Review Article

Pleural manometry: techniques, applications, and pitfalls

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Abstract: Pleural manometry (PM) is a novel tool that allows direct measurement of the pressure in the pleural space in the presence of either a pleural effusion or a pneumothorax. Originally it was used to guide therapy for tuberculosis (TB) before the development of anti-TB medications. It was relegated to highly specialized centers for thoracoscopies until Light used it to investigate pleural effusions in the 1980s. However, there remains lack of robust data to support the routine use of PM. Recently additional published studies have generated renewed interest supporting the use of PM in specialized cases of complex pleural disorders. In this paper we summarize the current different techniques, applications, and pitfalls for the use of PM.

Keywords: Pneumothorax; malignant pleural effusion (MPE); pleural disease; pleural effusions; pulmonary physiology; pleural manometry (PM)

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Introduction

Pleural manometry (PM) is the direct measurement of pressure in the pleural space through a catheter. PM was first performed well over a century ago by the German physician Heinrich Iraenaeus Quincke in 1878 (1). Prior to development of anti-tuberculous therapy, PM was used to guide collapse therapy in the treatment of active pulmonary tuberculosis to assist in the creation of an artificial pneumothorax to treat the disease (2). The use of PM was virtually abandoned and relegated to specialized centers for thoracoscopy until Light *et al.* reintroduced interest in 1980s for its use in the management of pleural effusions (3).

In 1997, Lan *et al.* described the first clinical utility of PM in optimizing yield of pleurodesis in patients with malignant pleural effusions (MPEs) (4). In 2004, Doelken improved the PM technique by introducing a customized electronic hemodynamic manometer (5). Subsequently, hand held digital manometers were approved by the FDA in 2010 to measure hemodynamics pressures from central vascular catheters and later this device was adopted to measure pleural pressures (Ppl). Though four decades have elapsed since Light's original observations, there is still a paucity of data supporting the use of PM in clinical practice. Recently, there has been renewed interest in the technique with multiple studies looking at the clinical utility of PM in the management of pleural disorders (6-8). In this review we discuss the techniques, novel use, current evidence and pitfalls of PM.

Techniques

The PM technique has evolved over the last 30 years, from simple a u-shaped water manometer to disposable digital units. Currently, there are three acceptable techniques for measuring Ppl directly: (I) hemodynamic electronic

Table 1 Comparison of available pleural manometry techniques

Technique	U-tube water	Hemodynamic	Digital	Custom electronic	Continuous
Availability	Universal	Universal	Commercial	Custom built	Custom built
Zero point	At the insertion site	Below the insertion site	At the insertion site	At the insertion site	At the insertion site
Measurement timing	Intermittent	Intermittent	Intermittent	Intermittent	Continuous
Data recorded	Written	Printed or Written or stored	Written	Digital	Digital
Advantages	Universal available	Easily available	Commercially available	Accurate, records pressure waveform	Same as electronic custom, no need to stop drainage during pressure measurement
		Data can be stored on monitor system	Small	Data can be saved	
			No need to zero		
Disadvantages	High pressure swings (10)	Unable to measure negative numbers, values in mmHg instead of cmH_2O (1 mmHg = 1.36 cmH_2O)	High pressure swings (10)	Custom built	Unable to do through large tube, bulky, more complex, custom built
	Needs mechanical dampening (5)		Needs additional dampening	Bulky	
			Low sampling rate	Complex and lengthy set-up	

transducer (ET), (II) digital manometer (DM), and (III) U-tube (UT) water manometer. The most acceptable technique is the ET system as it produces the most accurate and reproducible measurements (9). However, no gold standard has been established. In one study, ET and DM have strong linear correlation (r=0.9582, P<0.001), while UT and ET are poorly correlated (r=0.448, P=0.84) (9). A limitation to this correlative study may have resulted in not using a dampened UT. Using a dampened UT system Doelken *et al.* (5) demonstrated strong correlation between UT and ET. All three major techniques require stoppage of the drainage for measurement. Choice of technique is largely governed by the availability of equipment and operator preferences. Our preference is the use of the ET as it provides accurate detailed reading, continuous data points, and allows for identification of periods of quiet breathing. *Table 1* provides a summary of the currently available PM techniques.

Hemodynamic ET manometer

Ppl can be measured accurately by using a hemodynamic transducer system. This technique involves connecting the hemodynamic transducer with two three-way stopcocks in series, allowing for drainage and transducing a pressure without disconnecting the system.

There are two variants of this technique, one utilizing the hemodynamic monitoring systems (*Figure 1*) which are readily available, while the other uses a non-commercially available analog-to-digital converter through a signal processor to record the data (11). (*Figure 2*). The custom-built system allows accurate measurements at very high frequencies which is useful when patients have high respiratory rates, which occurs towards the end of the pleural drainage (10). It can show positive and negative Ppl of each individual respiratory cycle. A sample tracing is shown in *Figure 3*. Data can be stored and analyzed later to construct pressure/volume (P/V) curves (12) (*Figures 3*,*4*).

