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Varying Suction Techniques in Thoracentesis

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Abstract

Introduction: Thoracentesis is a common pulmonary procedure; however, great variability still exists in provider practices. Standard of care methods ranges from vacuum assisted to manual aspiration to use of wall suctioning. Few studies have compared efficiency, safety or patient comfort between different methods of pleural fluid evacuation. We sought to investigate which of three standard of care methods implemented most frequently at our institution took the least amount of time to perform and caused the least symptoms and complications. **Methods:** We performed a single center, randomized controlled study to determine which method of thoracentesis (wall suctioning [N = 15], manual aspiration [N = 8], or vacuum drainage [N = 12]) was the most efficient in terms of procedural time and post-procedural symptoms. 35 patients undergoing therapeutic thoracentesis were randomized to the study. Procedural time was recorded from the onset of pleural fluid drainage and was measured at 500 mL, 750 mL, 1000 mL and at termination of drainage. Pain and dyspnea scores were assessed on a verbal numerical pain rating sale (NRS) and Modified Borg Dyspnea Scale (MBS). Scores were reported pre-procedure, after thoracentesis catheter placement before fluid removal, after termination of drainage prior to removal of catheter, immediately after catheter removal, 5 minutes post-procedure, and 24 hours post-procedure. **Results:** The differences in procedural time among groups were significant ($p < 0.0001$). Specifically, the vacuum bottle group had the shortest average procedure time compared to the other two methods ($p < 0.0001$). There were no significant differences in pain pre-fluid, post-fluid, post-catheter insertion and at 5-min and 24-hr post procedure. The adjusted dyspnea score model did show a significant difference on dyspnea score 24-hr post procedure; specifically, vacuum bottle had the lowest score compared to manual and bottle suction (p = 0.006 and p = 0.004; respectively. **Discussion**: This study comparing various methods of pleural fluid drainage reveals reduced procedural time with vacuum bottle drainage and suggests that vacuum bottle drainage in our study population was more efficient with less associated symptoms compared to the other two standard of care methods. These findings would benefit from further analysis in a larger, randomized study to corroborate our findings.

Keywords

Thoracentesis, Pleural Effusion, Interventional Pulmonology, Malignant Pleural Effusion, Chest Ultrasound

1. Introduction

Thoracentesis is a common procedure; however, a great deal of variability still exists between providers and institutions in the practice of pleural fluid drainage. Standard of care methods varies from gravity drainage, to vacuum assisted, to manual aspiration and the use of wall suctioning. Although overall serious complications from thoracentesis including pneumothorax, bleeding and re-expansion pulmonary edema (REPE) occur very infrequently, procedural side effects are common and frequently present as cough, chest pain and dyspnea [1] [2]. Controversy still exists, in part due to conflicting and/or inadequate data, over the clinical correlations that have been made between symptoms experienced by patients and the volume of fluid removed, rapidity of lung re-expansion and excessively negative pleural pressure [3]-[8].

Only a few studies to date have been done comparing efficacy and tolerability of different methods of pleural fluid evacuation. The recent GRAVITAS trial compared manual aspiration to gravity drainage and found them to both be safe with comparable patient comfort and complication rates [9]. Likewise, other studies have been done to compare both manual aspirations to vacuum drainage and wall suction to vacuum drainage and found that patients had less discomfort with both manual aspiration and wall suction compared to vacuum drainage [10] [11]. No studies to date have been done comparing pleural fluid evacuation via wall suctioning versus manual aspiration in terms of either safety, patient comfort, or efficiency. To date, there also do not appear to be any studies that have investigated procedural time as a primary outcome when performing thoracentesis via different techniques, though several trials have reported on secondary outcomes of procedural time. For instance, the GRAVITAS trial found a mean difference of 7.4 minutes less time to complete thoracentesis using manual drainage versus gravity drainage [9]. Likewise, the randomized trial performed by Senitko *et al.* comparing vacuum drainage versus manual aspiration found that vacuum drainage was 3 minutes faster on average [10].

In an effort to optimize the experience of therapeutic thoracentesis for patients at our institution, we sought to investigate which of three standard of care methods implemented most frequently at our institution took the least amount of time to perform and caused the least symptoms and complications.

