stepwise Logistic Regression

Step	Variable	Adjusted OR (95% CI)*	Adjusted p*	r^2
1	Absence of diaphragmatic injury	4.7 (1.6–13.7)	0.005	0.069
2	Use of antibiotics on initial CT placement	3.3 (1.2–9.0)	0.023	0.116
3	Volume of retained HTX^2 900 cc	3.9 (1.4–13.2)	0.03	0.153

SD, standard deviation; PTX, pneumothorax; AIS, Abbreviated Injury Scale; HTX, hemothorax; CT, chest tube.

The p values for categorical variables were derived from χ^2 or Fisher's exact test; p values for continuous variables were derived from Student's t test or Mann-Whitney U test. For multivariate analysis, all variables with a p value of <0.2 on univariate comparison were entered into the logistic regression model: left-sided chest tube, bilateral chest tube placement, antibiotic use, volume of retained hemothorax (>900), diaphragm injury, chest tube placement > day 5, ISS C-statistic (area under the curve) for model: 0.74 (0.68–0.80), standard error = 0.03, $p < 0.001$. Hosmer and Lemeshow test (Goodness of fit) = 0.269.

jury (adjusted OR, 4.9; 95% CI, 2.4–9.9; $p < 0.001$), volume of RH >900 cc (adjusted OR, 3.2; 95% CI, 1.4–7.5; p = 0.007), and failure to give periprocedural antibiotics on the initial thoracostomy tube placement (adjusted OR, 2.3; 95% CI, 1.2–4.6; p = 0.015) were found to be independent predictors of the need for thoracotomy (Table 4).

After examining the correlation between the CT scan estimation of RH volume and results of operative evacuations (VATS or/and thoracotomy) by using the Scatter plot, we found a statistically significant (p = 0.004) weak correlation between the two variables with a Pearson Product-Moment Correlation Coefficient (r) equal to 0.246 and a squared correlation coefficient (r^2) equal to 0.06 (Fig. 2).

Infectious complications were also noted to be common in the setting of posttraumatic RH. Using the aforementioned definitions, empyema was identified among 26.8% (88 of 328) of study patients and pneumonia was documented in 19.5% (64 of 328). When compared with patients without empyema, patients who developed empyema after posttraumatic RH had a longer ICU (11.2 ± 13.0 vs. 6.5 ± 12.1; mean difference, 4.6; 95% CI, 1.5–7.8; p = 0.004) and hospital length of stay (23.6 ± 11.4 vs. 16.6 ± 19.5; mean

TABLE 4. Comparison of the Basic Demographics and Clinical Characteristics Between Patients Who Were Treated With Thoracotomy and Those Who Were Not and Independent Predictors of the Need for Thoracotomy on Logistic Regression

	Total (N = 328)	Thoracotomy (+) (n = 67)	Thoracotomy (−) (n = 261)	*p*
Mean age ± SD	38.6 ± 16.1	39.2 ± 15.4	38.4 ± 16.4	0.746
Age^{3} (55 yr)	18.0% (59/327)	17.9% (12/67)	18.1% (47/260)	0.975
Male	86.6% (284/328)	85.1% (57/67)	87.0% (227/261)	0.684
Mechanism of injury—penetrating	51.1% (167/327)	47.0% (31/66)	52.1% (136/261)	0.456
Initial chest tube placement*				
HD (Mean ± SD)	1.2 ± 0.9	1.3 ± 1.1	1.2 ± 0.9	0.304
Size^{2} (34)	51.8% (162/313)	46.3% (31/67)	53.3% (131/246)	0.311
Side				
Left	52.1% (171/328)	43.3% (29/67)	54.4% (142/261)	0.104
Right	42.7% (140/328)	43.3% (29/67)	42.5% (111/261)	0.911
Both	5.2% (17/328)	13.4% (9/67)	3.1% (8/261)	0.001
Indication				
HTX	53.4% (175/328)	55.2% (37/67)	52.9% (138/261)	0.940
PTX	14.0% (46/328)	13.4% (9/67)	14.2% (37/261)	0.468
Both	31.7% (104/328)	28.4% (19/67)	32.6% (85/261)	0.509
Other	0.9% (3/327)	3.0% (2/67)	0.4% (1/261)	0.330
Antibiotics used	40.6% (126/310)	32.3% (20/62)	42.7% (106/248)	0.133
Volume of retained hemothorax (cc)				
^{2}300	60.0% (186/310)	48.5% (32/66)	63.1% (154/244)	0.031
301–900	30.3% (94/310)	33.3% (22/66)	29.5% (72/244)	0.549
>900	9.7% (30/310)	18.2% (12/66)	7.4% (18/244)	0.008
Diaphragmatic injury	14.1% (46/327)	29.9% (20/67)	10.0% (26/260)	<0.001
Rib fractures	54.1% (177/327)	58.2% (39/67)	53.1% (138/260)	0.452
ISS (mean ± SD)	20.7 ± 13.0	22.8 ± 14.0	20.1 ± 12.6	0.144
ISS (>15)	58.1% (186/320)	63.1% (41/65)	56.9% (145/255)	0.365
ISS^{3} (25)	33.8% (108/320)	41.5% (27/65)	31.8% (81/255)	0.137
AIS chest^{3} (3)	95.6% (302/316)	95.5% (63/66)	95.6% (239/250)	0.959
AIS abdomen^{3} (3)	22.5% (71/316)	24.2% (16/66)	22.0% (55/250)	0.698

