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# Thoracentesis: State-of-the-Art in Procedural Safety, Patient Outcomes, and Physiologic Impact

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**Abstract**

Pleural effusions are common and account for high morbidity and mortality in a range of patients. Thoracentesis can provide significant symptom relief and improvement in physiologic parameters including dyspnea, exercise, and sleep. Recent advances, including the use of ultrasound and dedicated procedural teams, have improved the safety of thoracentesis. This has allowed thoracentesis to be performed on higher-risk individuals including those with elevated bleeding risk and bilateral pleural effusions. This review will summarize recent advances in thoracentesis procedural safety, symptom relief following thoracentesis, and understanding of the physiologic basis for such improvements.

**Keywords**

hemothorax, pleural effusion, pleural ultrasound, pneumothorax, thoracentesis

## Introduction

Pleural effusions are diagnosed in over 1.5 million people in the United States annually and are caused by various underlying medical conditions.[1] The most common causes of pleural effusion are congestive heart failure followed by pleural infection and malignancy.[2] The presence of a pleural effusion is associated with high mortality, regardless of its cause,[3] and significant morbidity, including dyspnea and impairments in quality of life.[4] The underlying mechanism for symptom relief following thoracentesis is multifactorial but likely primarily involves improvement in respiratory muscle mechanics with a smaller impact from improvement in lung volumes and pulmonary function.[5,6] Thoracentesis can be performed for both diagnostic and therapeutic purposes, with the goal of symptomatic relief and restoration of quality of life caused by dyspnea.

The most common complication of thoracentesis is pneumothorax. A wide range of pneumothorax rates has been reported in the literature (0%-39%).[7] Other complications include pain, shortness of breath, or vasovagal reactions. Less common but serious complications are bleeding, reexpansion pulmonary edema, and inadvertent organ puncture. In recent years, the complication rate associated with thoracentesis has decreased with the use of ultrasound (US) guidance, correct site selection, development of procedural teams, and strict observance to universal protocol. Observation of these safety measures has allowed for performance of thoracentesis on a broader range of patients without increased complications, including those with underlying bleeding risk and patients with bilateral pleural effusions. The following will review recent advances in thoracentesis procedural safety, symptom relief following thoracentesis, and understanding of the physiologic basis for such improvements.

## Safety Measures for Thoracentesis

### *Ultrasound Guidance*

Atelectasis, lung mass, parenchymal consolidation, and hemidiaphragm elevation can have similar radiographic and physical examination findings as a pleural effusion. Ultrasound has been shown to be more effective in identifying a pleural effusion than chest radiography and physical examination while still being nearly as sensitive as computed tomography (CT).[8-11] When compared to thoracic CT for pleural effusion detection, US is 92% sensitive and 93% specific.[10] This provides a portable means for evaluating patients at the bedside and obviates radiation exposure. Diacon et al compared the use of US to physical examination for determining appropriate

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thoracentesis sites and found that 15% of sites marked by physical examination alone were in potentially dangerous positions.[11] Additionally, they found that the use of US increased the ability to locate a pocket of fluid safe for aspiration when physical examination was not sufficient. It is not surprising that, prior to the routine use of US, complication rates from thoracentesis were higher with dry tap, pneumothorax, and inadvertent organ laceration being more commonly encountered.[12,13]

Guidelines now support the routine use of real-time US for identification of pleural effusion during thoracentesis. It has been consistently demonstrated that the use of US reduces the rate of complications, namely, pneumothorax and need for chest tube insertion.[14] One of the first small prospective studies to compare the use of US versus physical examination found that US reduced the rate of pneumothorax from 30% to 0%.[7] Since then, multiple other studies have confirmed this finding.[15-18] A meta-analysis performed by Gordon et al examined the rate of pneumothorax following thoracentesis and found that US use was the single strongest predicator of lower pneumothorax rate (odds ratio 0.3; 95% confidence interval 0.2-0.7).[19] The use of US has also been shown to be cost-effective and can potentially reduce the cost of hospitalizations, perhaps in part due to lower complication rates.[16]