2. Methods

This was a single center, randomized controlled study to determine which method of thoracentesis (wall suctioning, manual aspiration, or vacuum drainage) was the most efficient in terms of procedural time and post-procedural symptoms. All patients were enrolled at the University of Minnesota East Bank Campus (Minneapolis, MN). Adult patients being considered for clinically indicated therapeutic thoracentesis by hospitalist or pulmonary providers were screened for eligibility. Patients were excluded if they were less than 18 years of age, were only being assessed for diagnostic thoracentesis, were receiving mechanical ventilation, persistent symptomatic effusions for which an IPC was indicated, or if they opted out of research in the EPIC EMR system. Eligible patients underwent routine thoracentesis by qualified providers or under the direct supervision of a qualified provider at a tertiary academic medical center in either the outpatient procedural suite or at the bedside. Patients were randomized to one of the three methods of thoracentesis by sealed, opaque envelopes accessible only to providers and investigators. Providers opened the envelopes before starting the procedure in order to obtain the appropriate equipment needed for the stated procedure. The statistician was blinded to who received which type of thoracentesis method.

Prior to initiation of the study, we tested the amount of negative pressure created by our three methods while draining containers of water using manometry and the same drainage catheter kit used in the study. Use of glass vacuum drainage bottles created negative pressures in the range of −459 to −485 cmH_2O (approx. 337 to 357 mmHg). Eleven clinician or medical student volunteers were asked to perform manual aspiration with this sham set-up and an average of 5 attempts was recorded. Volunteers were not able to view the manometer screen during these attempts. The average negative pressure created during these trials was 198 cmH_2O (approx. 146 mmHg) with a standard deviation of 97 cmH_2O (71 mmHg). Inter-provider variation ranges during these attempts were anywhere from 8 to 83 cmH_2O (6 to 61 mmHg). Lastly, when testing wall suction with manometry in this manner we noted that pressures remained constant and consistent with the pressures set at the wall. After performing these tests and review of the literature a conservative setting was chosen as −50 mmHg continuously for patients in the wall suction group. Due to industry-wide shortages of one-way aspiration valves typically provided in our thoracentesis kits, manual aspiration was performed using a three-way-stopcock and additional length of pressure tubing connected in line with the standard plastic fluid collection bag. The remainder of the procedure was performed via standard practices at the discretion of the performing physician.

Procedure methods were standardized to use of a CareFusion 8 French dual indication catheter-over-the-needle drainage device kit. All procedures were performed based on best practice from the caring physician. The size and location of the pleural effusion was assisted by using bedside ultrasound (Sonosite PX, Fujifilm). The site was marked with a sterile marker. The patient was prepped in sterile fashion using chlorhexidine. The entry site for the catheter was anesthetized using 1% lidocaine using standard procedure. A finder needle was used to inject local anesthetic and aspirate some pleural fluid. Once this was confirmed, a scalpel was used to make a 1 cm incision on the skin. The catheter was then advanced while aspiration until pleural fluid was obtained. The sheath was advanced over the needle then the needle was removed. The catheter was then stabilized, and the appropriate tubing was connected. For this study, we used the same pressure tubing for each modality of suction.

Procedural time was measured at the time of initiation, during specified fluid removal volumes, and at the end of fluid drainage. The time from initiation of pleural fluid drainage occurred after collection of specimens for laboratory testing. During fluid removal, we recorded three time points reflecting specified fluid volumes (500 mL, 750 mL, 1000 mL). The end time was recorded at the time of fluid removal termination.

Patients were asked to indicate their dyspnea and pain level verbally using the Modified Borg Scale for Dyspnea [11] and Numerical Ratings Scale [12] of 0 - 10 (with 10 being highest level of pain) respectively during the following time points: immediately prior to starting the thoracentesis; after thoracentesis catheter placement before initiating fluid removal; after removal of fluid; prior to removing the thoracentesis catheter; 5 minutes post-procedure and 24 hours post-procedure.

An appropriate sample size was difficult to determine given the lack of data to calculate an effective size. We proposed *a priori* that a 5-minute difference in procedural time would be a reasonable minimally significant difference needed between methods. Regarding pain and dyspnea scores, we proposed that a clinically significant difference would be +/− 2 on our 10-point pain and dyspnea scales. Based on the GRAVITAS trial we would estimate a standard deviation of ~2.5 for these scales. These parameters demonstrated that a minimum of 34 patients would be required to reach a power of 90%, alpha of 0.05. Additionally, we included a sequential interim data analysis plan with the first 30 - 35 patients in order to identify appropriate stopping criteria.