Independent Predictors of Thoracotomy in Patients With Retained Hemothorax After Stepwise Logistic Regression

Step	Variable	Adjusted OR (95% CI)*	Adjusted *p**	r^2
1	Diaphragmatic injury	4.9 (2.4–9.9)	<0.001	0.062
2	Volume of retained HTX >900 cc	3.2 (1.4–7.5)	0.007	0.084
3	No antibiotics used on the initial CT placement	2.3 (1.2–4.6)	0.015	0.105

SD, standard deviation; PTX, pneumothorax; AIS, Abbreviated Injury Scale; HTX, hemothorax; CT, chest tube.

The *p* values for categorical variables were derived from χ^2 test or Fisher's exact test; *p* values for continuous variables were derived from Student's *t* test or Mann-Whitney *U* test. For multivariate analysis, all variables with a *p* value of <0.2 on univariate comparison were entered into the logistic regression model: left-sided chest tube, bilateral chest tube placement, antibiotic use, volume of retained hemothorax (<300 and >900), diaphragm injury, ISS C-statistic (area under the curve): 0.71 (0.64–0.78), standard error = 0.04, $p < 0.001$. Hosmer and Lemeshow test (Goodness of fit) = 0.059.

difference, 7.0; 95% CI, 3.5–10.4; $p < 0.001$). Similar patterns were observed for patients developing pneumonia after posttraumatic RH with both longer ICU (18.6 ± 15.6 vs. 5.1 ± 10.1; mean difference, 13.4; 95% CI, 10.3–16.6; $p < 0.001$) and hospital length of stays noted (30.1 ± 30.2 vs. 15.7 ± 11.9; mean difference, 14.5; 95% CI, 9.8–19.2; $p < 0.001$).

DISCUSSION

The diagnosis and optimal management of posttraumatic RH remains problematic. It is generally accepted that persistent blood within the thoracic cavity represents a troubling finding, primarily because of concern for the subsequent development of fibrothorax (trapped lung) or empyema. Although a link between uncomplicated RH and "trapped lung" has been less well established,[4] the presence of retained blood within the pleural space has clearly been identified as a risk factor for the development for subsequent empyema.[1,5–8]Although the diagnosis and management of posttraumatic empyema remains controversial,[9,10] this complication may occur in up to ~30% of patients with RH after serious thoracic injury[5,6,8] and contribute significantly to morbidity and mortality.[11] For this reason, the establishment of the ideal algorithm for the effective evacuation of RH has remained an area of active investigation.