UT water manometer

This simple device is made from sterile intravenous tubing, which is prefilled with sterile saline and is connected to a water column usually via a three-way stopcock in order to allow for drainage and measurements without having to disconnect the system. (*Figure 5*).

Ppl swings can be minimized by dampening the circuit by adding mechanical resistance, such as a 22-guage needle. This increased resistance dampens the system which lessens the pressure swings at both inspiration and expiration allowing for the mean Ppl to be directly read from the scale (5). The zero point of the water manometer is at the insertion of the

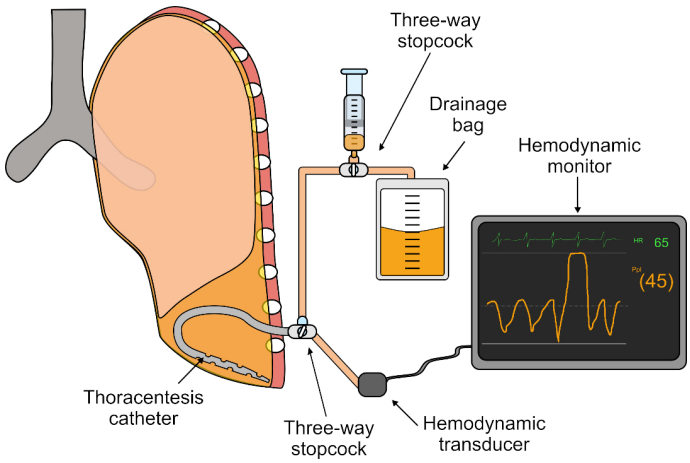

Figure 1 Hemodynamic transducer manometer. Normally reads positive pressures off the monitor, and this must be adjusted based on where the hemodynamic transducer is placed in relationship to the insertion point of the thoracentesis catheter for it to register an accurate negative pressure.

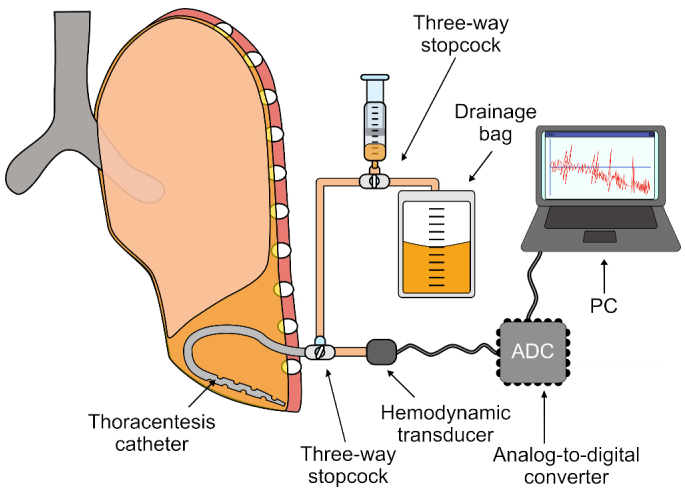

Figure 2 Custom electronic manometer. This system requires a custom-built analog-to-digital converter system. The thoracentesis catheter is connected to a hemodynamic transducer which in turn is connected to a custom-built analog-to-digital converter that filters and interprets the information as pleural pressures.

catheter at the chest wall and pressures should be measured in cmH_2O above this point at the end of expiration.

DM

There is currently one commercially available DM (Compass). This system measures general compartment pressures and is not specifically designed for Ppl measurements. These are disposable, single use, manometers that display a digital read of the pressure. A three-way stopcock is used to allow for drainage and measurement without having to completely disconnect the system (*Figure 6*).

Other manometer systems

A system for continuous measurement was developed by Salamonsen *et al.* (13) in which they utilize a thin epidural catheter passed through the thoracentesis catheter. Pressure measurement occurs through the epidural catheter, while

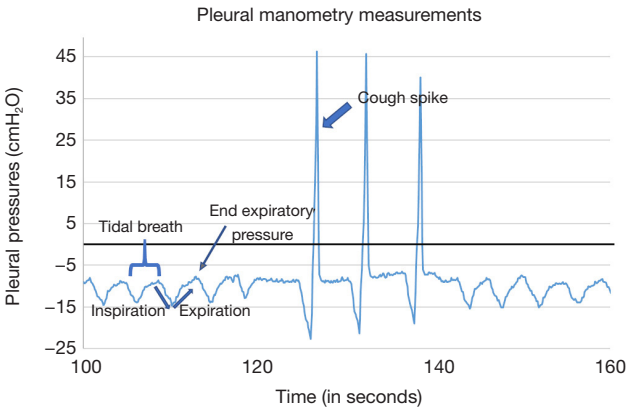

Figure 3 Ppl tracing of a custom electronic manometer. Negative deflections represent spontaneous inspiration, while positive deflections represent passive expiration. Intermittent spikes represent high Ppl during cough. Using this method, the end-expiratory pressures can be compared for consistency to allow for accurate end-expiratory measurements during periods of quiet breathing. Ppl, pleural pressures.