Participant characteristics were reported as counts and rates or means and standard deviations. Procedure times were estimated for each treatment arm using the Kaplan-Meier estimator to account for right-censoring due to early termination of procedures and compared among arms using the log rank test. Pain and dyspnea scores were compared among arms at each time point using longitudinal mixed effects models with fixed effects for treatment arm, time point, and arm-by-time interaction, and random effects for participant to account for within-participant correlation over time; results are reported as means with 95% confidence intervals. Analyses were conducted using R version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

A total of 59 patients were screened and 35 were enrolled into the study. Patients who were screened but not enrolled were excluded primarily due to patient refusal, small effusion size not amenable to thoracentesis or therapeutic drainage, or complex effusion necessitating indwelling pleural catheter placement.

Table 1 illustrates the demographic data of the study population (n = 35, Age 64 ± 13.2 years, Male 17 (50%). Half of the patients underwent thoracentesis for the first time. Mean lidocaine usage was 5.61 ± 2.75 mL. More patients had thoracentesis performed at the bedside than in a dedicated procedural suite (20 vs 15). A large portion of the patients enrolled (61.8%) had a significant clinical history of malignancy, though a smaller proportion (28.2%) had pleural fluid that resulted positive for a malignant effusion.

Table 1. Demographics.

n = 35	n (%) or mean ± SD
Age	0
Male	17 (50)
Race (White)	30 (88.2)
Smoker (current)	13 (38.2)
BMI	26.15 ± 4.8
Pleural Fluid Diagnosis	
Cirrhosis	5 (14)
Heart Failure	9 (26)
Cancer	21 (60)
Thoracentesis	
Exudate	20 (57)
Transudate	15 (43)
General Procedural Details	
Endoscopy	15 (44.1)
Bedside	15 (44.1)
1% Lidocaine (mL)	5.61 ± 2.75

Data expressed as mean and standard deviations or n (%); BMI = Body Mass Index (Kg/m^2).

Most of the procedures (20, 57.1%) were performed by hospitalist providers on a dedicated inpatient procedural service (see Table 2). Mean total volume removed in mL was 1017.9 ± 497.03 with total procedural time of 7.4 ± 4.5 minutes. Per group, the vacuum bottle method had the shortest mean overall procedural time compared to manual aspiration and wall suction (3.3 ± 1.69 min vs 17.96 ± 9.5 vs 8.9 ± 3.2; respectively). Interestingly, manual aspiration had the lowest total volume drained but had the longest procedural time compared to wall suction and vacuum bottle (640.6 mL vs 1055.1 mL vs 931.3 mL respectively). Compared to wall suction, one patient in the manual aspiration group had three times longer time for aspiration due to larger effusion. Early termination was commonly for chest pain and pneumothorax complication was relatively low (see Table 3).

Table 2. Thoracentesis outcomes.

n = 35	n (%) or mean ± SD
Operator Background	
Pulmonary	13 (38)
Medicine	23 (65)
Aspiration Time (min), All Groups	
Time to 500 mL	3.5 ± 2.5
Time to 750 mL	4.6 ± 2.3
Time to 1000 mL	5.8 ± 3.1
Total Volume Removed (mL)	1017.9 ± 497.03
Total Procedural Time	7.4 ± 4.5
Aspiration Time (min), Per Group	
Manual Suction	8 (23)
Time to 500 mL	4.4 ± 1.3
Time to 750 mL	6.5 ± 2.3
Time to 1000 mL	8 ± 3.1
Total Volume Aspirated (mL)	640.6 ± 320.6
Total Procedural Time	17.96 ± 9.5
Wall Suction	15 (43)
Time to 500 mL	4.4 ± 2.9
Time to 750 mL	5.3 ± 1.8
Time to 1000 mL	7.1 ± 2.8
Total Volume Aspirated (mL)	1055.1 ± 397.6
Total Procedural Time	8.9 ± 3.2
Vacuum Bottle	12 (34)
Time to 500 mL	1.5 ± 0.4
Time to 750 mL	2.3 ± 0.7
Time to 1000 mL	2.9 ± 0.5
Total Volume Aspirated (mL)	931.3 ± 584.1
Total Procedural Time (sec)	3.3 ± 1.69
Completion Time Comparison (min)	9 ± 5, $p < 0.0001$
Manual vs Wall Suction	8.8 vs 14.8, $p = 0.06$
Manual vs Vaccum Bottle	8.8 vs 4.2, $p < 0.0001$
Wall Suction vs Vacuum Bottle	14.8 vs 4.2, $p < 0.0001$

Data expressed as mean and standard deviations or n (%).