## Use of Handheld US Technology

With advancements in technology, smaller, handheld US machines have been developed, thus allowing physicians greater portability. These devices first found their place in echocardiography but soon were also used in pulmonary evaluation. Given their smaller size, there was concern that portable US may have suboptimal image quality. A small study evaluated the use of handheld US for guidance of thoracentesis (n = 3) and pericardiocentesis (n = 9).[20] This study found that handheld US could adequately identify the pleural effusion and that thoracentesis could be performed without increased risk of complications. A larger study (n = 73) used handheld US as an adjunct to chest X-ray in identifying pleural effusion.[21] Handheld devices were able to identify large pleural effusions in 63% of patients, whereas the remainder had small effusions or another etiology of the abnormality noted on chest imaging. Forty-six patients successfully underwent thoracentesis guided by the handheld USs without complications. The quality of the images was such that the examiners were able to identify nonuniform echogenicity or septations, suggesting hemorrhage or exudative effusion in 6 patients. Thus, when identified, US allows the user to not only identify the location for needle insertion but also determine characteristics such as echogenicity and the presence of septations or loculations that may aid in determining the underlying etiology.[22] Additionally, some practitioners advocate for the routine use of pleural manometry for monitoring of pleural pressures during thoracentesis. The advent of the use of handheld digital manometers, which have been shown to correlate well with electronic transducers, can make this approach easier.[23]

## Assessing Procedural Competency and Simulation Training

As technology becomes more readily available, there is concern regarding the proper training for US and these devices. In both of the above-mentioned studies using handheld devices, the operators were experienced in US and thoracentesis. Several studies have indicated that complication rate for thoracentesis is lower when performed by experienced operators.[7,24] Additionally, a meta-analysis demonstrated 3.9% overall complication rate compared to 8.5% ($P = .04$) when thoracenteses were performed by more experienced providers.[19]

Outside repeated patient encounters, the most appropriate teaching regimen for thoracentesis is questioned. The era of "see one, do one, teach one" for procedural training is shifting toward a more structured, competency-based teaching model. Studies in cardiology indicate that even after practice, new practitioners using handheld US failed to perform as well as those who were formally trained.[25] Simulation is an emerging educational tool. Simulation sessions in thoracentesis allow for systematized teaching and performance assessment on all aspects of the procedure, including adherence to universal protocol, use of US guidance, and management of potential complications. Studies have shown that thoracentesis skills can be improved after deliberate practice with simulation training.[26-28] Simulation is appropriate for all levels of trainees. Medical residents improved their performance on a thoracentesis clinical skills examination by 71% following simulation training.[26] Additionally, in a large pulmonary practice, it was found that initial simulation combined with limiting the number of providers who performed thoracentesis improved the rate of pneumothorax from 8.6% to 1.1%.[27]

To assess US competency, the Ultrasound-Guided Thoracentesis Skills and Tasks Assessment Test (UG-STAT) was developed and can be used on a simulation model prior to clinical practice.[29] This validated, 100-point assessment tool evaluates the users' familiarity with operating the US machine, identifying major organs, marking proper thoracentesis site, and characterizing the effusion. This assessment tool can be used on an ongoing basis to periodically gauge and document procedural competence.

## Use of Checklists and Adherence to Universal Protocol

Aside from allowing demonstration of US proficiency, simulation sessions can also emphasize the use of universal protocol to further reduce complication rates from thoracentesis. Universal protocol requires verification of correct patient, procedure, and site marking as well as a procedural time out immediately prior to starting a procedure. All providers involved in the procedure, including the patient's nurse, should be present when this is performed. Checklists should be used to ensure no elements are left out. In a root cause

analysis of 14 wrong-sided thoracenteses, it was found that failure to perform a time out and absent procedure site marking were the most common causes of error.[30] A thoracentesis simulation case was developed to highlight the need to adhere to universal protocol to prevent wrong-sided or wrong-patient procedures.[31] In this case, learners are presented with a radiograph of the wrong patient. If not caught and thoracentesis is performed, pneumothorax and other complications are expected. The simulation scenario was well liked by even experienced physicians (4.7 on a 5-point Likert-type scale), indicating that tools such as this can be used in clinical practice to assess the competency of both trainees and established physicians. Notably, combining US with simulation would ensure an additional layer of safety, given that, if performed incorrectly, no effusion would have been identified in the simulation session.

