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Suction pressures generated during thoracentesis using wall suction-based automated drainage: an *in vitro* and *in vivo* analysis

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Abstract

Equipoise exists regarding the optimal method to drain pleural fluid during thoracentesis. While several institutions use wall-based automated suction, others point to the risk of excessively high suction pressures and therefore elevated barotrauma risk as a reason to avoid it. We first performed *in vitro* experiments involving drainage of a 1-liter saline bag using standard thoracentesis apparatus, a digital manometer, and either manual drainage (using a 60 mL syringe) or automated drainage (using wall suction at the maximum setting). The proceduralist was blinded to measurements during manual aspiration. Separately, in a clinical setting involving consecutive hospitalized adults undergoing thoracentesis, dynamic suction pressures were similarly measured during automated drainage. Total aspirated volume, time-to-evacuation, patient discomfort, and complications were also recorded.

In vitro experiments showed that compared to manual aspiration, automated drainage using wall suction resulted in shorter average time-to-evacuation (230 sec *vs.* 365 sec), lower suction pressures (average maximum: -361±4.5 cmH2O *vs.* -496±5.1 cmH2O, $p<0.0001$), and less pressure variation (95% of values within a 20 cmH2O range *vs.* swings between 0 and -500 cmH2O). Twenty hospitalized adults undergoing thoracentesis via automated drainage (mean aspirated volume: 1649.5±685.5 mL) experienced similar suction pressures to those measured in *in vitro* experiments using automated drainage (average maximum: -350±59.2 cmH2O) and limited pressure variations (mean interquartile range: 19.3 cmH2O). There were no complications, including pneumothorax, hemothorax, or re-expansion pulmonary edema.

Thoracentesis using automated wall suction does not generate excessively high suction pressures and reduces pressure swings. It appears safe and effective and may reduce the time-to-evacuation of a pleural effusion.

Key words: thoracentesis, pleural pressure, manual aspiration, wall suction.

Introduction

Thoracentesis for diagnostic and therapeutic management of pleural effusions continues to be one of the most common bedside medical procedures performed by pulmonologists as well as by other clinicians. More than 170,000 procedures are performed each year in the United States alone [1,2]. There is no universally adopted technique for aspirating the pleural fluid once the temporary thoracentesis catheter has been inserted into the pleural cavity. Historically, manual aspiration has been favored by most internists whereas automated drainage using wall suction is favored by interventional radiologists. In contrast, automated drainage using vacuum bottles is utilized by nearly all practitioners when draining fluid using a tunneled pleural catheter. The choice of drainage modality may vary with availability, institutional culture, and operator preference.

Although automated drainage has historically been assumed to generate higher suction pressures and therefore portend a higher barotrauma risk, evidence is conflicting on the relative incidence of chest pain, cough, pneumothorax, and re-expansion pulmonary edema associated with each of these methods [3-5]. In particular, there is little evidence to support a preferred strategy between manual aspiration and wall suction-based automated drainage as these studies have previously only compared vacuum bottle versus manual aspiration and wall suction versus vacuum bottle [3-5].

One of the proposed potential mechanisms behind the development of discomfort or injury is thought to be excessive negative dynamic pleural pressures generated during fluid drainage [6]. We conducted measurements both at the bedside and in a simulated environment in order to better understand the suction pressures generated during automated fluid drainage via wall suction using standard thoracentesis apparatus.

Materials and Methods

In vitro experiments

A standard 1-liter normal saline bag was connected to an 8Fr. Safe-T centesis™ catheter (BD, Franklin Lakes, NJ, USA) along with an FDA approved Compass digital manometer (Centurion Medical Products, Williamston, Michigan, USA). The primary outcome was suction pressure at the level of the Safe-T centesis™ catheter, measured in cm of water. Pressures were measured using the digital pleural manometer. In the first experiment, the fluid bag was drained via the thoracentesis catheter using manual aspiration into a 60ml luer-lock syringe followed by emptying into the collection bag using a three way stop cock (Figure 1A). In the second experiment, the fluid bag was drained via the thoracentesis catheter using automated suction involving 10-feet-long Argyle suction tubing (Covidien, Mansfield, MA, USA) with a uniform

internal diameter of 0.25 inch that was connected to regulated hospital wall suction set at -250mmHg (maximum allowable pressure) (Figure 1B).

