High-Vacuum Drainage System in Percutaneous Image-Guided Thoracocentesis for Complex Pleural Effusions

Jiawei Alexander Yap[1] Krishna Mohan Gummalla[1] Martin Weng Chin H'ng[1]

[1] Department of Diagnostic Imaging, Tan Tock Seng Hospital, Novena, Singapore

Address for correspondence Jiawei Alexander Yap, MBBS, FRCR, Department of Diagnostic Imaging, Tan Tock Seng Hospital, 11 Jalan Tan Tock Seng, Singapore 308 433 (e-mail: alexyap@gmail.com).

J Clin Interv Radiol ISVIR 2023;7:159–165.

Abstract

Purpose Our retrospective study is aimed to analyze the efficacy and outcomes between high-vacuum suction drain (HVSD) over passive drainage in the setting of percutaneous image-guided thoracocentesis, with a secondary aim to determine if preprocedural computed tomography (CT) can aid decision-making.

Methods Clinical and imaging details of patients using HVSD between November 2012 and October 2018, who had a preceding CT within a month before drainage, were collated. The control group was selected from patients who had thoracocentesis with passive drainage performed between November 2017 and October 2018. Cases where HVSD was the sole device were compared with those using only a chest bottle.

Results The HVSD was the only device in 17 cases compared to chest bottle in 47 cases. Mean duration being on a drain for these two arms were 5.5 and 7.3 days, respectively ($p = 0.170$). Fewer from the HVSD arm needed a repeat procedure ($p = 0.424$). Patients in the HVSD arm had significantly smaller volumes ($p = 0.013$) of higher density ($p = 0.016$), associated with a more encapsulating wall ($p = 0.013$) but not septations ($p = 0.922$). Density of contents on CT was useful in distinguishing between straw-colored effusion versus hemoserous fluid or pus ($p = 0.008$).

Conclusions HVSD was not inferior to the chest bottle in the setting of thoracocentesis. Considering its potential adjunctive benefits, it should be an option for draining smaller volume complex effusions. Due to poor correlation with preprocedural CT, decision to insert a HVSD should be made by the procedurist at the time of thoracentesis.

Keywords

- complex pleural effusions
- high-vacuum
- thoracocentesis

Name and place of institution at which work was performed:
Department of Diagnostic Imaging, Tan Tock Seng Hospital, 11 Jalan Tan Tock Seng, Singapore 308 433.

article published online
February 13, 2023

DOI https://doi.org/10.1055/s-0043-1761629.
ISSN 2457-0214.

Thieme Medical and Scientific Publishers Pvt. Ltd., A-12, 2nd Floor, Sector 2, Noida-201301 UP, India

Introduction

Percutaneous image-guided pleural drain insertion (thoracocentesis) is a mainstay for treatment for pleural effusions. The drain tubes are usually connected to a chest bottle for gravity dependent passive drainage. Pleural effusions can be transudative or exudate via Light's criteria.[1] Radiologically, they can be broadly categorized as simple or complex.[2] Complex pleural effusions are defined as those containing dense contents, such as an empyema, associated with loculations, and/or thick pleural surfaces. Given its complexity, gravity-dependent drainage may be relatively ineffective. Applying a negative suction pressure could permit more effective drainage.

High-vacuum suction drains (HVSD) were initially reported in surgical procedures, and have been shown to have good outcomes in postsurgical patients,[3,4] by reducing the duration of drainage by utilizing continuous suction. However, literature is sparse regarding criteria for choosing a HVSD over passive drainage, especially when encountered with a complex effusion during percutaneous image-guided procedure.

Our retrospective study was aimed to analyze if HVSD would shorten the duration of drainage and avoid a repeat procedure when compared to a chest bottle. Our secondary aim was to see if preprocedural computed tomography (CT) findings can have a role in guiding the procedurist in making this decision.