The identification of individuals at greatest risk for subsequent complications because of RH is, however, prob-

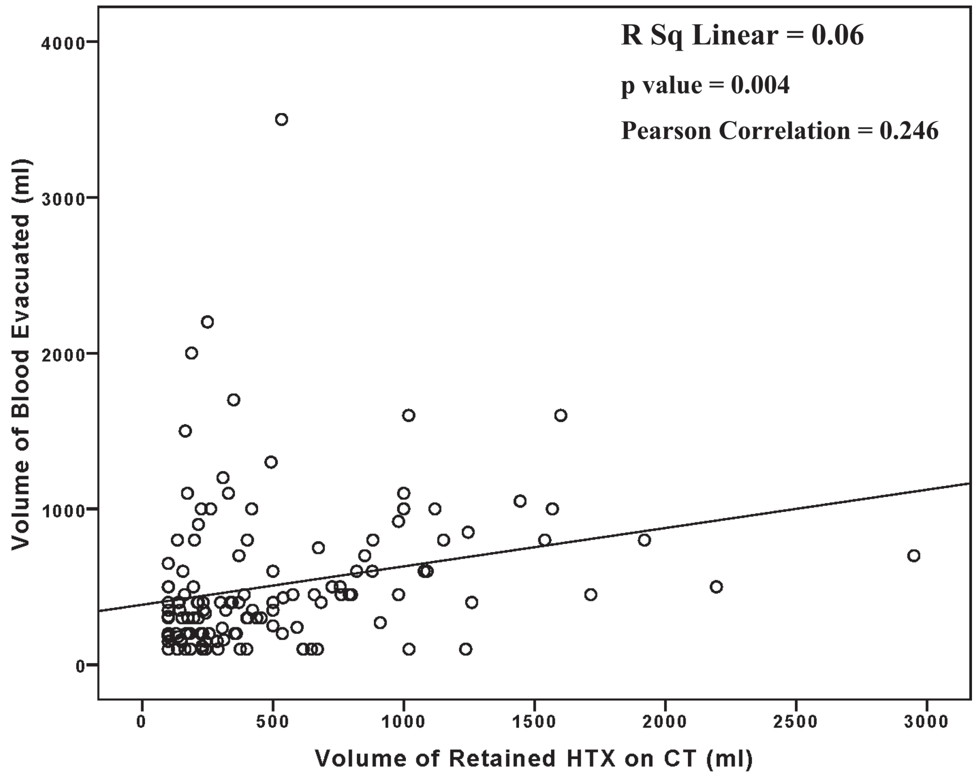

Figure 2. Scatter plot for the correlation of the volume of blood evacuated with the volume of retained hemothorax measured on the CT scan in patients treated with VATS or/and thoracotomy.

lematic. Although liquefied hemothorax can frequently be effectively drained with the placement of an initial or secondary thoracostomy tube, clotted and loculated collections may be more likely to require more aggressive management. The natural history of retained hemothoraces, particularly smaller collections, has also not been well defined.[12] Although largely dependent on the screening modality used, even the incidence of this entity has not been well established; although small studies have reported rates as high as 10%.[13] In addition, although computed tomography seems a more sensitive and specific modality by which to characterize and quantify RH,[2] the effective use of radiographic assessment to stratify risk and guide therapeutic decisions has remained elusive.[10,12,14] This study used a methodology previously validated by Mergo et al.[3] for the CT estimation of pleural effusions to examine the validity of CT in estimation of RH volume. In doing so, we found that CT estimations using this approach do seem to correlate significantly with evacuated blood at the time of VATS or thoracotomy, although weakly (correlation coefficient = 0.246). This provided us an opportunity to validate this approach for use in volume estimation of RH and subsequently used these volume estimations in predicting the success of subsequent interventions. Although these associations are interesting, the true value of this approach in the use of management algorithms must be validated prospectively. This would preferably be done in the context of a management algorithm.

Despite existing controversies, several management strategies for RH have been proposed, including observation, image-guided drainage, thoracostomy, VATS, intrapleural fibrinolytics, and thoracotomy. Thoracotomy remains the gold standard to which newer approaches are compared, but this surgical approach can be associated with significant morbidity and less invasive modalities are more commonly used as first-line modalities in the modern era. This study demonstrates that a wide variety of practices are presently used in an attempt to evacuate RH and mitigate the risk for subsequent development of posttraumatic empyema (26.8% in our present series). Figure 1 outlines the strategies for initial management used by the centers participating in our study. Our findings highlight that VATS is the most commonly used initial intervention in the modern era, although size of collection and a number of other factors likely contribute to choice of initial therapy.