## Development of Procedural Teams

The above-mentioned studies indicate that competency in US use and thoracentesis improves the safety and success of the procedure. It may be reasonable to consider limiting the practice or supervision of thoracentesis to only those practitioners who have undergone training and have established proficiency. Medical procedure services (MPSs) have proven efficacy in medical resident training of thoracentesis.[32-34] In a pilot study of MPS-assisted house staff procedures at a single institution, the 3% pneumothorax rate for thoracentesis was comparable to that of experienced practitioners.[33] Additionally, it has been found that MPS involvement in inpatient procedures increases the likelihood that best practice methods such as US use are employed.[32]

In addition to development of an MPS, limiting the number of practitioners who perform thoracentesis may be beneficial. In their multimodal training intervention, Duncan et al determined that limiting thoracentesis in their large academic medical center to 5 providers (total number of pulmonologists was 44) who were able to demonstrate competency and maintain proficiency reduced the rate of pneumothorax from 8.6% to 1.1% while increasing the total number of procedures performed.[27] Interventional pulmonary subdivisions at many larger medical centers may help facilitate the development of specialized procedural teams.

## Thoracentesis in Patients at Risk of Bleeding

Bleeding, including hemothorax, has been observed in 1% to 3% of patients undergoing thoracentesis.[13,35] A study of 19 339 thoracenteses indicated that the use of US reduces the likelihood of hemorrhage by 39%.[16] Patients referred for thoracentesis oftentimes have comorbid conditions or take medications that potentially put them at higher risk of bleeding. One study of thoracenteses done on 312 patients found that 42% had 1 or more risk factors for bleeding.[36] The Standards of Practice Committee of the Society of Interventional Radiology recommended in 2012 that for low-risk, nonvascular procedures such as thoracentesis, the target international normalized ratio (INR) should be <2.0 and platelets >50 000/μL.[37] Transfusion of blood products should be used to achieve this goal. Additionally, it is recommended that clopidogrel be held for 5 days and therapeutic dose low-molecular-weight heparin held for 1 day prior to the procedure. This recommendation is, however, based on minimal data and has been recently questioned.

In 2010, the British Thoracic Society (BTS) gave grade C level recommendation to avoid nonurgent thoracentesis in patients with an INR > 1.5.[14] The BTS guidelines were primarily based on 1 study by McVay and Toy in 1991. This study demonstrated that in 217 patients with an untreated mild coagulopathy (defined as prothrombin time [PT] or partial thromboplastin time [PTT] up to twice the midpoint of normal and/or platelet count 50 000-99 000/μL) had no increased risk of bleeding after thoracentesis.[35] Since the BTS guidelines were published, there have been several other studies examining bleeding risk in patients undergoing thoracentesis.[36,38-42] Table 1 summarizes the most recent studies on performing thoracentesis in patients with bleeding risks.

A retrospective study of 1076 patients performed by Patel and Joshi demonstrated that, despite uncorrected coagulation parameters, there were no hemorrhagic complications.[39] In this study, a significant portion of patients had both an abnormal INR and low platelet values (17% INR >2.0, 7% INR >2.5, 4% INR >3, 6% platelets <50,000/μL, and 1% platelets <25 000/μL). The authors concluded that preprocedure coagulation assessment is not necessary and that thresholds should be eliminated.

Hibbert and colleagues compared 2 groups of patients with abnormal preprocedural coagulation parameters (defined as INR >1.6 and platelets <50 000/μL).[41] One group had preprocedural transfusion of either platelets or fresh frozen plasma, whereas the control group did not receive any transfusion. A total of 706 patients did not have transfusion, and there were no bleeding complications in this group. A group of 303 patients had transfusions prior to thoracentesis, and there were 4 hemorrhagic complications in this group. They concluded that hemorrhage from thoracentesis is rare, that thoracentesis is safe to perform when coagulation parameters are abnormal, and that there is no benefit from preprocedural transfusion.

In a study performed by Puchalski and colleagues, 312 patients undergoing thoracentesis were assessed for preprocedural bleeding risks, including an elevated INR, thrombocytopenia, renal failure, and the use of medications associated with a perceived bleeding risk.[36] Compared to those without an increased risk of bleeding, there was no difference in bleeding complications in the higher risk group (n = 130). The authors concluded that thoracentesis can be safely performed without prior correction of these coagulation abnormalities

In a recent large, single-center 12-year prospective cohort study, Ault and colleagues reported that in 9320 patients who