Materials and Methods

Patient Selection

In our institution, HVSD using the Privac (Primed, Halberstadt, Germany) were occasionally employed for complex pleural drainages since 2012. Drainage procedure was similar to the hitherto ultrasound-guided insertion of a chest tube, only that it was now attached to this bottle. All thoracocenteses were performed by an experienced trainee and/or specialist in interventional radiology (IR) from the radiology department.

Using device name as the search criterion, we collated all HVSD inserted by IR from November 2012 to October 2018, over a period of 6 years. All these patients had a preceding CT within a month of the procedure. In this cohort, there were patients where the HVSD was the sole device used from beginning till resolution of drainage. Other patients, when encountered with an effusion that was slow or failed to resolve, returned to IR for a review and may have had these various combinations of management instituted: (1) Changing the bottle type from chest bottle to high-vacuum suction bottle, or vice-versa; (2) changing the tube for a new one, usually if there was occlusion from debris or a kink; (3) inserting an additional tube to supplement the current one; or (4) inserting a new tube at a different location for cases of loculated effusions, when the initial compartment had been drained leaving an adjacent sequestered residual collection. There were also patients with a nonresolving effusion who may have been referred to cardiothoracic surgery for video-assisted thoracoscopic surgery (VATS). Patients other than those where HVSD was the sole device used throughout were excluded from statistical analyses.

The control group was selected from an audit of all chest drainages using a chest bottle performed between November 2017 and October 2018, with a complex effusion diagnosed on a preceding CT within a month preceding the drainage. Inclusion terms in the CT report used for selection for this control group included "complex," "empyema," "septation(s)," and "loculation(s)." This timeframe was selected as it roughly coincided with the last 1 year of our study period and generated a sufficient number of comparable cases.

Data Acquisition

Retrospective analysis on data was performed by analyzing the patient medical records for demographics, clinical diagnosis as well as procedural details (which included side, appearance of aspirated contents, and duration being on a chest tube). Patients were followed up till the time the drain was removed and tracked for a further 6 months thereafter, to see if they remained drain-free or had returned for repeat procedure (either drainage and/or aspiration) of the same effusion.

We also analyzed the predrainage CT scan of these patients and stratified these by volume, density of contents, septation, and presence of wall thickening and/or enhancement. Three-dimensional CT volumetry was done manually to estimate the volume and its contents, using a best fit technique of drawing around the boundaries of the fluid collection. A lower limit of −20 Hounsfield unit (HU) and upper limit of 80 HU was selected for volume calculation. In certain scenarios, a lower limit of −80 HU had to be taken due to presence of beam hardening artefacts from the patient's ribs to include volume which would otherwise be omitted. In cases where there were very complex effusions, all three authors were involved to ensure that there was consensus on accuracy of volume estimation.

Statistical Analysis

Associations between continuous data were assessed using *t*-tests, while categorical variables were tested using the Pearson's chi-squared test, or Fisher's exact test if at least one of the expected cell counts was below 5. Analysis of variance was employed when there were more than two categories of continuous dependent variables against nominal-level and variables. Statistical significance was declared if a two-tailed *p*-value was less than 0.05. Analysis was performed using SPSS (SPSS Inc, Chicago, Illinois, United States) version 26. Ethics approval was granted by the NHG Domain Specific Review Board.

Results

Patient Demographics (►Table 1)

There were 33 insertions using a HVSD (►**Fig. 1B**). It was the only device ($n = 17$), used sequentially or in combination

Table 1 Patient demographics of the 64 comparative cases

	Only HVSD (n = 17)	Only chest bottle (n = 47)	HVSD and chest bottle (n = 11)	VATS (n = 13)
Demographics				
Male	14	35	10	12
Female	3	12	1	1
Age (y)	67.9 (SD = 13.3)	63.7 (SD = 16.0)	65.5 (SD = 13.2)	50.4 (SD = 10.8)
Race				
Chinese	15	34	9	10
Indian	1	5	0	1
Malay	0	4	2	1
Others	1	4	0	1
Clinical diagnosis				
Infective	10	29	9	13
Malignancy	2	11	2	0
Postoperative	4	6	0	0
Trauma	0	1	0	0
Unknown	1	0	0	0