Table 3. Early termination and complications.

n = 35	n(%) or mean ± SD	Suction Group
Early Termination		
Chest pain	5 (14)	2, 1, 3
Cough	4 (11)	2, 1, 0
Dyspnea	0	
Vagal episode	0	
Patient Request	2 (6)	1, 1, 0
Complications		
Pneumothorax	1 (2)	0, 1, 0
Pneumothorax Requiring Chest Tube	0	
Bleeding	0	
Re-expansion Pulmonary Edema	0	
Hospital Admissi0n	0	

Data expressed as mean and standard deviations or n(%); Suction group: Manual, Wall suction, Vacuum bottle.

In the adjusted model, the difference in procedural time among groups were significant ($p < 0.0001$, see **Table 4** and **Figure 1**). Specifically, the vacuum bottle group had the shortest average procedure time compared to the other two methods ($p < 0.0001$).

In the adjusted pain score model, there were no significant difference in pain pre-fluid, post-fluid, post-catheter insertion and at 5-min and 24-hr post procedure (see **Table 4**). The adjusted dyspnea score model did show a significant difference on dyspnea score 24-hr post procedure; specifically, vacuum bottle had the lowest score compared to manual and bottle suction ($p = 0.006$ and $p = 0.004$; respectively).

Table 4. Results of longitudinal mixed-effects models of pain or dyspnea scores, with fixed effect terms for time (categorical), treatment, time-by-treatment interaction, and pre-procedure pain or dyspnea score (adjusted models only), and a random effect term for participant to account for within-participant correlation. Pain scores were not significantly different between thoracentesis methods from pre-fluid to 24-hr post procedural assessment. Similar results observed in the dyspnea score; however, the vacuum bottle modality had significantly less dyspnea score at 24-hour compared to manual and wall suction.

Pain Score															
Unadjusted								**Adjusted for pre-procedure pain score**							
anon_group	time	mean	95% CI		contrast	time	p-value	anon_group	time	mean	95% CI		contrast	time	p-value
A	pre fluid	0.1	0.0	1.2	A - B	pre fluid	0.387	A	pre fluid	0.3	0.0	1.4	A - B	pre fluid	0.544
B	pre fluid	1.4	0.0	2.9	A - C	pre fluid	0.678	B	pre fluid	1.4	0.0	3.0	A - C	pre fluid	0.866
C	pre fluid	0.8	0.0	2.1	B - C	pre fluid	0.845	C	pre fluid	0.7	0.0	2.0	B - C	pre fluid	0.804
A	post fluid	2.2	1.1	3.4	A - B	post fluid	0.753	A	post fluid	2.4	1.2	3.6	A - B	post fluid	0.851
B	post fluid	2.9	1.4	4.5	A - C	post fluid	0.947	B	post fluid	2.9	1.3	4.6	A - C	post fluid	0.827
C	post fluid	1.9	0.7	3.2	B - C	post fluid	0.602	C	post fluid	1.9	0.6	3.1	B - C	post fluid	0.549