**Table 1.** Summary of Studies Examining Complications Following Thoracentesis in Patients With Bleeding.

| Author (Year) | Study Design | N | Bleeding Risk Factors | Significant Outcomes |
|---|---|---|---|---|
| McVay and Toy (1991)[35] | Retrospective | 217 | • Elevated PT/PTT<br>• Thrombocytopenia<br>• Elevated Cr | • No bleeding events requiring transfusion<br>• Cr >6.0 associated with greater average Hgb loss |
| Patel and Joshi (2011)[39] | Retrospective | 1076 | • Elevated INR<br>• Thrombocytopenia | • No bleeding complications |
| Zalt et al (2012)[40] | Prospective | 45 | • Clopidogrel | • No bleeding complications |
| Hibbert et al (2013)[41] | Retrospective | 1009 | • Elevated INR<br>• Thrombocytopenia | • 4 hemorrhagic complications in patients with coagulopathy corrected by transfusion<br>• No bleeding complications in patients with uncorrected coagulopathy |
| Puchalski et al (2013)[36] | Prospective | 161 | • Elevated INR<br>• Thrombocytopenia<br>• Clopidogrel<br>• Elevated Cr<br>• Heparin | • No bleeding complications |
| Mahmood et al (2014)[42] | Prospective | 17 | • Clopidogrel | • One hemothorax |
| Ault et al (2015)[38] | Prospective | 9320[a] | • Elevated INR<br>• Elevated PTT<br>• Thrombocytopenia | • 17 bleeding complications<br>• No significant association between bleeding complications and INR, PTT, and plt |

Abbreviations: PT, prothrombin time; PTT, partial thromboplastin time; Cr, creatinine; Hgb, hemoglobin; INR, international normalized ratio; plt, platelet.
[a]Not all patients had elevated bleeding risk; 412 patients had platelet <49 and 2306 had INR >1.49.

underwent thoracentesis, there was no association between bleeding complications and INR, PT, and platelet values.[38] In this study, approximately 25% of patients had INR >1.5 and 4.5% had platelets <50 000/μL. They concluded that their data do not support the current BTS guidelines regarding bleeding risk of thoracentesis.

In addition to abnormal coagulation parameters, medication use, specifically clopidogrel, has been associated with bleeding risk in patients undergoing surgery and is considered a contraindication to elective surgical procedures.[43,44] However, premature discontinuation of clopidogrel can have dramatic consequences such as increased risk of stent thrombosis with increased myocardial infarction and death.[43] Several studies have addressed the safety of performing thoracentesis on patients taking clopidogrel. Thirty patients taking clopidogrel without other coagulation abnormalities underwent thoracentesis by Zalt and colleagues.[40] This group found no significant bleeding postprocedure. Additionally, Mahmood et al studied 25 patients taking clopidogrel who underwent thoracentesis or small bore (14 French) chest tube placement.[42] One patient had a clinically significant hemothorax in this group. In the aforementioned study of 312 patients undergoing thoracentesis by Puchalski et al, 15 patients were taking clopidogrel. None of these patients experienced bleeding complications postprocedure.[36] Taken together, these several studies suggest that performance of thoracentesis may be safe in patients taking clopidogrel.

## *Anatomy of Thoracentesis: Aiming for the "Triangle of Safety"*

The major risk of bleeding due to thoracentesis comes from laceration of the posterior intercostal artery (ICA), which runs with the neurovascular bundle at the inferior aspect of the rib within the subcostal groove. The common procedural teaching in thoracentesis is to choose a site above the rib to avoid puncture of this vessel. However, the ICA can have a tortuous and unpredictable course.[45-49] In a CT scan study of 81 patients, Choi et al demonstrated increased tortuosity in elderly patients which decreased the effective "safe" space for puncture.[47] Yoneyama and colleagues also performed a CT angiography study in elderly patients and found that the lateral side (9-10 cm from spine) had a larger percentage area of safety than the medial side (5-6 cm from spine; 79.8% vs 61.2%; $P < .0001$).[46] Also using CT angiography, Helm and colleagues found that the ICA was exposed at a mean distance of 39 mm from the spine.[49] At 3 cm from the spine, the superior rib shielded only 17% of the ICA, but this percentage increased to 97% at 6 cm from the spine. The ICA can also be successfully visualized using US at the time of thoracentesis. In a study of 22 patients, 74 of 88 ICAs were identified at varying rib positions.[48] This study also demonstrated great variability in the ICA course with it more exposed in more posterior positions.