Abbreviations: HVSD, high-vacuum suction drain; SD, standard deviation; VATS, video-assisted thoracoscopic surgery.

with a chest bottle ($n = 11$) and progressed to VATS ($n = 5$). There were also 55 insertions using a chest bottle (►**Fig. 1C**), with one patient having two drains into separate locules. It was the only device ($n = 47$) and progressed to VATS ($n = 8$). The 11 cases where a HVSD was used interchangeably or in conjunction with a chest bottle were heterogenous in their management, whereby choice of device was arbitrarily changed midway. Eight cases were upgraded from chest bottle to a HVSD, one was downgraded after the HVSD dislodged, one was upgraded then downgraded, and the last one had simultaneous use of both devices. This group and those progressing to VATS were excluded from further data analysis. Cases where HVSD was the sole device (HVSD arm) were compared with those which solely used a chest bottle (control arm). Infection was the common cause for pleural effusions in both these groups accounting for more than 50%.

Procedural Details and CT Characteristics of the Effusion (►Table 2)

Visual inspection of drained contents was categorized into four groups, arbitrarily reflecting an increasing level of viscosity. It was significantly less straw-colored in the HVSD arm. Mean duration being on a drain for patients from the HVSD and control arms were 5.5 and 7.3 days, which was not significant. Tube size was not a factor in our study as all patients utilized 10F pigtail catheters, which is the default in our department. For the heterogenous group of 11 patients using a combination of HVSD and chest bottle, the duration of drainage was 10.4 (standard

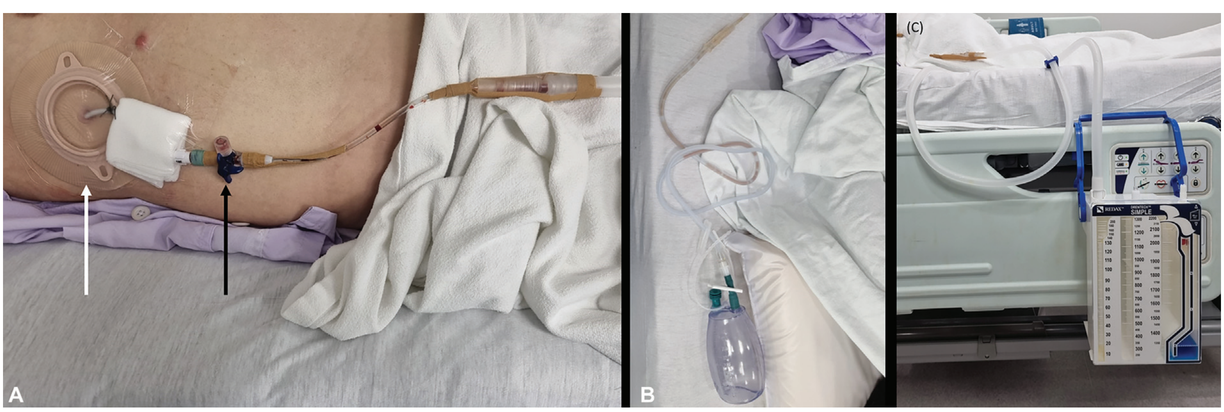

Fig. 1 (**A**) The technique of inserting and securing the chest tube (white arrow) using a baseplate are similar in both arms. The intervening three-way tap (black arrow) allows volume of drainage to be regulated. The difference lies in the whether the tube is ultimately connected to a high-vacuum suction drain bottle (**B**) or chest bottle (**C**).