Suction pressures were measured at 10-second intervals for automated suction. During manual aspiration, the maximum suction pressure generated during each round of fluid aspiration (totaling 60ml) was recorded (totaling 3 rounds). Three sets of measurements were taken using each of three operators, namely an attending pulmonologist, a physician assistant, and a pulmonary fellow who had each performed over 20 thoracentesis procedures. Care was made to not employ more vigorous suction than would be routinely done in the clinical setting, and steady traction force was applied on the syringe during manual aspiration. Operators were blinded to pressure recordings during manual aspiration. Mean and standard deviation of the maximum suction pressure generated with each method was calculated and students t-test was used to assess for statistical significance, keeping alpha at 0.05. Statistical analyses were performed using R statistical software (version 4.1.2).

Observations in the clinical setting

Separately, data measurements were made in the routine clinical setting as part of quality assurance efforts. This exercise involved 20 consecutive hospitalized adults receiving bedside thoracentesis by the hospital's Bedside Procedure Service using standard institutional protocol. The best insertion site was identified via point-of-care ultrasound. Patients were then prepped, draped, and administered local anesthesia (approximately 5-10mL of 1% lidocaine) at the insertion site. An 8Fr. Safe-T centesis™ catheter was inserted before attaching and zeroing the manometer to the drainage apparatus. A small amount of diagnostic fluid was drawn prior to starting pressure data collection when clinically warranted. The manometer was then connected to kit tubing using a tapered, 5-in-1 connector which was in turn attached to a wall suction cannister using commonly available bubble tubing per institutional practice. The wall suction was set to Line which applied the maximum pressure generated by the hospital vacuum system at -250mmHg (Figure 1C).

Suction pressures and volume aspirated were measured at 10 second intervals throughout aspiration with pauses to exchange suction cannisters when filled (approximately 1L of fluid). Patient discomfort and cough was also noted throughout the procedure. This was repeated for a total of 20 consecutive procedures. Electronic medical records were reviewed for immediate and delayed complications including pneumothorax, hemothorax, and re-expansion pulmonary edema up to 30 days post procedure, discharge from the hospital, or patient death (whichever occurred earliest).

The study was deemed Not Human Subjects Research by the institutional review board (IRB) and exempted from full IRB review (2021P002968).

Results

In vitro experiments

During in vitro experiments, the average maximum suction pressure generated during manual aspiration was -496±5.1cmH_2O compared to -361±4.5cmH_2O with wall suction ($p<0.0001$). With manual aspiration, the suction pressures ranged from 0 to -500cmH_2O during the multiple cycles of aspiration, whereas with wall suction they remained largely steady throughout drainage with 95% of suction pressure values falling within a 20cmH_2O range (Figure 2). Time to complete fluid evacuation (1L) was shorter using wall suction (230 seconds) compared to manual aspiration (365 seconds).

Observations in the clinical setting

Data measurements in the clinical setting included 20 bedside consecutive thoracentesis procedures performed on 18 unique patients (Table 1). Two patients, both male, received two thoracentesis procedures that were separated in time by one or more days (on the same side in one case, and on the contralateral side in the other). The average maximum suction pressure generated using wall suction was -350±59.2 cmH_2O with a mean interquartile range of 19.3cmH_2O while draining an average of 1649.5±685.5ml of pleural fluid (Figure 3). The procedure was terminated prior to full evacuation of fluid in 1 case due to chest pressure and in 2 cases due to cough. All symptoms resolved shortly after procedure termination. None of the patients suffered any post procedure complications.

Discussion

In this two-pronged study, we investigated the impact of automated wall suction-based drainage on suction pressures generated during a thoracentesis procedure. We found, both in an in vitro head-to-head setting and in the clinical setting, that the suction pressures generated through this mechanism were well within acceptable limits.