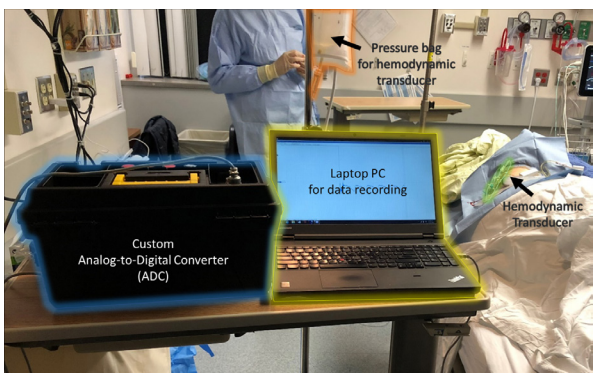

Figure 4 Setup while performing PM. A hemodynamic transducer used for an arterial line measurement is connected in a similar fashion to a fluid filled catheter in the pleural space. A pressure bag is used to create a pressure gradient. This is connected to the patient's chest-tube, this in turn is connected to a custom design analog-to-digital converter (ADC), housed in the black toolbox, which is connected to a PC for data acquisition. PM, pleural manometry.

drainage occurs through the larger thoracentesis catheter. This allows for continuous measurement of Ppl. However, the authors caution that there needs to be little to no movement of fluid in front of the measurement catheter for this method to work. Therefore, this method cannot be used in conjunction with larger bore drainage catheters (>15 Fr).

Considerations

Pressure in the pleural space is not uniform; it is affected by the hydrostatic forces and the natural movement of pleural fluid generated by gravity, ventilation, cardiogenic forces, and lymphatic drainage (14,15). Pressure measurements through a pleural catheter represents the pressure at the level of catheter insertion and is influenced by the elastic forces of the lung, chest wall, as well as the vertical height of the pleural effusion. Therefore, the absolute numbers are of less importance. It can be assumed that most of the variables within the pleural space remain relatively constant during drainage so that pressure change during drainage can be used to calculate pleural elastance (Pel) (5). Elastance are measured in units of P/V and is the inverse of compliance. It represents the resistance to change. In order to directly measure the Ppl utilizing currently available methods, there must be either a small amount of pleural fluid or pleural air present. The pleural space is normally approximately 20 μm in thickness and the introduction of a catheter leads to measurement of the local deformation forces and not the Ppl akin to what is observed in the lobar areas of a normal pleural space (16). A minimum of 50 mL of pleural fluid by either further drainage or by ultrasound should remain in order to prevent these geometric deformation forces to obscure final Ppl readings.

Clinical application

The role for routine use of PM is not completely established. However, PM can be useful in the following clinical scenarios: (I) diagnosis of non-expandable lung (NEL); (II) guidance in large volume pleural drainage; (III) guidance for pleurodesis in MPEs; (IV) and management of selective pneumothorax cases. Most of prior studies were proof of concepts with several trials underway to establish the clinical role of PM (7,8,17). *Table 2* summarizes the current evidence concerning the application of PM.

Identification of NEL

NEL is defined as the inability of lung to expand to the volume of the chest cavity allowing for normal parietal and visceral pleural apposition. There are three mechanistically distinct causes of NEL, endobronchial lesion resulting in lobar collapse, chronic atelectasis and visceral pleural restriction due to pleural disease (21). PM can accurately identify NEL, but cannot differentiate between mechanisms

Table 2 Current major studies regarding the application of PM

Study	N	Technique	Study design	Aims and objectives	Outcome
Light, 1980 (3)	52	Undampened U-shaped water manometer Pleural fluid measurement at every 200 mL aliquots	Prospective observational	PM guided large volume thoracentesis and safety	Large volume thoracentesis is safe if Ppl remains above –20 cmH_2O
Lan, 1997 (4)	65	Undampened CVP water column manometer Elastance at 500 mL removed	Prospective observational	Factors that may aid in predicting the outcome of pleurodesis in malignant pleural effusions	Patients with pleural elastance >19 cmH_2O/L had high incidence of trapped lung and decreased pleurodesis success
Heidecker, 2006 (18)	367	Custom electronic manometer Pleural measurement at every 100 to 250 mL aliquots	Retrospective chart review	Pathophysiology of post-procedure pneumothorax	Normal values for pleural elastance of 0.5 to 14.5 cmH_2O/L. Post thoracentesis pneumothorax are due to NEL
Feller-Kopman, 2007 (19)	169	Custom electronic manometer or dampened water manometer Pleural measurement at every 240 mL	Prospective observational	PM and development of drainage related symptoms	Vague chest discomfort may correlate with potential development of unsafe negative pressures
Feller-Kopman, 2007 (20)	185	Custom electronic manometer or dampened water manometer Pleural measurement at every 240 mL	Prospective observational	PM and development of re-expansion pulmonary edema	Re-expansion pulmonary edema is rare and independent of fluid volume removed, Ppl, and pleural elastance
Lentz, 2019 (6)	124	Digital manometer	Single-blinded randomized control	PM and development of drainage related symptoms	PM does not prevent drainage related symptoms, such as chest pain, but reduces pneumothorax *ex vacuo*
Chopra, 2020 (7)	70	Custom electronic manometer Pleural measurement at every 100 to 250 mL aliquots	Prospective observation	Relationship of PM and chest X-ray in malignant pleural effusion	PM does not correlate well with X-ray findings
Pre-EDIT, 2019 (8)	31	Rocket Medical digital manometer	Prospective, feasibility	PM utility in identifying pleurodesis candidates in malignant pleural effusions	Feasibility study. Awaiting results from EDIT trial

