ORIGINAL RESEARCH PAPERS

Feasibility and early experience with venous Doppler congestion assessment in post-operative lung transplant patients

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ABSTRACT

Background: The role of venous Doppler ultrasound in assessing venous congestion in the setting of post-lung transplantation surgery is unknown. We performed a feasibility study on the use of venous Doppler ultrasound in the immediate post-operative period after lung transplantation in a retrospective, single-center observational evaluation. Patients had at least two venous congestion Doppler ultrasound exams involving interrogation of IVC diameter, hepatic vein, portal vein and renal vein Doppler assessments.

Results: A total of 9 patients were included in our study with a median age of 60 years, 66.7% being male, and a median BMI of 20.9. All patients had VExUS grade ≥1 on their first venous Doppler exam. All nine patients had a decrease in portal vein pulsatility from initial to final exams. Correlation between portal venous pulsatility and net fluid balance was not statistically significant R= 0.33 (P= 0.39). Other parameters, including VExUS grade, IVC diameter, HV and RV Doppler changes from initial to final ultrasound exams showed variable changes in the post-operative period.

Conclusion: Venous congestion Doppler ultrasound assessments appear feasible in immediate postoperative lung transplant patients. A multitude of factors beyond fluid status likely affect waveforms.

Key words: Point-of-care ultrasound, VExUS, Lung transplant, Critical care ultrasonography, Venous congestion

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Background

The optimal assessment of fluid status and venous congestion immediately after lung transplantation remains unclear. Transplanted lungs carry high rates of pulmonary edema due to increased vascular permeability and disrupted lymphatic drainage (1). With urgency-based allocation combined with the growing use of extracorporeal life support as a bridge to transplant, lung transplant candidates in the current era are more complex and critically ill, often requiring large volume resuscitation intra-operatively. Post-operative care frequently requires careful attention to venous congestion and de-resuscitation, as practitioners attempt to avoid primary graft dysfunction (PGD) while balancing optimal organ perfusion. A high central venous pressure (CVP) has been associated with prolonged mechanical ventilation and hospital mortality after lung transplantation (2). However, CVP is affected by a multitude of factors, including venous compliance, intra-thoracic pressures and cardiac function (3). Many practitioners dose diuretics based on CVP alone, even without overt clinical signs of volume overload. Inferior vena cava (IVC) size and respirophasic measurements to estimate CVP can be unreliable, particularly in mechanically ventilated patients (4). Recently, the assessment of venous congestion in critically ill patients by point-of-care Doppler ultrasound has gained traction. Venous congestion Doppler ultrasound, combining IVC size, hepatic vein (HV), portal vein, and renal vein (RV) Doppler, was shown to predict acute kidney injury after cardiac surgery and also correlate with CVP (5, 6). Venous congestion Doppler may capture the dynamic interplay between elevated CVP and upstream venous organ congestion. In the immediate post-operative lung transplant population, point-of-care ultrasound has traditionally focused on thoracic evaluation to detect early and late pulmonary complications (7, 8). There is a lack of reliable methods to assess organ venous congestion after lung transplantation, and this presents a significant research gap in regard to optimal postoperative care. Whether Doppler ultrasound can help assess organ congestion in this patient population has not been evaluated. We retrospectively reviewed a cohort of immediate post-operative lung transplant recipients who had venous Doppler exams performed. We observed changes between initial and final venous Doppler ultrasound exams, setting out to assess feasibility and describe observed variations in venous physiology during their post-operative care.

Methods

We conducted a retrospective, single-center observational study at an academic hospital (Jacksonville, Florida, USA). The Institutional Review Board (24-004390) approved the study and waived the requirement for informed consent due to the retrospective design. All adult patients (>18) who received lung transplantation between January 2023 and April 2024 and had at least two post-operative venous Doppler exams recorded after lung transplantation were included. Twelve post-operative lung transplant patients were initially identified. Three patients were excluded due to poor quality images or were missing >1 venous Doppler waveform, resulting in 9 patients finally included. None of the patients had evidence of preoperative cirrhosis or portal venous hypertension.