Taken together, these studies support the recommendation to perform thoracentesis puncture in the triangle of safety,

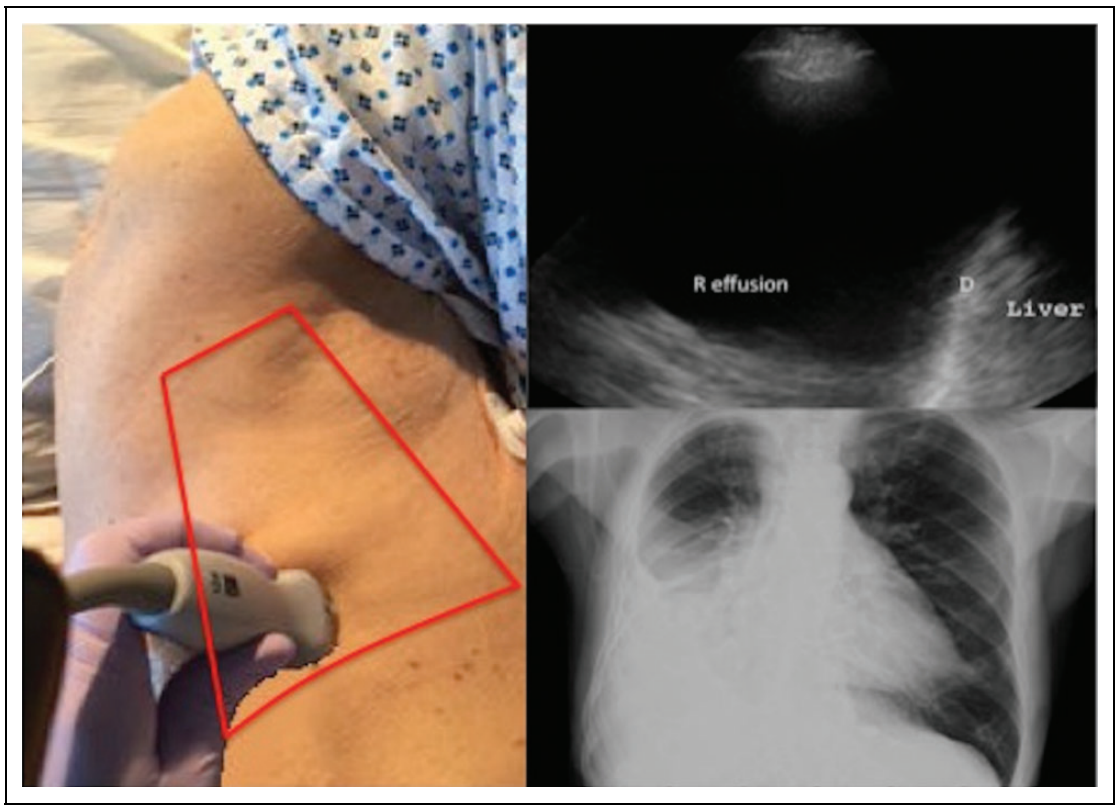


**Figure 1.** Correct ultrasound position for thoracentesis in the triangle of safety (left); ultrasound image identifying landmarks including the right pleural effusion (R effusion), diaphragm (D), and liver (right upper); chest X-ray demonstrating large right pleural effusion (right lower).

which is bordered anteriorly by the lateral edge of the pectoralis major, laterally by the lateral edge of the latissimus dorsi, superiorly by the base of the axilla, and inferiorly by the line of the fifth intercostal space.[14] Figure 1 depicts the ideal location for the performance of US-guided thoracentesis in the triangle of safety, taking into account the course of the ICA.

### *Safety of Performing Bilateral Thoracenteses*

Bilateral pleural effusions are common, accounting for 15% of cases in noncritically ill patients and up to 55% of those in the intensive care population.[50] Common clinical practice is to perform a unilateral thoracentesis. If bilateral effusions are present and the patient is felt to gain benefit from drainage from both sides of the chest, or if there is concern over differing etiologies, then typically thoracenteses are performed 1 side at a time. This practice is often due to the concern of pneumothorax. In Ault et al's review of 9320 thoracenteses, 41% were bilateral procedures performed sequentially.[38] Patients undergoing unilateral procedures were at higher risk of complications compared to bilateral ($P < .0001$). Given that the procedures were not done concurrently, it is possible that if a complication was noted after a unilateral thoracentesis, the contralateral side was not attempted. Puchalski and colleagues evaluated the safety of concurrent bilateral thoracentesis in 100 consecutive patients.[51] Ultrasound guidance was used for all patients, and the procedures were performed and/or supervised by experienced personnel. Of the 200 thoracenteses performed, there were 7 pneumothoraxes (3.5%). Four of these were determined to be ex vacuo while 3 (1.5%) required chest tube placement. There were no episodes of bilateral pneumothoraxes. These complication rates are similar to those reported in the literature for unilateral procedures, and the authors concluded that performing concurrent bilateral thoracenteses using standard US practice is safe. This may be particularly indicated for patients with moderate to large bilateral effusions in need of therapeutic intervention.