It has been suggested that the effective utilization of a protocolized approach may both improve patient outcome and cost-effectiveness in the management of posttraumatic RH.[15] In the development of such algorithms, the absence of Level I data and the potential benefits and limitations of each available therapy must be carefully considered for individual patients.

As the natural history of RH has not been well elucidated, observation remains a valid option for consideration. The risk of intervention must be weighed in each individual patient, recognizing that each procedural approach likely increases subsequent risk for subsequent complications, including empyema. In this study, 30.8% of patients with posttraumatic RH were initially treated with observation, which proved successful in 83.2%. Patients selected for observation were more likely to be older, and more severely injured, than counterparts selected for intervention.

The size of the identified RH may also prove important when considering observation. Our findings noted that, in modern practice, patients with collections ≤300 cc on CT estimation were more likely to be observed, as were patients who initially required thoracostomy tube placement for the treatment of pneumothorax (as opposed to hemothorax). On multivariate analysis, the clinically relevant independent predictors of successful observation in our study were volume of RH ≤300 cc and pneumothorax as initial indication for trauma thoracostomy tube placement.

Placement of additional drainage catheters in the form of either additional thoracostomy tube placement or IGDP has been advocated as the initial therapy of choice by some investigators.[16,17] The proposed benefits of these interventions include the rationale that additional drainage access may promote better clearance of retained blood and mitigate the risk of subsequent need for more invasive interventions. IGDP has the added benefit of facilitating greater precision in placement of drainage under direct radiographic guidance. These procedures are not, however, without their own risks, including pulmonary injury and the potential introduction of additional threat for infectious complications. This report demonstrates that additional thoracostomy tubes were placed in 18.6% of patients after identification of posttraumatic RH with IGPD chosen as the initial therapy of choice in 5.2%. Combined, patients were more likely to have had these procedures conducted when pneumothorax was the indication for initial thoracostomy tube placement.

In our present series, thoracostomy tube placement and IGPD both demonstrated appreciable requirements for a second intervention after their performance. Over half of additional thoracostomy tubes required a subsequent intervention (39 of 61, 63.9%). Although less commonly used (Fig. 1), IGPD was followed by a required additional drainage procedure in 41.2% (7 of 17). Patients undergoing both procedures beyond HD 5 were more likely to require additional intervention (Table 3). On multivariate regression analysis, independent predictors for successful utilization of additional thoracostomy tube placement or IGPD as definitive therapy for RH were pneumothorax as initial indication for thoracostomy tube placement after trauma and CT-estimated volume of RH ≤300 cc.

The use of intrapleural fibrinolytics for the degradation and subsequent drainage of RH and infectious complications of the pleural space has already been reported by several groups.[10,13,18–27] In a review of studies from the Cochrane Database of Systematic Reviews reported in 2008, Cameron and Davies[10] identified seven randomized control trials examining the use of fibrinolytics for empyema and parapneumonic effusions. These investigators found that fibrinolytics used in these settings safely resulted in a significant decrease in the risk of requiring subsequent surgical drainage. Although these findings seem to demonstrate the utility of intrapleural fibrinolytic use, none of these studies included posttraumatic RH in their examinations.

At present, no Level I evidence supporting the use of fibrinolytics for the treatment of posttraumatic RH exists. In one small, prospective observational study reported by Kimbrell et al.[23], however, the use of fibrinolytics resulted in successful resolution of residual hemothorax in 92% of patients. Another limited retrospective examination conducted by Oguzkaya et al.[13] compared the use of VATS with intrapleural streptokinase for management of posttraumatic RH finding that the use VATS resulted in shorter hospital stay and a decreased need for subsequent thoracotomy. In addition, although it has been suggested that timing of administration may improve success rates with thrombolytic use, no study to date has demonstrated clearly any relationship between timing of use and success rates.[28] In this study, thrombolytics administered through the existing thoracostomy tube were used as initial intervention for posttraumatic RH in only 4.6% of patients (15 of 328), with 66.7% of these patients requiring additional interventions for treatment.