Ppl, pleural pressure; CVP, central venous pressure; NEL, non-expandable lung; PM, pleural manometry.

contributing to the NEL processes.

Utilizing PM, Pel, which is the change in pressure/change in volume (dP/dV), can be calculated. PM in an expandable lung with a pleural effusion generally demonstrates an initial positive mean Ppl which drops only minimally after fluid removal generating a P/V that is monophasic. The calculated Pel is <14.5 cmH_2O/L. Conversely a restricted pleura, as in those with NEL, will have a very high Pel (>14.5 cmH_2O/L), as a little change in volume will cause precipitous decreases in Ppl.

Normal values for Pel were derived by Heidecker *et al.* (18) from a series of thoracentesis done under PM. They assumed that pleural mechanics were determined by the overall respiratory mechanics, both hemi-thoraces

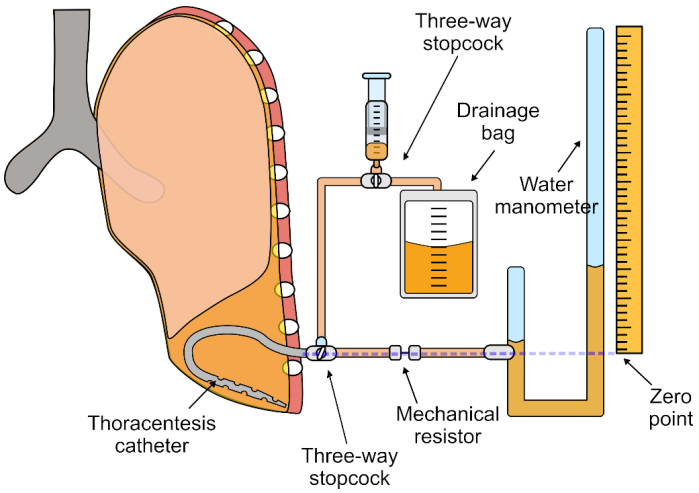

Figure 5 Damped U-shaped water manometer. Constructed from stiffened pressure transducing tubing connected to the thoracentesis catheter or chest tube. This is connected to a mechanical resistor (22-gauge needle inserted into a capless luer lock adapter), to create a dampening effect. Note that the reference point should be at the level of the insertion point of the thoracentesis catheter.

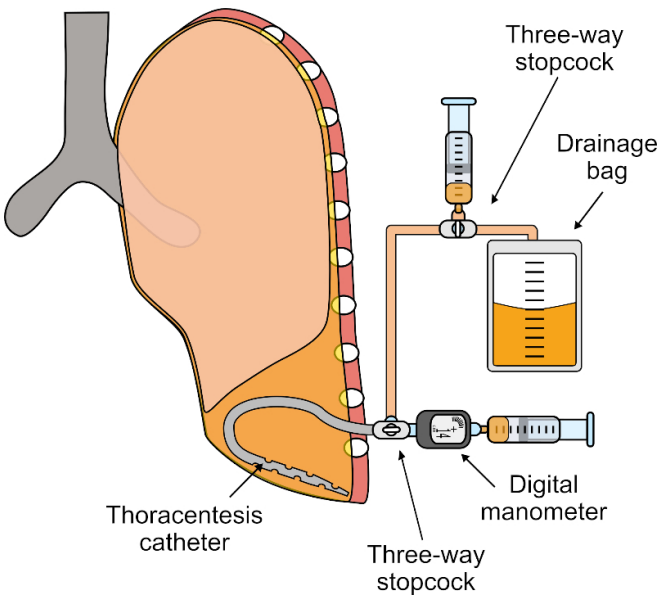

Figure 6 Digital manometer. The digital manometer is a commercially available system that places the instrument at the level of the thoracentesis catheter.