All patients underwent an initial venous Doppler exam on postoperative day (POD) 0 upon arrival to the ICU from the operating room, and a subsequent venous Doppler exam within the first fifteen days post-transplant, based on availability of the intensivist performing the studies. IVC diameter, hepatic vein (HV), portal vein and renal vein (RV) Doppler signals were assessed. Of note, if the IVC was less than 2 cm in diameter, we proceeded to continue to measure the other venous Doppler parameters in the Venous excess ultrasound (VExUS) protocol, which is in contrast to the originally described protocol (5). Simultaneous electrocardiogram (EKG) tracings were obtained during all hepatic vein and renal vein Doppler exams. The IVC diameter was measured adjacent to the entry of the HV in either the subcostal or transhepatic imaging planes, depending on the best view available, and measured in both long and short axes when possible. HV Doppler was obtained via a right coronal or subcostal imaging plane, with the highest quality images included. For HV Doppler, systolic (S) and diastolic (D) spectral Doppler waveforms were identified and graded as either systolic predominant flow (S>D), diastolic predominant flow (D>S), or systolic flow reversal. The portal vein was identified with the transducer placed in the right midaxillary region, and portal vein pulsatility (PVP) was calculated as (Vmax – Vmin)/Vmax. RV Doppler of the interlobar renal veins was performed in a right coronal imaging plane, and recorded as continuous, biphasic or monophasic. All spectral Doppler signals were acquired at end-expiration.

All ultrasound examinations were conducted by an intensivist with extensive training in critical care ultrasound, using a GE (General Electric) Vivid S70N ultrasound machine in the intensive care unit. Vital signs, laboratory parameters, and preoperative echocardiograms were reviewed from the electronic health record. Other data obtained included the patients' demographics, indication for lung transplantation, serial creatinine levels and urine output before and after transplantation. Net fluid balance (NFB) was calculated by subtracting the cumulative output from the cumulative intake between initial and final ultrasound exams. Post-lung transplantation outcomes were obtained, including primary graft dysfunction (PGD) at day 0 and day 3 (72 hours), days on mechanical ventilation, ICU length of stay, hospital length of stay, and mortality at day 90.

Continuous variables were expressed in median and interquartile range due to the non-parametric nature of the data, given the small sample size. The categorical variables were expressed as percentages. The Spearman correlation test was used to explore the linear correlation between net fluid balance change and change in venous Doppler congestion ultrasound parameters between the initial and final exams. Given the continuous nature of the IVC diameter, PVP and NFB variables, the linear correlation was performed with percentage change in the variables IVC, PV or NFB calculated from their values in study 1 (x1) and study 2 (x2) as: percentage change = ((x2 − x1) / x1). Given the discrete nature of the variables Hepatic vein (D>S or S>D), the change in hepatic vein doppler were recoded as: 1 if both final and initial studies are D>S, 0 if both final and initial studies are S>D or −1 if final study is S>D and initial study is D>S, for the purpose of linear correlation. Similarly, given the discrete nature of the renal vein Doppler (biphasic, monophasic or continuous), they were recoded as monophasic=2, biphasic=1 or continuous=0 to reflect the degree of congestion. Spearman correlation was used, given the non-parametric nature of the data. All tests were two-sided, with a p-value <0.05 considered statistically significant. The analysis was done using R4.2.2 and Microsoft Excel.

Results

Demographics and lung transplant outcomes

Nine patients were included in our cohort, with a median age of 60 years, 66.7% male, and a median BMI of 20.9. Seven patients underwent bilateral lung transplantation, one patient underwent a single lung transplant, and one patient received a combined heart-lung transplant. All nine patients (100%) in the cohort were mechanically ventilated during the initial ultrasound exam, but only one patient (11.1%) remained on a mechanical ventilator during the final ultrasound exam, with the rest spontaneously breathing during their final ultrasound exam. A total of 2 patients (22%) had PGD on Day 3. All patients were alive until day 90. Further details are elucidated in Table 1.