Continued

A	post catheter	2.1	1.0	3.2	A - B	post catheter	0.889	A	post catheter	2.2	1.1	3.3	A - B	post catheter	0.907
B	post catheter	2.5	1.0	4.0	A - C	post catheter	0.715	B	post catheter	2.7	1.0	4.3	A - C	post catheter	0.534
C	post catheter	1.4	0.2	2.6	B - C	post catheter	0.513	C	post catheter	1.3	0.1	2.5	B - C	post catheter	0.388
A	5 min	1.1	0.0	2.2	A - B	5 min	0.627	A	5 min	1.3	0.2	2.4	A - B	5 min	0.719
B	5 min	2.0	0.5	3.5	A - C	5 min	0.986	B	5 min	2.1	0.4	3.7	A - C	5 min	0.887
C	5 min	1.0	0.0	2.2	B - C	5 min	0.565	C	5 min	0.9	0.0	2.1	B - C	5 min	0.475
A	24 hr	1.3	0.0	2.6	A - B	24 hr	0.781	A	24 hr	1.5	0.1	2.8	A - B	24 hr	0.775
B	24 hr	2.1	0.2	4.1	A - C	24 hr	0.372	B	24 hr	2.4	0.1	4.6	A - C	24 hr	0.278
C	24 hr	0.0	0.0	1.5	B - C	24 hr	0.196	C	24 hr	0.0	0.0	1.4	B - C	24 hr	0.161
Dyspnea Score															
Unadjusted								**Adjusted for pre-procedure dyspnea score**							
anon_group	time	mean	95% CI		contrast	time	*p*-value	anon_group	time	mean	95% CI		contrast	time	*p*-value
A	pre fluid	1.0	0.1	1.9	A - B	pre fluid	0.945	A	pre fluid	1.3	0.6	2.0	A - B	pre fluid	0.949
B	pre fluid	0.7	0.0	2.0	A - C	pre fluid	0.320	B	pre fluid	1.1	0.1	2.1	A - C	pre fluid	0.979
C	pre fluid	2.0	1.0	3.0	B - C	pre fluid	0.279	C	pre fluid	1.4	0.6	2.2	B - C	pre fluid	0.893
A	post fluid	1.8	0.9	2.8	A - B	post fluid	0.938	A	post fluid	2.1	1.4	2.9	A - B	post fluid	0.961
B	post fluid	1.6	0.3	2.8	A - C	post fluid	0.797	B	post fluid	2.0	1.0	3.0	A - C	post fluid	0.728
C	post fluid	2.3	1.2	3.3	B - C	post fluid	0.658	C	post fluid	1.7	0.9	2.5	B - C	post fluid	0.920
A	post catheter	2.0	1.1	2.9	A - B	post catheter	0.797	A	post catheter	2.3	1.6	3.0	A - B	post catheter	0.852
B	post catheter	1.5	0.2	2.8	A - C	post catheter	0.968	B	post catheter	2.0	1.0	3.0	A - C	post catheter	0.372
C	post catheter	2.2	1.1	3.2	B - C	post catheter	0.691	C	post catheter	1.6	0.8	2.4	B - C	post catheter	0.820
A	5 min	1.1	0.2	2.1	A - B	5 min	0.948	A	5 min	1.4	0.7	2.1	A - B	5 min	0.804
B	5 min	1.4	0.1	2.6	A - C	5 min	0.569	B	5 min	1.8	0.8	2.9	A - C	5 min	0.931
C	5 min	1.8	0.8	2.9	B - C	5 min	0.839	C	5 min	1.3	0.5	2.0	B - C	5 min	0.647
A	24 hr	1.1	0.1	2.2	A - B	24 hr	0.879	A	24 hr	1.5	0.6	2.3	A - B	24 hr	0.617
B	24 hr	1.6	0.1	3.1	A - C	24 hr	0.263	B	24 hr	2.3	0.8	3.7	A - C	24 hr	**0.006**
C	24 hr	0.0	0.0	1.1	B - C	24 hr	0.190	C	24 hr	0.0	0.0	0.3	B - C	24 hr	**0.004**

Results are reported as estimated marginal means with 95% confidence intervals. *p*-values for pairwise comparisons between treatments are corrected for multiple comparisons among 3 groups using the Tukey method.