had similar properties and acted in series, local geometric distortion played little to a minimal role, and hydrostatic forces had no effect. Using these assumptions and complex derivations, they determined that the expected mean Pel was 7.44 cmH_2O/L for a respiratory system with a normal compliance (100 mL/cmH_2O), while the maximum Pel was 15.5 cmH_2O/L for a stiff respiratory system (compliance of 40 mL/cmH_2O). Utilizing this model, they found 124 patients with "normal" Pel values. Their sample cohort was normally distributed with a mean of 7.5 and a standard deviation (SD) of 3.5 cmH_2O/L, which in turn was in close agreement with the hypothesized model. Therefore, the

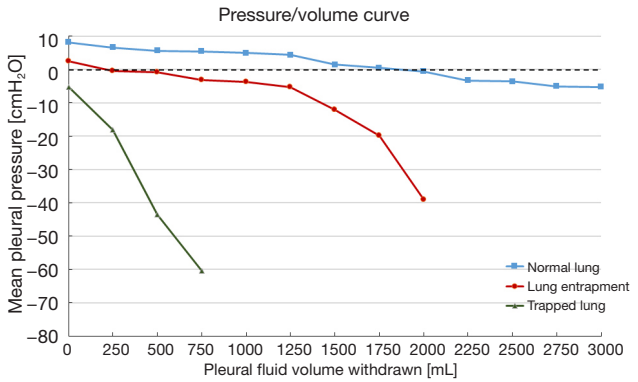

Figure 7 PM demonstrating 3 distinct pressure/volume curves. The horizontal axis represents volume removed. The vertical axis represents mean Ppl. The slope between each point therefore represents pleural space elastance. A normal lung will have a low pleural elastance and is monophasic in nature (blue line). Lung entrapment has a biphasic nature, where initially there is normal pleural space elastance followed by an increase in pleural space elastance toward the end of drainage (red line) Patient with trapped lung will typically have monophasic high elastance (black line). Ppl, pleural pressure; PM, pleural manometry.

normal Pel range was accepted as 0.5 to 14.5 cmH_2O/L (mean ± 2 SDs).

Traditionally, NEL due to visceral pleural restriction is separated into trapped lung and lung entrapment. To best visualize the differences of these NEL, a P/V curve can be utilized (*Figure* 7). Trapped lung is due to visceral thickening, results in a transudative effusion in most cases and is a form of defective pleural space healing from remote pleural space infection, inflammation or hemothorax. The P/V curve is monophasic, usually represented by an initial negative mean pressure and a steep decline in pressure with minimal fluid removal (5). Lung entrapment is due to visceral restriction from active inflammation and usually results in an exudative effusion. Unlike a "trapped lung", lung entrapment is not representative of a true clinical entity but does describe the presence of an NEL in diseases such as malignancy or a parapneumonic effusion. The initial Ppl is usually positive and initially changes in a normal fashion with a steeper decline in Ppl later when the lung can no longer re-expand. This results in two distinct portions of the curve, known as a biphasic P/V curve (18).

Large volume thoracentesis

Large volume thoracentesis guided by PM may potentially help reduce re-expansion pulmonary edema (RPE) and chest symptoms.

RPE is rare (<2%) complication of large volume thoracentesis, and carries a mortality of 20% (22). The proposed pathophysiology of RPE is the presence of excessive negative pressure in the pleural space, surfactant deficiency, and reperfusion injury (23). Large volume thoracentesis is defined as drainage greater than 1–1.5 liters of fluid in one session (24). PM can be used guide the volume to be drained. Current data suggests that drainage should be stopped when there is a change of >10 cmH_2O between two drainage aliquots (usually 250 mL) reaching a value of ≤–10 cmH_2O, or if there is an absolute Ppl of < –20 cmH_2O (25). These values were originally derived from animal studies. In rabbits, RPE started at a Ppl of < –20 mmHg (note not cmH_2O) and all had RPE by Ppl of –40 mmHg (23).

Without PM, it has been proposed that drainage should be terminated by symptomology of either chest pain or hypotension or when complete aspiration of pleural fluid occurs. In a series of 169 patients, Feller-Kopman *et al.* (19) reported that onset of chest discomfort was associated with lower Ppl and a total change in Ppl, while cough did not correlate with lower Ppl or the change in Ppl. Therefore, the presence of cough should not be an indication for termination of further pleural drainage. In fact, the group with the higher incidence of cough had lower Pel, suggesting expandable lungs. Majority of those who developed chest discomfort had a Ppl >–20 cmH_2O, while only 22% of patients had potentially unsafe decreases in their Ppl. This suggests that stopping fluid removal at the onset of chest discomfort avoids "unsafe" Ppl in most patients. However, despite using PM five patients who had "normal" Ppl developed RPE, with one being clinically significant (20).