Venous Doppler ultrasound findings

All nine patients had a decrease in PVP from initial to final ultrasound exams. A weak correlation was seen between PVP percent change and net change in NFB from initial to final ultrasound exams: however, this change in PVP was not statistically significant R= 0.33 (P= 0.39). The IVC diameter decreased in 6 patients (66.6%), remained the same in 2 (22.2%) and increased in 1 (11.1%) patient. The correlation coefficient between the percentage change of IVC and net change in fluid balance was very weak (R=0.11, p=0.78). HV Doppler showed diastolic predominance (D>S) in both initial and final exams in 6 (66.6%) patients, systolic predominance (S>D) in both exams in 2 (22.2%) and a change from D>S to S>D in the final exam in 1 (11.1%) patient. The correlation coefficient of HV change with net change in fluid balance was close to nil (R=-0.01, p=0.98). RV doppler showed a biphasic pattern in both initial and final exams in 3 (33%), a continuous pattern in both exams in 2 (22.2%) and a change from biphasic to continuous in 2 (22.2%) patients. The correlation coefficient between

Table 1. Summary of demographic data, baseline characteristics and outcomes.

Characteristic	N = 9
Age	60 (56, 66)
Female Sex	3 (33%)
BMI	20.9 (19.2, 26.1)
Preoperative ECMO	3 (33%)
Lung Transplant Indication	
ILD	8 (89%)
ILD + COPD	1 (11%)
Lung Transplant Type	
Bilateral lung	7 (78%)
Heart-Lung	1 (11%)
Left single lung	1 (11%)
Pre-Operative Right Ventricle Size	
Normal	3 (33%)
Mild enlargement	1 (11%)
Moderate enlargement	5 (56%)
Pre-Operative Right Ventricle Function	
Normal	3 (33%)
Mild dysfunction	1 (11%)
Mild-moderate dysfunction	1 (11%)
Moderate dysfunction	3 (33%)
Moderate- severe dysfunction	1 (11%)
Pre-Operative Tricuspid Regurgitation	
Trivial	2 (22%)
Mild	4 (44%)
Mild- Moderate	2 (22%)
Moderate- Severe	1 (11%)
Creatinine preop	0.53 (0.47, 0.79)
Creatinine POD 0	0.59 (0.46, 0.73)
Creatinine POD 7	0.65 (0.58, 0.81)
Creatinine POD 14	0.79 (0.62, 1.06)
Post operative ECMO	
No	9 (100%)
Vasopressor/inotropes post-op	7 (78%)
PGD 0	
0	5 (56%)
1	2 (22%)
2	1 (11%)
3	1 (11%)
PGD 72	
0	6 (67%)
1	1 (11%)
2	2 (22%)
Mechanical Ventilator, days	2.0 (1.0, 7.0)
ICU length of stay, days	7.0 (3.0, 15.0)
Hospital length of stay post-transplant, days	23 (17, 36)
Mortality at 90days	0 (0%)

(ECMO-extracorporeal membrane oxygenation, ICU-intensive care unit, ILD-interstitial lung disease, COPD-chronic obstructive pulmonary disease, PGD-primary graft dysfunction, POD-postoperative day.)

RV Doppler change and net change in fluid balance was nil (R=0, p=1). All patients had VExUS grade ≥1 on their first venous Doppler exam, with a decrease in score to 0 in 4 (44.4%) patients. The degree of correlation of VExUS change with net change in fluid balance was again very weak (R=-0.056, p=0.89). The patient-level data on changes in venous ultrasound parameters are represented in Table 2, and the PVP changes represented in Figure 1 and Figure 2.