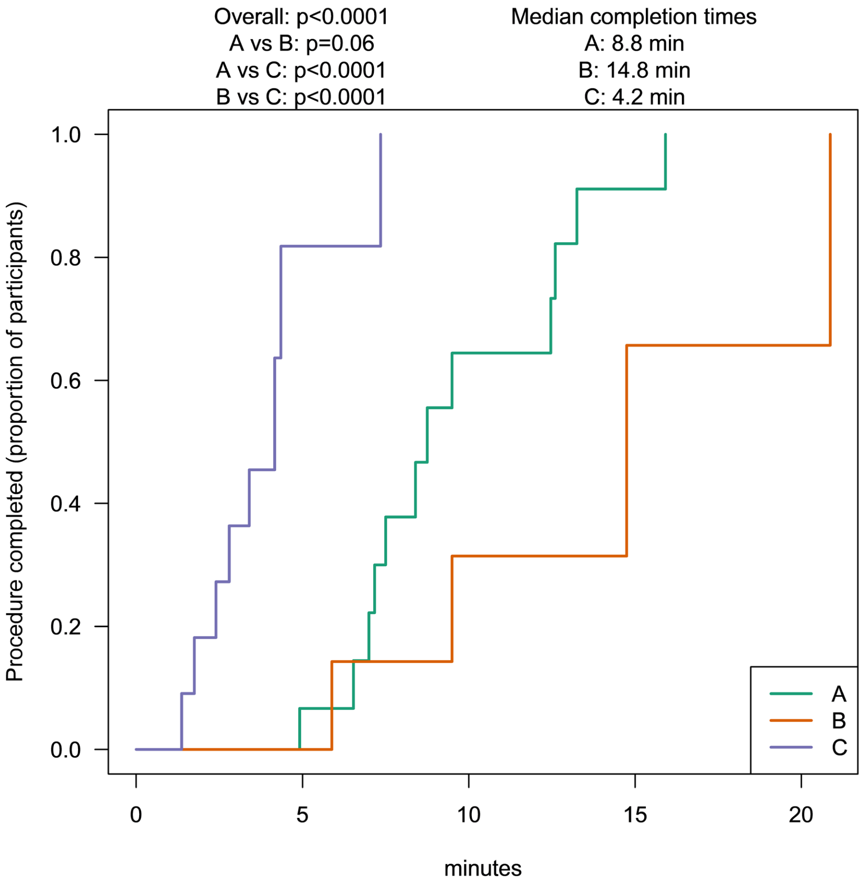

Figure 1. Procedural Time between manual suction (A), wall suction (B), and vacuum bottle (C). There is a significant difference with regard to procedural time between manual suction and vacuum bottle compared to wall suction. In this study, vacuum bottle method had the fastest completion time.

4. Discussion

In the United States, pleural effusion occurs at a rate of approximately 320 cases per 100,000 people, with common causes including congestive heart failure, cancer, pneumonia, and pulmonary embolism. The thoracic cavity, which houses the lungs, heart, and other essential structures, is vital for respiratory function [13]. Its anatomy and the pathophysiology of pleural fluid are critical for diagnosing and managing pleural and respiratory conditions. The thoracic cavity is enclosed by the rib cage, thoracic vertebrae, and diaphragm and is divided into three main compartments: the right and left pleural cavities, each surrounding a lung, and the mediastinum, which contains the heart, esophagus, trachea, and major blood vessels. Each pleural cavity is lined by two serous membranes: the visceral pleura, which covers the lungs, and the parietal pleura, which lines the chest wall and diaphragm. Between these layers lies a thin film of pleural fluid, typically 10 - 20 milliliters in volume. This fluid is essential for reducing friction between the pleural surfaces as the lungs expand and contract during breathing, facilitating smooth and efficient respiratory movements. Pleural fluid is produced by the parietal pleura through the filtration of plasma from capillaries. This production is balanced by the absorption of fluid through lymphatic vessels located in the parietal pleura and mediastinum. Under normal conditions, the rates of fluid production and absorption are finely regulated to maintain a small, stable volume in the pleural space. This balance is crucial for lubricating the pleural surfaces, minimizing friction, and protecting delicate lung tissue.

An imbalance between pleural fluid production and drainage can lead to pleural effusion, characterized by the accumulation of excess fluid in the pleural cavity. This excess fluid can impair lung expansion and result in symptoms such as shortness of breath, chest pain, and cough. Pleural effusions are classified into two main types based on their underlying pathophysiology: transudative and exudative effusions.