In the in vitro study examining the impact of drainage strategy on suction pressures exerted through standard thoracentesis apparatus while draining a 1L bag of normal saline, we found that automated wall suction generated lower peak suction pressures compared to manual aspiration. Although there are no previous studies directly comparing wall suction to manual drainage, a study comparing wall suction to vacuum bottle drainage during a similar drainage procedure (paracentesis) had also reported lower peak suction pressures with the former technique [5]. Furthermore, a recent study examining over 10,000 thoracentesis procedures performed at a large referral center showed that wall suction-based drainage can be performed without an increased risk of complications [7]. These results contradict the often-cited reasoning to prefer other drainage methods over automated wall suction: excessively high

suction pressure risking barotrauma. The two drainage techniques also differed on the observed range of pressure swings during the active suction time. The manual aspiration technique resulted in wide pressure swings between active suction and release compared to the consistent wall suction. (Figure 2). This was similar to what has previously been reported [8]. The mechanism involves the cyclical filling and emptying of the aspiration syringe. Suction pressure is exerted on the pleural space while the proceduralist is actively withdrawing the plunger, followed by a rapid drop to zero when the aspiration syringe is full and the proceduralist proceeds with emptying the syringe. Similar to how wide swings in airway pressure have been correlated with atelectrauma and worse clinical outcomes during mechanical ventilation, this raises a theoretical concern about high swings in suction pressures causing pleural injury leading to a higher risk of rare adverse outcomes such as chest pain, pneumothorax, or re-expansion pulmonary edema [9,10].

The data collected during wall suction-assisted bedside thoracentesis procedures were consistent with our proof-of-concept in vitro studies across variable pleural fluid volumes, types of pleural fluid, and patient positions encountered at the bedside (Table 1). Although the pressures were not directly compared with other suction modalities, this method of drainage appeared to be safe – and potentially safer than alternative methods – in terms of the maximal suction pressures it generated and the consistency of suction pressure applied during the procedure.

Previously, a single-center randomized trial showed higher frequency of adverse outcomes with vacuum bottle drainage compared to manual aspiration and reported higher peak suction pressures with the former drainage strategy [3]. Our findings point to a need for head-to-head comparison between manual drainage and wall suction in the clinical setting, since the latter appears to not only generate lower suction pressures compared to both vacuum bottle drainage and manual aspiration, but also avoids the pressure swings seen with manual aspiration.

Our in vitro study has several limitations including small sample sizes. Despite being blinded to pressure recordings, there is a potential for Hawthorne effect among operators while using manual aspiration and within a study environment. Our measurements were limited to a single brand and type of thoracentesis equipment and, for the wall suction arm, a single brand and type of drainage tubing. The maximum negative pressure detectable with our digital manometer was -500cmH_2O and a review of the pressure tracings seen with manual aspiration (Fig 2) suggest that it may in fact have resulted in even higher suction pressures than were recorded.

The observational portion similarly had several limitations, the most important being a limited sample size. Although we did not observe any post-procedure complications, our study contained a small sample size, which limits our ability to comment on complication rates for

an inherently low-risk procedure. Additionally, there are various patient-related factors of clinical relevance at the bedside that were not controlled for or studied in detail here. These would include pleural elastance, degree of spontaneous breathing effort and the resultant overall pressures generated within the chest, and pain threshold. These factors should be studied further, but the consistent results we obtained despite variable "real world" conditions is reassuring for a clinical setting in which no two clinical scenarios are alike.

Conclusions

In conclusion, this study offers evidence to support the use of automated wall suction-based pleural fluid drainage as a safe drainage technique during thoracentesis. It adds to the body of scientific literature, which has mostly compared gravity-based drainage versus suction-based drainage but not automated wall-based suction versus manual suction. Larger studies that directly compare the physiologic and clinical impact of different suction-based drainage strategies in a clinical setting should be performed next.

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Table 1. Baseline patient characteristics and procedure details.

Category	Sub-category	Count (20 Total)	%	Combined Average ± SD
Gender	Male	12	60	N/A
	Female	8	40	
Age (y)	18-35	0	0	70±11
	36-65	4	20	
	66-69	16	80	
Intubated	Yes	2	10	N/A
	No	18	90	
Patient position	Sitting	15	75	N/A
	Lateral decubitus	5	25	
Effusion laterality	Right	11	55	N/A
	Left	9	45	
Loculated effusion (based on prior CT or pre-procedural US)	Yes	2	10	N/A
	No	18	90	
Fluid type (per Light's criteria)	Exudative	11	55	N/A
	Transudative	4	20	
	Unable to determine	5	25	
Volume removed (ml)	<1000	3	15	1649.5±685.5
	1000-2000	11	55	
	>2000	6	30	
Drainage time (sec)	0-180	3	15	337±147
	181-360	8	40	
	>360	9	45	
Maximum suction pressure (-cmH_2O)	200-300	3	15	350±59.2
	301-400	14	70	
	401-500	3	15	
Average suction pressure (-cmH_2O)	0-200	1	5	294±62.9
	201-300	10	50	
	301-400	9	45	
Intraprocedural symptoms	Cough	12	60	N/A
	Chest discomfort	3	15	