## Understanding the Physiologic Impact of Thoracentesis

As noted previously, advances in the safety of thoracentesis have enabled experienced physicians using US to perform the procedure in traditionally "higher-risk" patients, including those requiring mechanical ventilation, those with perceived bleeding risks, and those with bilateral effusions. This is quite important, as pleural effusions can have a large impact on dyspnea, quality of life, sleep, and exercise.[4,6,52,53] Table 2 summarizes the most recent studies on the physiologic impact of thoracentesis. The physiologic basis for improvements is likely multifactorial. Furthermore, a recent study demonstrated a profound mortality rate in all-comers with pleural effusions, not just those with

**Table 2.** Summary of Recent Literature of the Physiologic Impact of Thoracentesis.

| Author (Year) | Physiologic Parameters | Significant Findings |
|---|---|---|
| Goligher et al (2011)[54] | • Oxygenation | • Thoracentesis improved $PaO_2$-$FIO_2$ in mechanically ventilated patients |
| Razazi et al (2014)[55] | • Oxygenation<br>• Lung mechanics | • Thoracentesis improved $PaO_2$-$FIO_2$ in mechanically ventilated patients<br>• Thoracentesis increased lung compliance and end expiratory lung volume |
| Agustí et al (1997)[56] | • Ventilation/perfusion | • Arterial hypoxemia due to pleural effusion is mostly related to degree of intrapulmonary shunt<br>• Thoracentesis mildly improved blood flow to low ventilation/perfusion regions<br>• Thoracentesis had minimal effect on $PaO_2$, $AaO_2$ |
| Spyratos et al (2007)[57] | • Expiratory flow limitation<br>• Spirometry | • Thoracentesis improved expiratory flow limitation<br>• Pleural effusion limited expiratory flow most in the supine position |
| Wang et al (2007)[58] | • Spirometry<br>• Oxygenation<br>• Dyspnea | • Thoracentesis improved $FEV_1$, FVC, $PaO_2$, $AaO_2$ and dyspnea in patients with paradoxical hemi-diaphragm movement<br>• Thoracentesis had no impact on these parameters in patients without paradoxical hemi-diaphragm movement |
| Cartaxo et al (2011)[6] | • Spirometry<br>• Exercise<br>• Dyspnea | • Thoracentesis improved FEV1 and FVC<br>• Thoracentesis resulted in longer 6-minute walk test distances<br>• Maximum relief of dyspnea after thoracentesis occurred at the end of exercise |
| Boshuizen et al (2013)[53] | • Dyspnea | • Maximum improvements in dyspnea occurred during exercise<br>• Patient reported dyspnea correlated with need for reintervention |
| Marcondes et al (2012)[52] | • Sleep<br>• Dyspnea | • Thoracentesis resulted in no change in apnea-hypopnea index or nocturnal desaturations<br>• Thoracentesis improved sleep efficiency, total sleep time, and dyspnea<br>• Thoracentesis decreased stage 1 sleep |
| Argento et al (2015)[4] | • Dyspnea<br>• Quality of life | • Thoracentesis improved dyspnea and mental QOL up to 30 days postprocedure in a majority of patients<br>• Thoracentesis improved physical QOL and basic activities of daily living in a minority of patients |

Abbreviations: $PaO_2$, partial pressure of arterial oxygen; $FIO_2$, fraction of inspired oxygen; $AaO_2$, alveolar arterial oxygen gradient; $FEV_1$, forced expiratory volume in 1 second; FVC, forced vital capacity; QOL, quality of life.

malignancy.[3] In a population of 308 patients undergoing thoracentesis, there was a 21% mortality rate at 30 days and 51% at 1 year. Subgroups of those with malignant pleural effusion, bilateral pleural effusions, or effusion due to multiple benign etiologies had the highest mortality rates. This study highlights the need for a greater emphasis on symptom management and treatment of the underlying etiologies in these patients. Given the significant morbidity and mortality associated with pleural disease, the following examines the effect of thoracentesis on gas exchange, pulmonary mechanics, lung volumes, and symptom relief following thoracentesis.