Lentz *et al.* (6), in a series of 128 patients, with ≥0.5 L free-flowing pleural effusions, were randomly assigned to either cessation of drainage based on symptoms or based on symptoms in addition to use of PM. Their primary outcome was chest pain prevention with PM. Drainage termination parameters in the PM group were Ppl of <–20 cmH_2O, or a drop of Ppl of >10 cmH_2O between two readings to a value <–10 cmH_2O. They found no difference in chest discomfort (mean difference of 2.4 mm based on a 100 mm VAS score,

95% CI: –5.7 to 10.5, P=0.56). However, 6/62 patients in the non-PM group developed pneumothorax *ex vacuo* (non-clinically relevant finding as it did not lead to a change in clinical management), while there was none in the PM group (P=0.01).

None of the studies demonstrated that using PM routinely prevented RPE or chest pain. However, the use of symptoms alone cannot be used as a surrogate of excessive levels of negative Ppl, especially if altered sensorium prevents the patient from reporting chest pain. Nonetheless, the absolute value of an unsafe Ppl in humans is unknown. In our practice we use PM to guide large volume thoracentesis in selected cases where NEL is suspected or in patients who can't report symptoms because of altered sensorium to reduce the risk of RPE.

Guidance for pleurodesis in MPEs

Currently guidelines recommend indwelling pleural catheter or pleurodesis depending on the decision of the patient. However, NEL is an absolute contraindication for chemical pleurodesis. A recent study found that >50% of patients with MPEs have NEL, which is consistent with the reported success of pleurodesis through an indwelling pleural catheter (26,27). Moreover, chest radiographs and PM have a discordance in predicting NEL immediately following pleural fluid drainage. Currently, it is not known how to guide pleurodesis based on the post-thoracentesis chest radiography showing adequate lung re-expansion. A quarter of patients may have high terminal elastance despite chest radiograph showing full expansion after complete drainage of pleural effusion in MPE patients. This erroneously indicates expandable lung and thereby may lead to failure of pleurodesis (7).

The most important requirement for pleurodesis is complete lung expansion. Currently lung expansion for the pleurodesis is most commonly determined by a chest X-ray (24). Lan and colleagues found that MPE patients with Pel of >19 cmH_2O/L resulted in failed pleurodesis by bleomycin, while those with a Pel <19 cmH_2O/L and absence of trapped lung had a 98% success rate (4). Chopra *et al.* (7) recently found elevated Pel (>14.5 cmH_2O/L) even when >90% pleural apposition was found on chest X-ray. The authors concluded that chest X-ray alone may not be the best modality to rule-out NEL (26,27). Similarly, other recent studies have found pleurodesis rates of <50% despite near complete lung expansion as detected by chest radiograph (27-29), suggesting that chest radiograph alone may not be the best modality to select patients for pleurodesis. An ongoing trial (EDIT - elastance-directed indwelling pleural catheter or talc slurry pleurodesis) is examining the role of PM in selecting patients for pleurodesis (8). Currently, we are unable to make strong recommendations for the use of PM to separate those who would benefit from chemical pleurodesis versus IPC placement. A recent editorial by Pannu *et al.* (30) calls for the need for PM data to provide further insight into pleural pathophysiology to improve the care of MPE patients. We do agree that chest X-ray may not be a good way to determine complete lung expansion.

Management of selective cases of pneumothoraces

PM may aid in distinguishing between pneumothorax *ex vacuo* versus procedure related traumatic pneumothorax.

Conceptually, pneumothorax is categorized as stable or unstable. Stable pneumothorax usually occurs after pleural drainage in patients with NEL, often appearing as a basilar, loculated pneumothorax without contralateral shift in the mediastinum. This type of pneumothorax is also known as pneumothorax *ex vacuo*, which is a misnomer. The phenomenon was originally thought to occur because of persistent negative pressures. Heidecker *et al.* (18) demonstrated that even under PM and controlled withdrawal of the pleural effusion, a pneumothorax may occur. They conjectured that it was likely due to a mismatch in the shape of the lung and thoracic cavity resulting in a localized stretch which causes lung deformation letting air to escape. Once deformation is relieved by the replacement of air, the leak is abolished. They further demonstrated that the Ppl would always return to a similar point and representative of normal Ppl, even if attempts at evacuating the pneumothorax occurred on a cyclic basis. These type of pneumothoraces do not result in symptoms or tension physiology. PM can accurately identify this type of pneumothorax, as when sequential Ppl are measured after clamping of the chest tube to simulate a closed system, the Ppl will not rise over time (*Figure 8*). Once a stable pneumothorax is identified, tube thoracostomy can be discontinued. Constant suction should be discouraged as constant applied drainage pressure induces a persistent air leak (PAL) delaying chest tube removal and increasing hospital stay. Therefore, the best therapy is monitoring in the absence of suction.