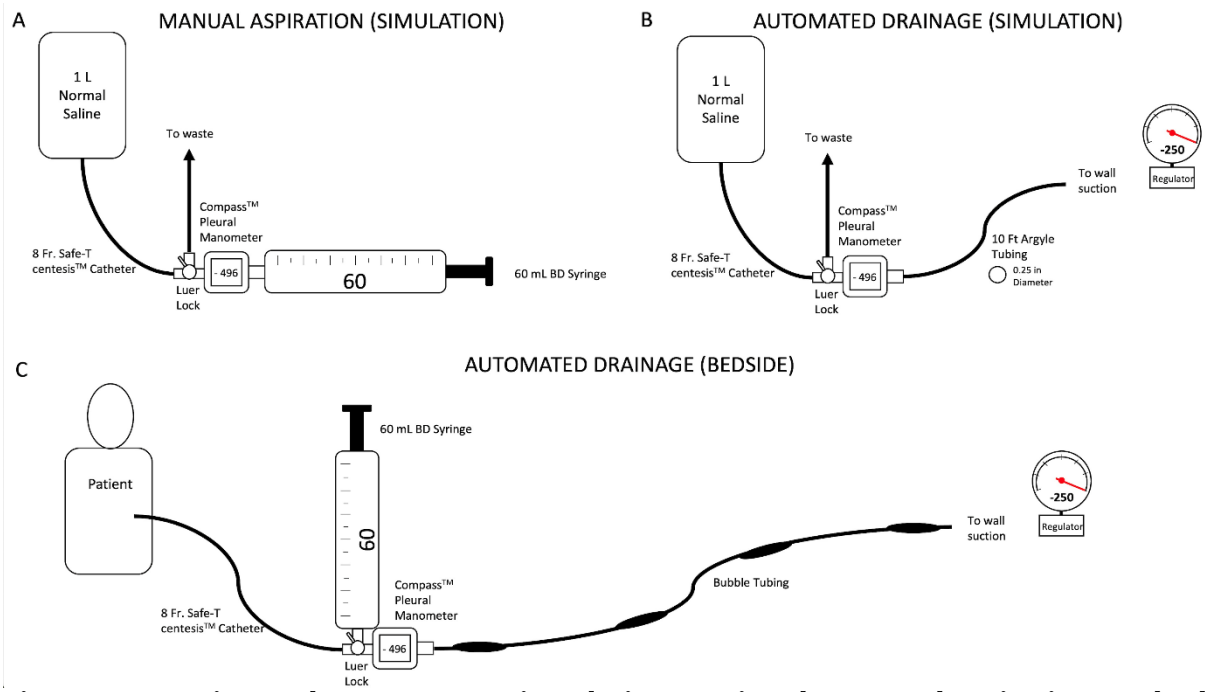

Figure 1. Experimental set up. A) In vitro drainage using the manual aspiration method; B) in vitro drainage using the wall suction-assisted method; C) in vivo drainage using the wall suction-assisted method during clinical bedside thoracentesis.