## *Effects on Gas Exchange*

Pleural effusions can cause hypoxemia and have been shown in animal models to reduce the partial pressure of arterial oxygen ($PaO_2$).[59] Studies in humans have demonstrated conflicting results, with some demonstrating that thoracentesis can improve oxygenation,[54,55,60] whereas others demonstrate no immediate change in $PaO_2$.[56,61,62] One large meta-analysis of mechanically ventilated patients demonstrated that the partial pressure of arterial oxygen to fraction of inspired oxygen ratio ($PaO_2$-$FIO_2$) improved by 18% (31 mm Hg) in 118 patients after thoracentesis.[54] The studies included in the meta-analysis had variable correlation with improvements in oxygenation and volume of fluid withdrawn. Razazi and colleagues studied 20 mechanically ventilated patients and similarly found that $PaO_2$-$FiO_2$ improved from a mean of 191 to 250 mm Hg after drainage of a mean of 1570 mL.[55] This improvement was significantly correlated with an increase in end-expiratory lung volume but not with volume of fluid withdrawn. A 10% increase in lung volume was found to be a good predictor of at least a 15% improvement in $PaO_2$-$FiO_2$.

## *Effects on Ventilation–Perfusion*

In the presence of pleural effusion, low arterial oxygenation is most likely due to the presence of mild intrapulmonary shunt.[56] Agustí and colleagues demonstrated in a series of 9 patients that the degree of arterial hypoxemia was related to

the amount of intrapulmonary shunt. They also evaluated the effect of thoracentesis on $PaO_2$, alveolar–arterial $O_2$ ($AaO_2$), and ventilation–perfusion (V/Q) ratios. Thoracentesis had no effect on $PaO_2$, $AaO_2$, and shunt and had a very mild augmentation of blood flow to low V/Q regions.

## Effects on Pulmonary Function and Lung Volumes

Multiple studies have aimed to define the impact that thoracentesis has on pulmonary function. The earliest studies indicated small improvements in functional residual capacity and total lung capacity 3 hours after thoracentesis but no correlation with symptom improvement or gas exchange.[61] Several studies have shown a small improvement in vital capacity both 2 hours and 24 hours after thoracentesis (300 and 410 mL, respectively).[5,63] Cartaxo and colleagues demonstrated that these results are sustained to at least 48 hours postprocedure.[6] Twenty-five patients had improvements in forced vital capacity ([FVC] 350 mL, 18.5%) as well as forced expiratory volume in 1 second (FEV1) (280 mL, 18.4%). These results did not correlate with the volume of fluid removed. In addition to improvements in all spirometric measurements, a study of 21 patients demonstrated significant improvement in expiratory flow limitation that was most pronounced in the supine position.[57]

## Effects on Lung Mechanics

While the above-mentioned studies established that thoracentesis can have small effects on gas exchange, pulmonary function values, and lung volumes, many patients experience dramatic relief of dyspnea following thoracentesis. These findings indicate that symptoms related to pleural effusion are more likely related to its effect on respiratory mechanics rather than compression of lung volume. Animal models of both dogs and rats show that pleural effusion leads to an increase in thoracic cage volume, mainly through downward displacement of the diaphragm but also by increases in anteroposterior and lateral rib cage diameters.[64,65] Wang and colleagues studied the effects of thoracentesis on patients with paradoxical movement of the hemidiaphragm ($N = 21$) versus those without paradoxical hemidiaphragm movement ($N = 41$).[58] Patients with paradoxical movement experienced significant improvements in FEV1, FVC, $PaO_2$, $AaO_2$, and dyspnea, whereas changes in these measures in those without hemidiaphragm dysfunction were not observed. These findings support the belief that relief of dyspnea following thoracentesis is mediated primarily by a shift in the inspiratory muscle pressure–volume curve, allowing the muscles to work via a more favorable length–tension curve through reduction in the thoracic cage volume.[5] Klecka and Maldonado demonstrated improvement in dyspnea after large volume thoracentesis in a patient with no lung perfusion.[66] Despite no perfusion to the ipsilateral lung, therapeutic thoracentesis repeatedly reduced the patient's dyspnea and allowed performance of strenuous exercise without limitation. The authors suggested that the pleural effusion likely led to dyspnea through alterations in the length–tension relationship of the inspiratory muscles.