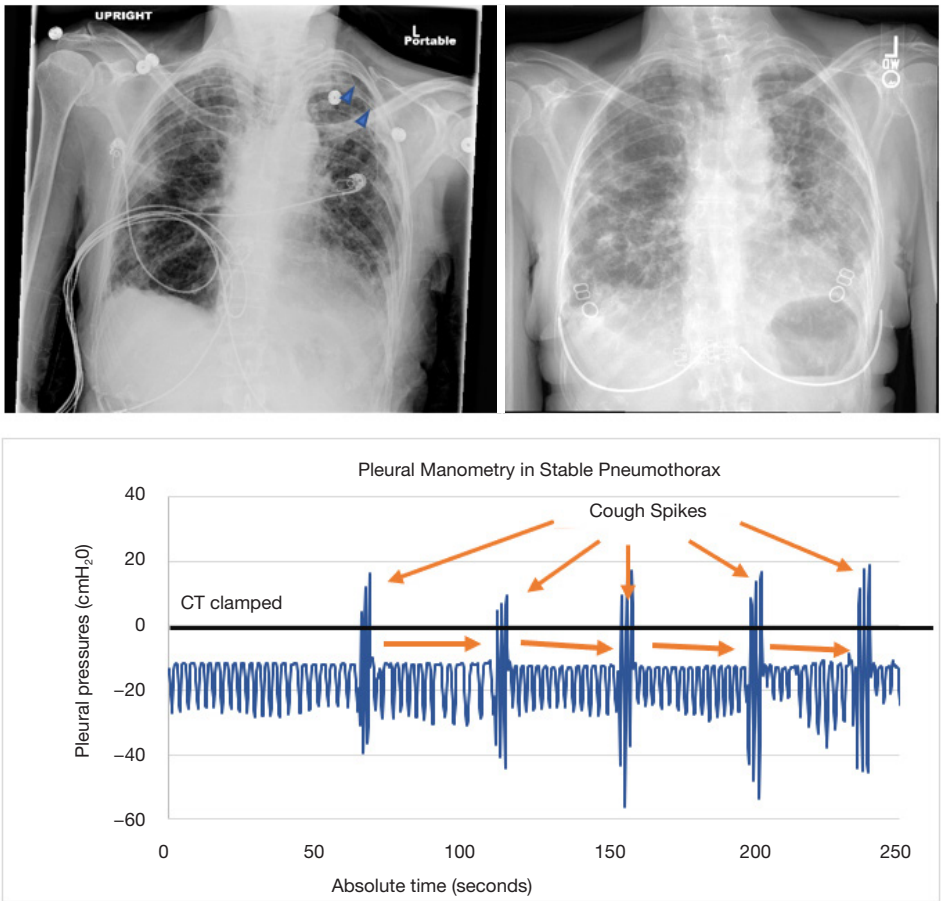

Figure 8 Radiographic finding and PM tracing of a stable pneumothorax. The left CXR shows a small apical pneumothorax when this patient first presented to the hospital. The right CXR was taken 30-days post chest tube removal which shows the pneumothorax space replaced by a pleural effusion. The PM tracing shows a typical pattern of a stable pneumothorax. PM, pleural manometry; CXR, chest X-ray.

With the use thoracic ultrasonographic guidance, unstable pneumothorax from traumatic injury rarely occurs. Heidecker *et al.* (18) in a study of 192 therapeutic thoracentesis reported only 9 pneumothoraces, out of which eight patients had NEL due to a pressure dependent pneumothorax. PM was able to identify these correctly and patients did not need additional interventions.

Conversely, an unstable pneumothorax usually occurs due to direct injury of the lung parenchyma, either from trauma, primary spontaneous pneumothorax, or secondary spontaneous pneumothorax. These tend to have a more global appearance on radiograph, and when large enough will cause lung collapse and hemodynamic instability. When measured by PM, these tend to start with a positive Ppl which slowly increases over time (*Figure 9*). The nature of most unstable pneumothoraces are from direct damage; therefore, this continual leak of air continues to build up in the pleural space and creates increasing positive pressure. This will eventually collapse the lungs and compresses the adjacent vascular structures leading to hemodynamics compromise. The management of this type of pneumothorax involves draining of the pleural space.

PM can reliably differentiate between stable and unstable pneumothoraxes (*Table 3*). Finding a stable alveolar pleural fistula (APF) may have significant clinical benefit which include early removal of chest tube, decreased length of stay, and decreased the need for additional pleural procedures. PM may also be used to further support Brown *et al.* (31) assertion that conservative versus invasive therapy is noninferior by adding a pathophysiological basis for their findings. It may explain why certain patients with primary spontaneous pneumothoraces develop increase recurrence