Expanded experience with thoracoscopy has increased the enthusiasm for the use of this modality to evacuate retained hemothoraces.[29–39] Although early VATS seems to be beneficial, the definition of "early" has varied among available retrospective series and there is a paucity of prospective studies available in the literature.[29–32,34,36–39] In one prospective, randomized report of VATS use within 72 hours of initial thoracostomy tube placement, Meyer et al.[29] found that VATS at this interval was associated with shorter hospital stays and lower hospital costs compared with individuals randomized to additional thoracostomy tube placement.

In this study, VATS was chosen as the initial therapy of choice for posttraumatic RH among 33.5% of patients (110 of 328), proving the most common initial intervention after diagnosis. On univariate comparison between patients in which VATS proved definitive treatment and those requiring additional intervention, VATS was more commonly successful among patient who had received periprocedural antibiotics and those without diaphragm injury. Although our present analysis was not designed to examine this question, these findings may be reflective of increased risk of empyema[40] and subsequent difficulty in clearing associated infection of the pleural space. The most common procedure required after failed VATS in our present series was thoracotomy.

Despite examining several timing cutoffs from both admission and time of RH identification (24, 48, and 72 hours and 5 and 7 days), we were unable in our present examination to demonstrate any association between timing of VATS and success with this procedure as definitive treatment of posttraumatic RH. Several factors may have contributed to this finding, including the time to diagnosis of RH. In our study population, the diagnosis of RH from initial thoracostomy tube placement varied from 1 day to 30 days with 65.4% of patients having diagnosis established greater than 72 hours after initial thoracostomy placement. Delays in diagnosis may have both altered the management choice and the success rate of VATS for the treatment of RH. On multivariate regression analysis of available data, the independent predictors of successful VATS in our study population were absence of diaphragm injury, use of periprocedural antibiotics, and CT-estimated volume of RH ≤900 cc.

Thoracotomy affords the best visualization of the thorax for evacuation of RH and empyema and also likely carries the greatest procedural risk of the procedures used. In our present examination, thoracotomy was more commonly performed when patients had bilateral hemothoraces, had CT-estimated RH volumes of >900 cc, or had concomitant diaphragm injury. The independent predictors of the need for thoracotomy among all patients with RH in our study were diaphragm injury, CT-estimated volume of RH >900 cc, and failure to use periprocedural antibiotics during initial thoracostomy tube placement. Thoracotomy proved to be the procedure with the highest success as definitive procedure for treatment among patients not deemed appropriate for intervention, with 79.2% of patients undergoing this intervention requiring no additional therapy.

Despite its prospective design, our present investigation has important limitations. The indications for the use of computed tomography to diagnose the presence of RH, including what constituted a suspicious chest X-ray for indication, may have varied between participating centers. This may have contributed to potential bias in enrollment. Capabilities of participating centers and individual surgeons may have precluded the access to all of the aforementioned management tools available for the treatment of RH. Interpretation of our description of the practice patterns should, accordingly, be used with caution. In addition, other variances among centers and providers that were not recorded in our study design may have contributed to subsequent outcome and the need for additional procedures. Our study population also represents a more severely injured cohort with a mean ISS of 20.7. Extrapolation to the management of less severely injured patients should, therefore, may not be appropriate. Finally, the mean time from placement of initial thoracostomy tube after trauma to the time of RH diagnosis varied considerable in our population (range, 1–30 days). Diagnosis of RH was identified in 32% of patients by HD 3 with 87.2% diagnosed by HD 10. Delays in diagnosis may have contributed to an increased opportunity for RH to organize in a fashion that might have contributed to lower rates of success with less invasive modalities.