Discussion

The optimal method for evaluation of venous congestion after lung transplantation remains unclear, and there remains a lack of consensus on which parameters are useful to guide evaluation of venous congestion and volume assessments. CVP, when high, has been associated with prolonged mechanical ventilation and hospital mortality (2); however, CVP is a poor measure of intravascular fluid status and can be affected by a multitude of factors when used to assess systemic venous congestion. Lung transplant recipients can have altered hemodynamics because of surgical changes, large fluid shifts, and anatomic changes such as pulmonary artery stenosis, which can complicate interpretation of CVP as a marker for venous congestion. Patients with cardiac or thoracic tamponade from bleeding or donor-recipient size mismatch can also manifest with elevated CVP, further complicating its value in this

Table 2. Details of each patient's venous Doppler ultrasound exams, mode of breathing, and fluid balance details.

Patient	Time of Exam	Mode of Breathing	IVC Diameter (cm)	HV Doppler	PVP (%)	RV Doppler	VExUS Grade	Cumulative Fluid Balance (mL)	Net Fluid Balance (mL)
1	POD 0	MV	2.3	D>S	25.8	Biphasic	1	+8653	
	POD 7	MV	2	D>S	12.2	Biphasic	1	+8523	-130
2	POD 0	MV	2	D>S	39.3	N/A	1	+7224	
	POD 15	SB	1.6	S>D	8.8	Continuous	0	+2117	-5107
3	POD 0	MV	2.1	D>S	56.4	Biphasic	2	+3059	
	POD 10	SB	1.2	D>S	21.6	Continuous	0	+2291	-768
4	POD 0	MV	2.2	D>S	45.9	Continuous	1	+2695	
	POD 3	SB	1.1	D>S	20.3	Continuous	0	+865	-3560
5	POD 0	MV	2	D>S	34	Biphasic	1	+4520	
	POD 3	SB	2.2	D>S	15	Continuous	1	+3314	-1206
6	POD 0	MV	2.6	S>D	52.5	N/A	2	+25681	
	POD 6	SB	2.1	S>D	18.7	Continuous	1	+22902	-2779
7	POD 0	MV	2	D>S	33.9	Biphasic	1	+17180	
	POD 6	SB	2	D>S	13.5	Biphasic	1	+5154	-12026
8	POD 0	MV	2.2	D>S	39.2	Biphasic	1	+3729	
	POD 1	SB	1.7	D>S	35.7	Biphasic	0	+2781	-948
9	POD 0	MV	2.1	D>S	54.8	Continuous	2	+7691	
	POD 2	SB	2.1	S>D	32.1	Continuous	1	+5839	-1852

Abbreviations: MV: mechanical ventilation; SB: spontaneous breathing; N/A: not available; D: diastole; S: systole; IVC: Inferior Vena Cava; HV: Hepatic Vein; PVP: Portal Vein Pulsatility.

setting. Venous Doppler ultrasound is a technique which may capture the dynamic interplay between upstream venous pressure and CVP, providing a window to organ congestion (9).

To the best of our knowledge, this is the first study highlighting venous Doppler ultrasound congestion assessments in the immediate postoperative period after lung transplantation. Of the venous Doppler waveforms assessed, PVP assessment appears feasible in the post-operative lung transplant population and uniformly decreased in our patient cohort. The poor correlation between PVP and NFB is not surprising, as venous congestion patterns are affected by a multitude of factors. A congested venous Doppler profile must be contextualized in the framework of a 'venous restrictive syndrome', affected by not just fluid balance, but many factors including positive pressure ventilation, right heart hemodynamics, and catecholamine surge (10). All these factors remain dynamic in post-operative care. NFB may therefore be a weak comparator in this patient population, since venous congestion and fluid overload represent related, but not interchangeable physiologic patterns. The decrease in PVP seen in our cohort is likely multifactorial. Anatomically, the portal vein is separated from direct right heart pressures by the hepatic sinusoids, and this separation may protect the portal vein from direct right heart congestion. Only in the presence of significant congestion, elevated right atrial pressures transmit across the hepatic sinusoids to the portal vein, reflecting true capillary level congestion (11). In ESRD patients, a decreased PVP was seen after volume removal after ultrafiltration, although without a direct correlation with fluid balance (12). In a study of ICU patients, PVP was predictive of diuretic-induced fluid depletion, whereas the VExUS score was not (13). The PVP, of all the venous Doppler