Table 2 Procedural details and CT characteristics of the effusion of the 64 comparative cases from the Privac and control arms

	HVSD arm	Control arm	Level of significance
Side			0.164
Right	12	24	
Left	5	23	
Visualized contents at time of drain insertion			<0.001
Straw-colored	2	33	
Hemoserous	9	10	
Turbid	1	1	
Pus	5	3	
Duration on tube (d)	5.5 (SD = 4.0)	7.3 (SD = 4.6)	0.170
Days of CT before drainage (d)	5.1 (SD = 4.2)	3.6 (SD = 4.2)	0.203
Volume of pleural effusion (mL)	196.6 (SD = 242.3)	453.4 (SD = 384.4)	0.013
Density of contents (HU)	22.4 (SD = 8.7)	16.5 (SD = 5.5)	0.016
Presence of septations			0.922
Yes	10	27	
No	7	20	
Wall thickening and/or enhancement			0.013
Yes	16	29	
No	1	18	

Abbreviations: CT, computed tomography; HVSD, high-vacuum suction drain; HU, Hounsfield unit; SD, standard deviation.

deviation [SD] = 0.8) days. This group had aspirated contents appearing straw-colored ($n = 3$), hemoserous ($n = 5$), turbid ($n = 2$), and pus ($n = 1$), mimicking those in the HVSD arm.

Predrainage CT scans for the HVSD and control arms were performed at an average of 5.1 and 3.6 days prior. The HVSD arm had a significantly smaller volume of higher density associated with a surrounding thickened and/or enhancing wall. Presence of septations was not significant. Density of contents on CT appears to be able to predict if aspirated contents at time of insertion were straw-colored versus being hemoserous or pus (►**Table 3**). However, despite its subjectively lower viscosity, hemoserous fluid can yield higher attenuation values due to the presence of hemorrhagic products within. There was no significant association with presence of septations or wall thickening and/or enhancement.

A visual guide has been included to link the predrainage CT image with the peri-procedure ultrasound image (►**Fig. 2**). It should be appreciated that these parings are a rough guide given that they are different modalities of imaging, including a delay between time of performance and most importantly, that ultrasound features were not evaluated as part of this study.

Table 3 Comparison between CT characteristics of the effusion and visualized contents upon aspiration

	Straw-colored	Hemoserous	Turbid	Pus	Level of significance
Density of contents (HU)	15.6 (SD = 5.0)	21.6 (SD = 7.8)	16.1 (SD = 2.2)	21.1 (SD = 8.8)	0.008
Presence of septations					0.585
Yes	21	9	1	6	
No	14	10	1	2	
Wall thickening and/or enhancement					0.218
Yes	21	15	2	7	
No	14	1	0	1	

Abbreviations: CT, computed tomography; HU, Hounsfield unit; SD, standard deviation.