Transudative effusions are caused by systemic conditions that disrupt fluid balance. For example, congestive heart failure increases hydrostatic pressure in the pulmonary capillaries, causing fluid to leak into the pleural space. Similarly, conditions like cirrhosis and nephrotic syndrome can lower oncotic pressure in the blood, leading to fluid accumulation in the pleural cavity. Exudative effusions, in contrast, arise from local pathologies and are characterized by higher concentrations of proteins and cells in the fluid. These effusions can result from inflammatory or infectious processes, such as pneumonia or tuberculosis, which increase the permeability of the pleural membranes. Malignancies, such as lung cancer or metastatic tumors, can also lead to exudative effusions either by directly invading the pleural space or causing lymphatic obstruction. The pathophysiology of pleural effusion involves several mechanisms. Increased hydrostatic pressure from conditions like heart failure causes fluid transudation from capillaries into the pleural space. Increased vascular permeability due to inflammation or infection allows proteins and cells to enter the pleural space, resulting in exudative effusions. Decreased oncotic pressure from liver disease or kidney disorders reduces the ability of blood vessels to retain fluid, leading to leakage into the pleural cavity. Obstruction of lymphatic drainage, caused by malignancies or other blockages, further contributes to fluid accumulation. The clinical presentation of pleural effusion varies with the underlying cause and fluid volume. Small effusions may be asymptomatic or cause mild symptoms, while larger effusions can lead to significant respiratory distress and impact overall lung function. Diagnostic evaluation typically involves imaging studies such as chest X-rays or ultrasound to detect fluid accumulation and assess its extent. Thoracentesis can be performed for both diagnostic and therapeutic purposes. The fluid is analyzed to differentiate between transudative and exudative effusions and to identify the underlying cause. Tests may include measuring fluid protein levels, lactate dehydrogenase (LDH), cell counts and conducting cultures or cytological examinations. Treatment for pleural effusion depends on its underlying cause. Managing transudative effusions often involves addressing the systemic condition, such as optimizing treatment for heart failure or managing liver disease. For exudative effusions, treatment focuses on addressing the local pathology, such as administering antibiotics for infections or chemotherapy for malignancies. In some cases, repeated thoracentesis may be necessary to relieve symptoms and manage fluid accumulation. Procedures like pleurodesis, which involves fusing the pleural surfaces to prevent recurrent effusion, may be considered for chronic or recurrent cases. Maintaining the balance of pleural fluid production and drainage is crucial for ensuring a stable pleural environment that supports smooth lung movement. Disruptions in this balance can lead to pleural effusion, which can be classified as transudative or exudative based on the underlying causes. A thorough understanding of pleural fluid physiology and its impact on lung function is essential for the effective diagnosis and management of pleural diseases.

The technique for thoracentesis has evolved over the years with newer and safer catheter technology; but more importantly, the evolution of bedside ultrasound technology and techniques [14]. Bedside ultrasound technology has significantly advanced patient care; especially, regarding thoracic procedures. Improvements in this technology are focused on enhancing image quality, increasing portability, and integrating advanced features to support clinical decision-making. Modern bedside ultrasound devices have seen substantial improvements in image quality, a key factor in accurate diagnosis. Advances in transducer technology and imaging algorithms have led to higher resolution images and better tissue differentiation. High-frequency transducers now provide finer detail, which is critical for assessing small structures and subtle abnormalities. Additionally, new imaging techniques such as elastography and contrast-enhanced ultrasound are being integrated, offering enhanced diagnostic capabilities. These advancements enable clinicians to make more accurate assessments and guide interventions with greater precision. Portability is another significant area of enhancement. Traditional ultrasound machines were bulky and required dedicated space, making them less accessible in emergency or bedside situations. However, the latest innovations in ultrasound technology have led to the development of compact, handheld devices. These portable systems are lightweight and battery-operated, allowing for easy transport and use at the bedside. The convenience of portable ultrasound devices has revolutionized patient care by providing immediate imaging in various settings, including emergency rooms, intensive care units, and even remote or resource-limited areas. This portability ensures that ultrasound technology is more widely accessible and can be used to perform quick assessments in critical situations. Integration of advanced features and artificial intelligence (AI) is also transforming bedside ultrasound technology. AI algorithms are being incorporated into ultrasound systems to assist with image acquisition, interpretation, and diagnosis. For example, AI can help automate the process of identifying anatomical structures and measuring dimensions, reducing the reliance on the operator's skill level and increasing diagnostic consistency. Additionally, AI-powered tools can provide real-time guidance during procedures, such as needle insertion or catheter placement, by highlighting optimal trajectories and reducing the risk of complications. This integration of AI not only enhances the accuracy of diagnoses but also streamlines workflow and improves efficiency in clinical settings. Furthermore, advancements in connectivity and data management are enhancing the utility of bedside ultrasound. Modern ultrasound devices are equipped with wireless capabilities that enable seamless integration with electronic health records (EHRs) and other hospital information systems. This connectivity allows for the immediate sharing of imaging data and reports with other healthcare professionals, facilitating collaborative decision-making and ensuring that critical information is readily available. Cloud storage options also support remote access to images and data, enabling telemedicine consultations and follow-up care without requiring the physical presence of the patient. These advancements have significantly expanded the capabilities of bedside ultrasound, making it a more powerful tool for diagnosis and treatment in diverse clinical settings. As technology continues to evolve, bedside ultrasound is expected to become even more integral to patient care, offering greater accuracy, efficiency, and accessibility.