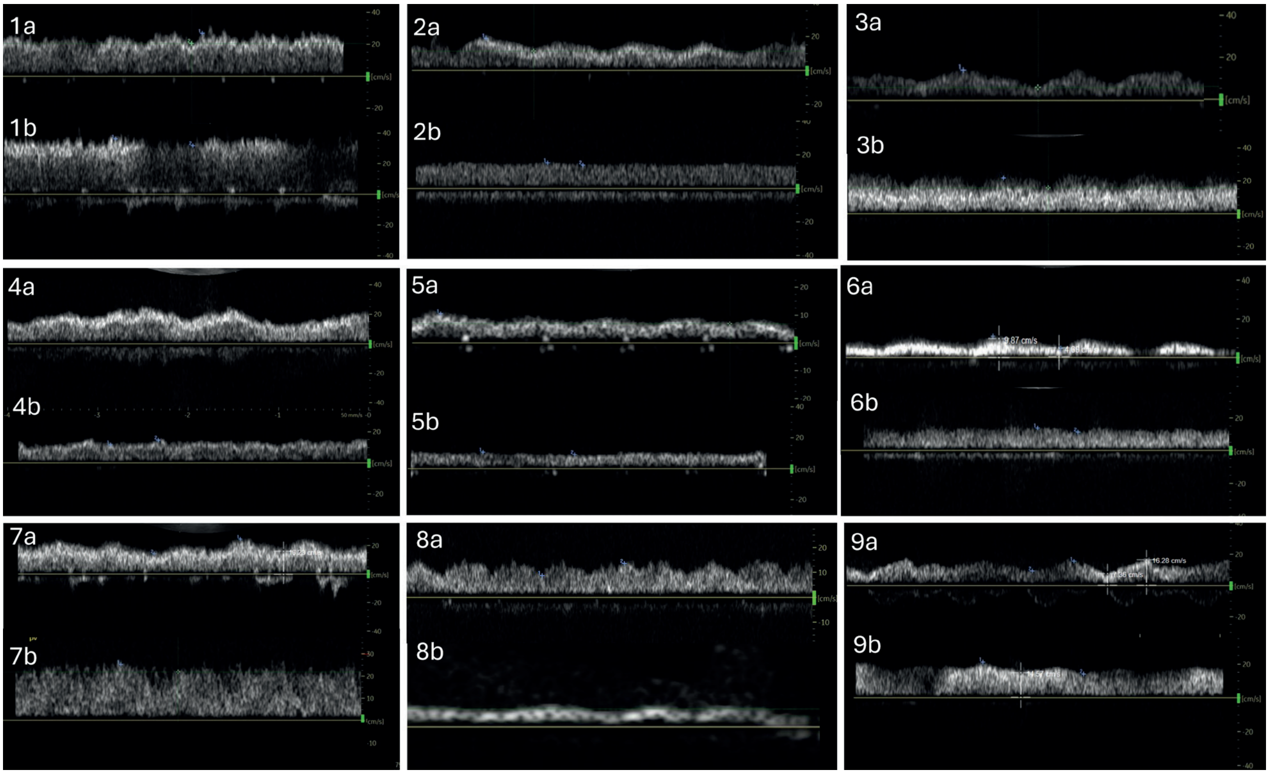

Figure 1. Portal vein pulsatility of all nine patients post lung transplant. Panels labeled as "a" show the initial postoperative PVP exam, and panels labeled "b" show the final PVP exam. Note differences in velocity scales between exams.