CONCLUSION

This study represents the largest examination of posttraumatic RH in the modern medical literature. Recorded practice patterns illustrate an acceptance of VATS as initial therapy for the treatment of posttraumatic RH, although the appropriate timing of this intervention remains unclear. With success rates as definitive therapy approaching those of thoracotomy (70.0% vs. 79.2%, respectively), this less-invasive alternative may prove the approach of choice among patients with CT-estimated RH volumes of 300 cc or greater. Our data also suggest, however, that appropriately selected patients with volumes on CT of ≤300 cc can in many instances be safely observed. Among patients with volumes exceeding 900 cc or associated diaphragm injury, thoracotomy remains an appropriate intervention. Further investigation is warranted to examine the specific risk factors for complications of RH, including empyema, in order that risk stratification can effectively be included in algorithms designed to optimize the outcome of this entity after trauma.

AUTHORSHIP

This work represents the original efforts of the investigators. All authors contributed to study design, data collection, data interpretation, and manuscript development.

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DISCLOSURE

The authors declare no conflicts of interest.

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DISCUSSION

Dr. Clay Cothren Burlew (Denver, Colorado): This is a contemporary experience on the management of retained hemothorax from a multitude of practicing institutions. Although this is a timely topic, this multi-center observation raises more questions than answers.

In reviewing the author list there is a wide range of practices included, from Brazil to Santa Barbara, Dallas to D.C., and Scottsdale to Medellin, Columbia. Do you think these groups had a different indication for CT scanning at different institutions and, hence, a different identification rate of retained hemothorax? In other words, aren't we really picking up the small retained hemothoraces that we missed a decade ago on plain chest film due to the ubiquity of CT scanning at some institutions? And, hence, is the categorization of a retained hemothorax different at different institutions based upon their local resources and the role of CT imaging?

On a related note do you feel that size classification of the retained hemothorax impacts success rates? With 80 percent of the success in the observation group found in patients with volumes of retained hemothorax less than 300ccs aren't we really just saying that most of us don't intervene on a small amount of blood in the chest?

Regarding your empyema data, 27 percent of patients developed empyema, an indication for an operation. By including these patients in your overall analysis do you feel this skews your results regarding intervention? By excluding those patients with empyema from those undergoing operative intervention only 14 percent of patients in the study population underwent operation for treatment of their retained hemothorax. In relation to this, what were the conditions of chest tube placement? Were they emergent? Semi-elective? Placed in the Emergency Department, operating room or in the ICU or ward? Do you think that type of placement and technique impacts the overall re-intervention rate in these patients?

Perhaps most importantly, where do we go from here? Several groups have proposed management algorithms in the literature and I'm guessing that at least one or two of those authors will be standing up to comment on your study. Based upon your review and this study, what do you recommend as a management protocol for retained hemothorax? What size classification warrants an operation? And what should our timing of intervention be? What is your list of future prospective studies on this topic?

Again, I found this to be an interesting study. I look forward to your future work on this topic. I'd like to thank the Association for the privilege of discussing this manuscript.

Dr. Therese M. Duane (Richmond, Virginia): My question is related to the antimicrobial use. How do you link antimicrobials with the need for thoracotomy when it's not predictive of empyema and you didn't include the concept of the duration of chest tube placement when that is the biggest risk factor? Thank you.

Dr. Peter Rhee (Tucson, Arizona): A quick question on the denominator issue, whether you had any idea of how many people who got chest tubes got retained hemothorax.

The second is the chest tube size: You know that there is a push towards smaller chest tubes in trauma. As a result of this have you changed your practice?

Dr. Ronald Gross (Springfield, Massachusetts): Back to the antibiotic question, half of your patients got antibiotics at the time of the thoracostomy placement. I'm going to assume that all of your patients were given antibiotics perioperatively prior to the VATS. How do you relate the two with respect to the development of the empyema?

And where do you go with respect to recommending antibiotics or not? Cohen did a paper on this over a decade ago. Are we reinventing the wheel?

Dr. Michael L. Hawkins (Augusta, Georgia): I'm curious about your diaphragm injury. Was this associated with intraabdominal problems also or strictly just that little sheet of muscle that we call the diaphragm?

Regarding the diaphragm injury – were all of these recognized and treated operatively initially? Were these identified at the time of VATS?

Dr. Norman McSwain, Jr. (New Orleans, Louisiana): Now that you've identified that the volume of the blood clot is important, do you routinely measure these? And if you do not routinely measure them by CT scan, how are you using the information for patient care?