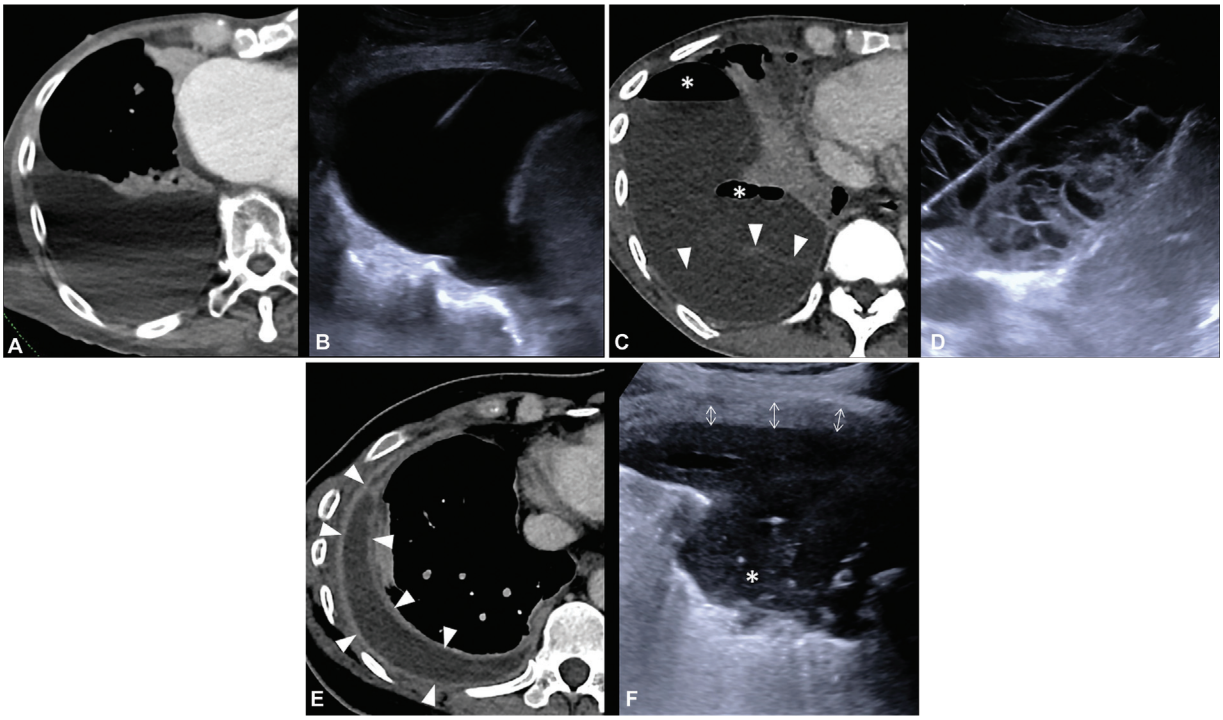

Fig. 2 A 78-year-old male patient with heart failure, pneumonia, and a simple effusion. (**A**) Computed tomography (CT) image shows a homogenous low-density effusion devoid of internal septations and without wall thickening and/or enhancement. (**B**) Ultrasound image at time of needle insertion also reveals an anechoic effusion in the pleural space. A 46-year-old male patient with recurrent effusions from lung malignancy. (**C**) CT image shows faint internal septations (arrowheads) resulting in a multiloculated effusion. Locules of gas (asterisk) were from a previous procedure. (**D**) Ultrasound image reveals more conspicuous septations. A needle has been inserted to traverse several locules for better drainage. A 50-year-old lady with tuberculous infection and empyema. (**E**) CT image shows an effusion with thickened and enhancing walls (arrowheads). (**F**) Ultrasound image confirms wall thickening (double arrows) as well as dependent echogenic contents (asterisk).

Returning for a Repeat Procedure

After removal of the chest tube, nine cases returned for a repeat procedure, one (5.9%) from the HVSD arm, and eight (17.0%) from the control arm. This was not significant ($p = 0.424$). The repeat drainage was performed within an average of 13.7 (SD = 15.5) days.

Discussion

Management of pleural drainage is varied and depends on many factors, including the underlying etiology, preferences of the procedurist, and hospital practices.[1] In our practice, pleural drainage tubes are routinely connected to a chest bottle and left to drain passively utilizing gravity. This may be theoretically effective for simple effusions, but for complex pleural collections containing viscid contents with septations and loculations, negative suction pressure could be advantageous for optimal drainage. However, there is ongoing controversy over the application of HVSD for pleural effusions.

Although literature for preferred management of complex pleural collections is lacking, there is plenty in support of postoperative chest tube management with vacuum-assisted drains. A study for postoperative complex collections demonstrated favorable clinical outcomes in the context of traumatic chest injury,[5] with prevention of persistent air leakage and concomitant reduction in chest tube duration and length of hospitalization. In addition, the American College of Chest Physicians guidelines have recommended adding suction if gravity alone is insufficient for draining a pneumothorax.[6] Retained hemothoraces and other complex fluid collections act as a medium for bacteria growth and increase complications related to infection.[7] Newcomb et al revealed a lower incidence of residual pleural effusions as well as shorter period of drainage time for equivalent volume compared to conventional drains.[4] In line with this reasoning, we hypothesize that a viscid as well as septated and loculated effusions may benefit from earlier re-expansion of collapsed lung, leading to early patient recovery and reduction in morbidity related to immobility.