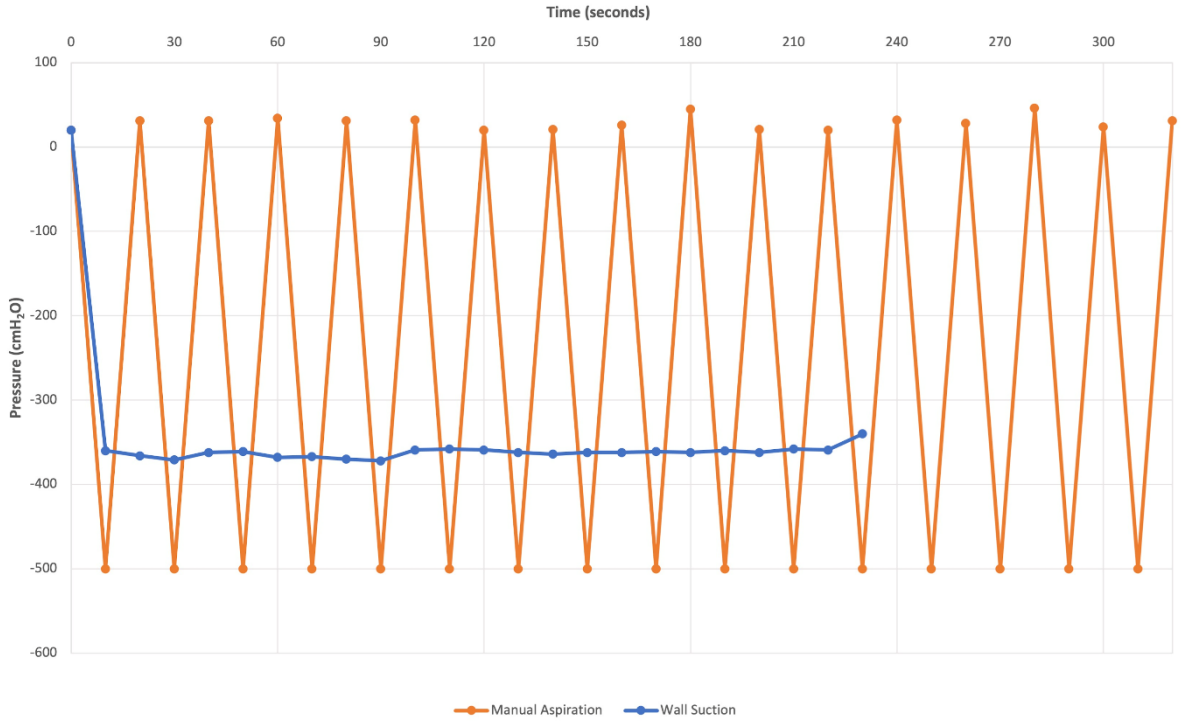

Figure 2. Average pressure variation over time during in vitro experiments comparing the manual aspiration (orange) vs. wall suction-assisted (blue) methods.

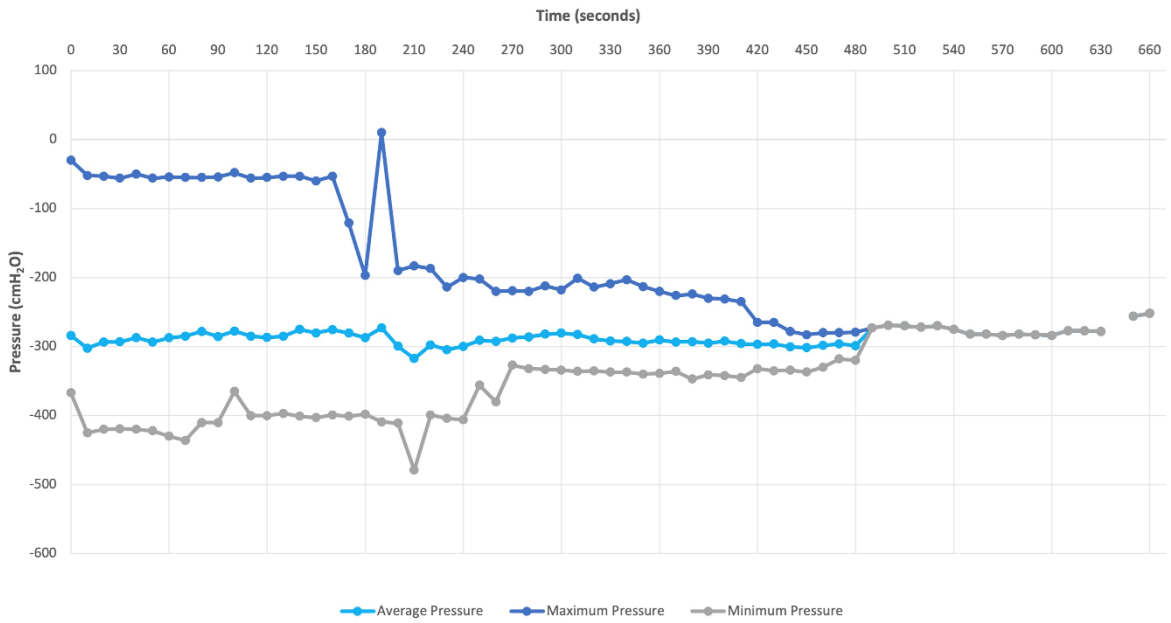

Figure 3. Average pressure variation over time during 20 bedside thoracentesis procedures using the wall suction-assisted method (dark blue: maximum; gray: minimum; light blue: average).