The main finding of this study is a significantly decreased procedural time with vacuum bottle drainage for therapeutic thoracentesis without significant increase in patient discomfort or complications when compared to manual aspiration or wall suction. The results of our study are contrary to previous literature that has revealed an increase in procedure-related symptoms with the use of vacuum bottle drainage [9] [10]. We did not find, as in previous studies, that there was any increased incidence of complications such as pneumothorax with the use of vacuum bottles [9]. It has been theorized previously that pain and complications with vacuum bottle use may be due to increasing negative pleural pressures generated by vacuum bottles [4] [9] [10]. Although our pre-study manometry testing of pleural pressures also demonstrated the highest negative pressures with vacuum bottle drainage, there was evidence of greater variability in pressures produced with manual aspiration. It might be concluded then that shear stress in the setting of rapidly changing pressures that are not constant can also significantly contribute to pleural irritation and pain. Like the findings of the larger GRAVITAS trial, we also found the patient pain scores increased during thoracentesis with highest scores reported at the end of large volume drainage and then decreased post-procedure. This finding makes sense clinically as somatic pain fibers supplied by the phrenic nerve innervating the parietal pleura are highly sensitive and may become activated as the pleura stretches during lung expansion [15]. Also contrary to the GRAVITAS trial, we did not find a progressively declining rate of dyspnea with pleural fluid removal as might be expected in the vacuum bottle group. Our patients in the manual aspiration and wall suction groups generally reported increased dyspnea towards the end of fluid drainage with some improvement post-procedure but not back to pre-procedure baselines at 24 hours.

There are several limitations of this study. First, this study is limited to a specified population of patients within a single-center, academic institution; therefore, may not be representative in more generalized settings. From the researcher perspective, a blinded design could have reduced some bias; however, this was not practical due to the logistics and efficiency of obtaining all the necessary equipment before starting a sterile procedure. From a patient's perspective, a blinded design may have reduced some inherent bias to a previous method of drainage; however, most of the patients in this study underwent thoracentesis for the first time therefore this type of bias is likely to be negligible. Some variability is inherently present between proceduralists (11 different providers total) and based on whether the procedure was done inpatient at the bedside or outpatient in endoscopy. For example, pulmonary providers when doing thoracentesis in our outpatient procedure suite tended to send larger volumes of pleural fluid for analysis (usually at least 200 mL) when compared to inpatient hospitalist providers at the bedside (usually <100 mL). There also seemed to be more technical difficulties encountered by providers (ex. difficulty with suction tubing or inadequate suction) when using wall suction compared to the other methods of drainage. This mechanism of drainage is used more commonly by our radiology colleagues and in our outpatient procedure suites and so may have been a less familiar method to some of our other providers. These variables were not controlled for as our intention was for this to reflect real-world practices at our institution. Lastly, our setting of −50 mmHg continuous wall suction was a conservative choice. Although early animal models have suggested an increased rate of REPE with pleural pressures greater than −20 mmHg [2] [10] [16] [17], several groups using pleural manometry have measured pleural pressures well more than this with standard manual aspiration and vacuum bottle drainage practices; however, as previously mentioned, REPE incident due to thoracentesis remains incredibly low (0.1%, 95% CI 0.06 - 0.1 of cases). The analysis of the safety of wall suctioning for thoracentesis performed by Kim et al and the radiology department at Brigham and Women's Hospital found no increased risk of complications even at full wall suction (−527 mmHg) and have standardized their settings to −100 mmHg [10].

Future studies comparing different wall suction settings for pleural fluid aspiration would be helpful in determining what setting is optimal for shortening procedural time without increasing risk or discomfort for patients. Likewise, a study evaluating higher wall suction settings versus vacuum bottle drainage would be helpful in further elucidating how we can improve this experience for patients and, as glass vacuum drainage bottles can be quite costly when compared to plastic wall suction canisters, hopefully also work to reduced healthcare costs for this very common medical procedure. Despite these limitations, we feel that our findings are noteworthy and add to the current scarce literature in this specific area of pleural disease.

This study comparing various methods of pleural fluid drainage reveals reduced procedural time with vacuum bottle drainage and suggests that vacuum bottle drainage in our study population was more efficient without an increase in symptoms compared to the other two standard of care methods. These findings would benefit from further analysis in a larger, randomized study to corroborate our findings.

IRB Statement

This study was approved by the University of Minnesota's Institutional Review Board.

Informed Consent

All subjects had written and signed consent to be eligible to participate in the study.

Statement

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All figures and images are solely from the work of the authors.

Conflicts of Interest

The authors have no conflict of interest.

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