Negative suction may be achieved by performing regular daily flushing and aspiration or by connecting to a wall suction or portable suction bottle. Wall suction can reach a maximum pressure −70 kPa, whereas vacuum bottles have a pressure suction of up to −95 kPa.[8] Our Privac bottle has a pressure suction value of around −90 kPa.[4] Manual flushing and aspiration by the bedside may not be carried out effectively, thwarted by inability to gauge the suction pressure. Our retrospective study demonstrates a shorter duration of drainage when using a HVSD compared to chest bottle, albeit the former had a smaller volume with thicker contents and a more encapsulating wall. It may be argued that duration of drainage for these patients could have been prolonged if a chest bottle was used for a comparable volume of similar viscosity. This is partly supported by the heterogenous group of 11 patients, where unfamiliarity on the part of the procedurist or indecision to use the Privac bottle early may have contributed to a longer duration being on a tube. Despite our small numbers, the results were noninferior compared to the normal chest bottle, and may have contributed to a reduction in number of patients returning for a repeat procedure.

There are indirect advantages of using the Privac system. It is less bulky compared to the conventional drainage system and decreases the risk of dislodgement during patient movement. Newcomb et al in their study on pediatric patients confirmed this and additionally claimed that a similar HVSD required less level of care.[4] When compared to wall suction drainage, the smaller size and relative portability of the Privac bottle allow early mobilization, whereas the latter restricts patient to the bedside. Early mobilization permits rehabilitation and physiotherapy leading to efficient drainage and early recovery.[4]

Although the technique for inserting the chest tube is similar for both devices, a few salient complications must be highlighted. There is the theoretical risk of re-expansion pulmonary edema with large volume thoracentesis in a short period of time.[8] Kim et al reported rates of 2.1 and 0.9% in vacuum bottle and wall suction groups, respectively, which were comparable to the reported incidences with conventional drainage systems of 0 to 2.7% suggesting no increased risk.[8] Hence, it is recommended to drain not more than 1 to 1.5L of fluid drainage per day.[8] Our procedurists are aware of this complication when using the chest bottle and regularly provide this cautionary statement in the report, and recognition of this risk is reflected by the Privac system being favored for smaller volume collections in our study.

The vacuum of the Privac bottle can be rendered ineffective should there be an air-leak[4] such as from a bronchopleural fistula or indrawing of air through a capacious chest wall incision. We recommend checking for potential air-leaks after deploying the chest tube before deciding to connect to the Privac bottle. If an air-leak is identified peri-procedurally or later in the ward, there are one of three things that can be done: (1) replace the Privac bottle with a new one, (2) substitute it with a chest bottle that has an underwater seal or (3) clamp the tube and await review by IR the next day. These instructions were added to our report in early 2017 as its usage became more commonplace, so as to educate ward personnel on how to manage this complication.

Active suction may also be associated with transient chest pain and coughing. In the study by Kim et al, the wall suction pressure was limited to −13.3kPa to reduce these symptoms.[8] It did not affect the overall procedure time for draining 1 to 1.5L of fluid.[8] Rarer complications include decreased venous return due to mediastinal shift (if the lung is resistant to expansion) and theoretical exacerbation of low-pressure bleeding,[9] leading to hemothorax. These are quoted in the context of postoperative lung resection with the use of vacuum-assisted drainage. We are fortunate not to have encountered any peri or postprocedural morbidity or mortality related to the drainage in both our arms.