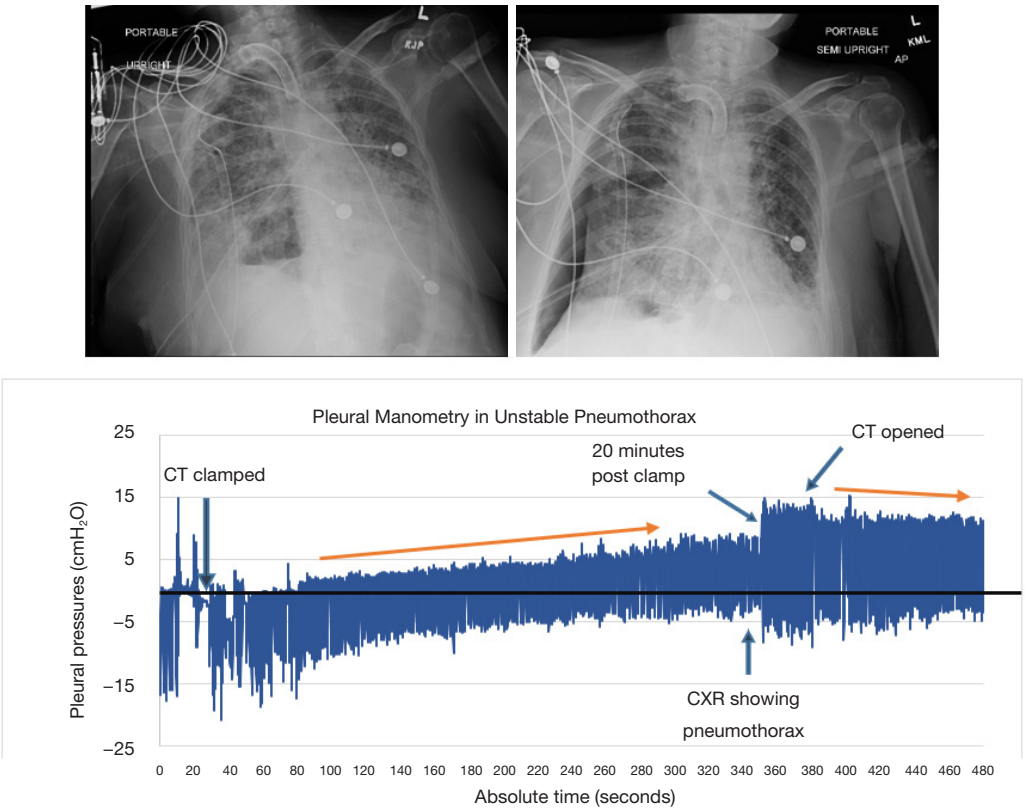

Figure 9 Radiographic finding and PM tracing of an unstable pneumothorax. The left CXR shows a patient with a persistent air leak before clamping the tube. The right CXR was taken post clamping of the chest tube which shows the pneumothorax enlarging. The PM tracing shows a typical pattern of an unstable pneumothorax, with pressure increasing over time. PM, pleural manometry; CXR, chest X-ray.

Table 3 Difference between stable and unstable pneumothorax

Type	Stable pneumothorax	Unstable pneumothorax
Origin	Pressure-dependent alveolar-pleural fistula	Pressure-independent broncho-pleural fistula
Radiographic	basilar loculated	Usually apical
Hemodynamics	Stable	Usually unstable
Occurrence	After pleural drainage in patients with NEL	Trauma or spontaneous
Lung disease	Usually present	Usually not present in trauma, present in spontaneous
Manometric findings	Ppl doesn't rise over time after clamping and cough maneuver	Ppl rises over time after clamping and cough maneuver
Treatment	Monitoring	Drainage

NEL, non-expandable lung.

and PAL after tube thoracostomy placement. This is likely due to deformation of subpleural alveolar conformation changes after application of pleural drainage and may also occur even under water seal, where the pressure remains variably negative, not zero.

The use of PM can aid in creation of artificial pneumothoraces for both diagnostic and therapeutic purposes. Normally, the pleura cannot be seen clearly on

conventional computed tomography (CT). For diagnostic purposes, air is introduced into the pleural space under ET manometry guidance, to create a contrast between the chest wall and pleura allowing for more accurate characterization of visceral and parietal pleura (19). Guided therapeutic pneumothorax can be used to relieve chest pain during pleural drainage when a NEL is encountered. By doing this, complete drainage of the pleural space can occur without discomfort (32).

Pitfalls

Currently, there is a paucity of data concerning the application of PM. Most prior studies are small, proof of concept, single center studies and difficult to generalize to routine practice. However, there are currently multiple studies underway to expand the clinical utility of PM. The prior studies have inconsistent methodology of PM with a few using ET and have not derived meaningful clinical outcomes. The techniques of PM have not been standardized as previously published by Doelken *et al.* (5).

Conclusion and future directions

PM is a useful additional tool in in the management of complex pleural diseases. Our understanding of pleural space physiology is incomplete. Direct PM may be an insight into some of the forces at play. Unfortunately, there is no robust data to support the routine use of PM. At the time of this review, there remains a scarcity of data to make general conclusions regarding its usefulness in pneumothoraces. These applications are mostly used as research tools but can be helpful in selected cases at experienced centers. There are several ongoing studies that are awaiting completion that may provide stronger evidence of PM in selected cases, such as MPE.

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Footnote

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