## Dyspnea Relief

The sensation of dyspnea is in part due to the activation of mechanoreceptors in response to changes in stretch, cough, and lung volumes.[67] Drainage of pleural effusion has been shown to significantly improve patient-reported dyspnea.[68] In one of the largest cohorts studied, Argento and colleagues followed 163 patients 30 days after therapeutic thoracentesis and demonstrated that the majority (60%) of patients had a sustained improvement in dyspnea scores, as measured by the modified BORG (mBORG) scale, regardless of the volume of fluid removed.[4] Other outcomes measured in this cohort included improvements in mental quality of life in 56% of patients and physical quality of life in 48% of patients, 30 days after thoracentesis. Dyspnea has previously been shown to improve in the acute period following thoracentesis.[6,52] In 25 patients who underwent thoracentesis for unilateral pleural effusion, dyspnea was significantly reduced postthoracentesis (mBORG score $2.7 \pm 1.3$ to $1.5 \pm 1.4$, $P < .001$).[6] Additionally, in 19 patients, the mBORG improved from $2.3 \pm 2.1$ to $0.8 \pm 0.9$ in the 36 hours after thoracentesis.[52]

Boshuizen and colleagues studied patient perception of dyspnea by various scales and their association with the need for reintervention.[53] They analyzed 49 patient reports of dyspnea using a visual analog scale and mBORG for 14 consecutive days following thoracentesis. They found that patient-reported dyspnea improved following thoracentesis and that patient assessment of their dyspnea through mBORG was able to predict the need for reintervention. Patients with higher reported dyspnea, especially during exercise, had an increased rate of reintervention within 30 days. These data indicate that the use of daily dyspnea assessment following thoracentesis is a useful aid in identifying patients who would benefit from a repeat, or possibly more definitive, procedure.

## Exercise

In addition to relief of dyspnea, many patients emphasize the importance of returning to prior activities, including light exercise, after thoracentesis. In the aforementioned studies, the effect of thoracentesis on exercise was also studied.[6,53] Six-minute walk tests were performed on 25 patients before and 48 hours after thoracentesis.[6] Following thoracentesis, the mean distance walked increased significantly (63 m, 14.6% increase). Additionally, patients experienced a maximal improvement in perceived dyspnea, measured via mBORG, at the end of exercise ($5.1 \pm 2.3$ to $2.4 \pm 1.6$). Boshuizen et al's study of patient-reported dyspnea scores following thoracentesis also showed maximal improvements in dyspnea with exercise and that the median time to

maximal improvement was 2 days.[53] Thus, thoracentesis enables most patients to experience maximal symptom relief during exercise and improvements in daily activities.

### *Sleep*

Sleep impairment is common in patients with underlying pulmonary disease. One study has been published examining sleep parameters in patients with pleural effusion.[52] Nineteen patients with large pleural effusion who were referred for thoracentesis had a full polysomnography the night prior to thoracentesis and 36 hours after thoracentesis. Sleep quality, as measured by the Pittsburg Sleep Quality Index (scale of 0-21 with poor sleep classified as score >5) was poor prior to thoracentesis ($9.1 \pm 3.5$). Following thoracentesis, there were improvements in sleep efficiency (76% vs 81%, $P = .006$), total sleep time ($344 \pm 92$ vs $380 \pm 69$, $P = .056$), and percentage of rapid eye movement sleep (15% vs 20%, $P = .053$). There was also a significant decrease in stage 1 sleep (16% vs 14%, $P = .002$). There were no changes in the apnea–hypopnea index or total time with oxygen saturation below 90%, despite large effusions being present. This study strongly suggests that therapeutic thoracentesis may aid in maximizing patient sleep quality and further improve quality of life.

## Conclusion and Future Studies

Pleural effusions are commonly encountered in clinical practice and have a dramatic impact on patients, causing shortness of breath, impairments in quality of life, and other morbidities. Patients with pleural effusion have a high short- and long-term mortality, regardless of the etiology. Thoracentesis can have a significant effect on symptom relief and physiologic parameters. Changes in the approach to thoracentesis have allowed for improved safety. The state-of-the-art approach to thoracentesis includes use of US, entry of the pleural space in the triangle of safety, and use of a dedicated but limited group of practitioners. Using this approach, conventionally high-risk patients, including those with perceived bleeding risks and bilateral effusions, may potentially be treated more expeditiously.

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