There was poor correlation between CT findings and actual pleural contents, similar to that in recent literature.[10] Low-density contents may suggest a transudate but higher densities may not differentiate between hemoserous from infected contents. Longer duration between the CT scan and drainage procedure may also cause a simple effusion to become secondarily infected. In our study, we discovered that there was a statistically significant difference between the density of straw-colored versus hemoserous ($p = 0.002$) and versus pus ($p = 0.034$) contents, with an overall $p = 0.008$. This implies that effusions with a thick wall with contents of more than 15HU favored those with more complex constituents. Given these findings, decision to use a HVSD should be made after appreciating the nature of aspirated contents at the point of drainage, rather than basing that on the prior CT which may be potentially confounded by the time interval between imaging and actual drainage.

Limitations

This is a retrospective study with a small sample size. There is also an inherent selection bias where the procedurists might have favored using the high-vacuum suction drain after discovering a complex effusion and aspirating viscid contents. A prospective randomized controlled study may be undertaken for future confirmatory studies.

Conclusion

When compared to the chest bottle, we found that patients on HVSD spent a slight shorter time being on a tube and were less likely to return for a repeat drainage, although these were not statistically significant. Taking into consideration their portability, earlier immobilization of patients with potential cost benefits, it should be added to the armamentarium for draining smaller volume complex effusions. Given that preprocedure CT was not accurate at predicting the nature of effusion, decision to use a HVSD is best made by the procedurist at the time of thoracocentesis based on imaging of a complex effusion, nature of aspirated contents, and exclusion of an air-leak.

Ethical Approval
Ethics approval was granted by the National Healthcare Group (NHG) Domain Specific Review Board.

Conflict of Interest
None declared.

References

1 Yu H. Management of pleural effusion, empyema, and lung abscess. Semin Intervent Radiol 2011;28(01):75–86
2 Shen KR, Bribriesco A, Crabtree T, et al. The American Association for Thoracic Surgery consensus guidelines for the management of empyema. J Thorac Cardiovasc Surg 2017;153(06):e129–e146
3 Deng B, Tan QY, Zhao YP, Wang RW, Jiang YG. Suction or non-suction to the underwater seal drains following pulmonary operation: meta-analysis of randomised controlled trials. Eur J Cardiothorac Surg 2010;38(02):210–215
4 Newcomb AE, Alphonso N, Nørgaard MA, Cochrane AD, Karl TR, Brizard CP. High-vacuum drains rival conventional underwater-

seal drains after pediatric heart surgery. Eur J Cardiothorac Surg 2005;27(03):395–399
5 Feenstra TM, Dickhoff C, Deunk J. Systematic review and meta-analysis of tube thoracostomy following traumatic chest injury; suction versus water seal. Eur J Trauma Emerg Surg 2018;44(06): 819–827
6 Venuta F, Diso D, Anile M, Rendina EA, Onorati I. Chest tubes: generalities. Thorac Surg Clin 2017;27(01):1–5
7 Savage SA, Cibulas GA II, Ward TA, Davis CA, Croce MA, Zarzaur BL. Suction evacuation of hemothorax: a prospective study. J Trauma Acute Care Surg 2016;81(01):58–62
8 Kim H, Shyn PB, Wu L, Levesque VM, Khorasani R, Silverman SG. Wall suction-assisted image-guided thoracentesis: a safe alternative to evacuated bottles. Clin Radiol 2017;72(10):898.e1–898.e5
9 Lang P, Manickavasagar M, Burdett C, Treasure T, Fiorentino FUK Cardiothoracic Trainees' Research Collaborative UK Cardiothoracic Trainees' Research Collaborative. Suction on chest drains following lung resection: evidence and practice are not aligned. Eur J Cardiothorac Surg 2016;49(02):611–616
10 Abramowitz Y, Simanovsky N, Goldstein MS, Hiller N. Pleural effusion: characterization with CT attenuation values and CT appearance. AJR Am J Roentgenol 2009;192(03):618–623