Dr. Robert A. Maxwell (Chattanooga, Tennessee): I enjoyed the paper. We published a multi-center trial sponsored by EAST about ten years ago. Basically, we showed that antibiotics did not reduce the incidence of post-thoracostomy empyema and we found that we grew out a lot of more resistant bugs when they developed subsequent infections like VAP. So I'd caution you with your enthusiasm in this trial of the antibiotic usage. And I had two questions:

How many of those patients that got antibiotics got them specifically for prophylaxis of the chest tube? And how many got them for say orthopaedic prophylaxis? Because there is a lot of confounding data when you include patients that are so sick they often had to get antibiotics for something else.

I thought your repeat procedure after initial VATS was high relative to the experience of others. And I was wondering if you had any thoughts about why your repeat procedure rate after an initial VATS was that high.

Dr. J. Wayne Meredith (Winston-Salem, North Carolina): To use your data I need to know an answer to a different question than I think you asked and that is, of a given size hemothorax without intervention what is the likelihood of that leading to (undistinguishable) or fibrothorax or empyema, some need for decortication, not what is the likelihood of the surgeon taking care of this patient deciding to operate on them to evacuate a hematoma subsequently.

And – because that's the endpoint we're trying to prevent. Do you have the tools to dissect that out from the database that you have?

Dr. Joseph DuBose (Baltimore, Maryland): Thank you, Dr. Britt. I will attempt to address all of these wonderful questions. With regards to Dr. Cothren, I thank you again for your wonderful review.

The categorization of these differences were very difficult. Obviously between centers there are certain things you cannot correct for, including surgeon judgment.

I would say that based on our results I think that we all agree that probably the small collections that we do as a collective group, typically observe. Hopefully our data supports that that is an appropriate practice and that we may be causing more problems by sticking a small drainage catheter in when it's not adequately indicated.

Empyema and the timing issue of empyema relative to the procedure, or whether empyema was actually a contributing indication for thoracotomy is a very important question that we are subsequently in the process of examining.

As you mention, there were variances with regards to thoracostomy placement techniques. Some of these were placed in the operating room universally at many of these centers, particularly our colleagues in South America and some of them in Canada. Some of them were placed in the emergency room by a surgical resident. Techniques, likewise may certainly have varied. These differences were obviously a limitation of our study.

With regards to a protocol and additional study, I do think that we have now at least an early foundation to move forward with additional prospective study validating a protocol. We look forward to collaborating on this endeavor. I think one of the important things that we found and can validate prospectively are those cut-offs for the CT estimation and the validity of these values as an adjunct to the decision process.

For Dr. Duane, I thank you for your question. With regards to the antibiotic linkage and association with the need for thoracotomy, your point is exceptionally well-taken. Clearly, that is a limitation of this study.

There were several questions about antibiotics. I will say that among the types of antibiotics used, the most common choice was Ancef. But, again, we did not adequately discern from our study design whether they had been given in isolation for chest tube placement or for other indications.

Dr. Rhee, unfortunately we do not have the data for the incidence of retained hemothorax in these populations. That has remained an elusive question in trauma care.

In response to your second question, I have not personally changed my practice in chest tube placement size based upon our findings.

Dr. Gross, I believe I already spoke on the antibiotic data. There was obviously a depth of data that we could have collected that we did not and it was one of our limitations for this study.

Dr. Hawkins, diaphragm injuries were noted in isolation. We had collected abdominal AIS but not other specific abdominal injuries. Obviously another limitation.

Dr. McSwain, we do – I do, personally–measure this. This technique is exceptionally simple to use, even for a trauma surgeon to estimate the volume of the size of the collection. So I do utilize it in my thought processes and perhaps our study validates this practice.

And I think I answered many of the questions from our Chattanooga colleague. I apologize for not getting to everyone.

The repeat procedures, obviously, were very high. It's one of the things that we do need to examine more carefully.

And, finally, Dr. Meredith, your point is exceptionally well-taken that perhaps the question we asked was needs to be revised as we move on to additional study, including the validation of prospective algorithms. We hope to provide you an answer in the future meetings. Thank you.