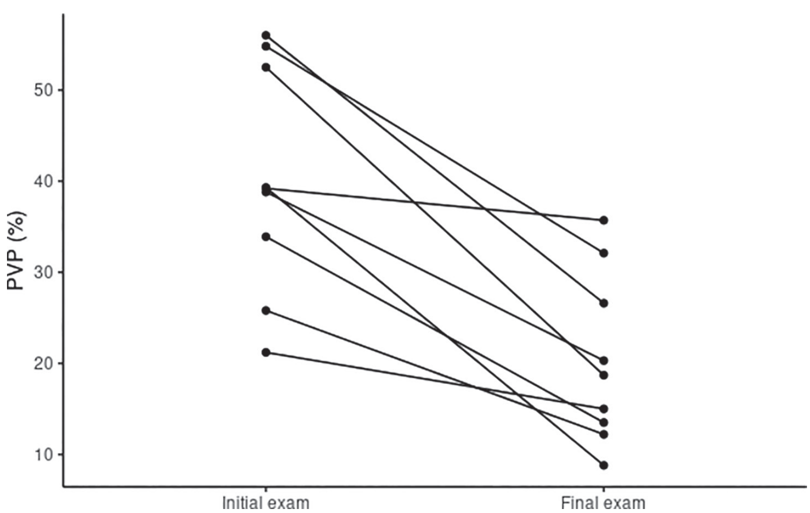

Figure 2. Portal vein pulsatility changes between the initial and final venous Doppler ultrasound studies among all 9 patients from the cohort.

waveform parameters, appears to be very sensitive to fluid shifts and has shown promise in monitoring real-time decongestion (12). Prognostically, in studies of post-operative cardiac surgery patients, a high PVP was shown to correlate with increased complications and a worse overall prognosis in in patients with heart failure (14, 15). Following PVP after lung transplantation may provide a relatively simple parameter to follow in comparison to the complete venous Doppler exam. Doppler assessment of PVP changes in our cohort appears to have physiologic feasibility, and further research is needed to elucidate its clinical use in the post-operative lung transplant population.

Another key factor worth discussion is the effect of positive pressure ventilation (PPV) on PVP and venous Doppler waveforms. PPV increases pulmonary vascular resistance, leading to increased RV afterload (16). This effect may translate further upstream in the venous vasculature and therefore affect venous Doppler waveforms. We have noted anecdotally that extubating some patients with congested venous Doppler waveforms can decrease waveform pulsatility without any other concurrent physiologic changes. Venous Doppler waveforms do not differentiate between congestion due to volume versus pressure overload states (17). In a cohort of cardiac surgery patients, portal vein congestion was associated with the use of positive pressure ventilation (18). In another cohort of cardiac surgical patients, intra-operative and post-operative PVP was higher than pre-operative PVP, as waveforms were potentially affected by PPV during their intraoperative phase of care, among other factors (15). Similarly, in our cohort, some of the changes observed between initial and final studies could reflect ventilatory transition regardless of changes in fluid balance, as all nine patients were on initially on PPV during their first venous Doppler exam, while eight were extubated breathing spontaneously during their final exam. The nature and magnitude of PPV effect on PVP and venous Doppler waveforms require further study going forward.

Other venous Doppler congestion parameters evaluated (IVC diameter, HV Doppler, RV Doppler, VExUS grade) in the study showed inconsistent changes in our patient cohort in the post-operative period. Limitations in the assessment of each parameter likely played a role and are discussed here individually.

Ultrasound assessment of the IVC has many physiological limitations, limiting its broad use as a marker of fluid balance. The main determinants of IVC size and collapsibility include not only blood volume, but also intrathoracic pressure, cardiac function, intra-abdominal pressures and IVC parietal compliance (19). Application of PEEP in intubated patients is known to decrease venous return, and CVP estimation by IVC ultrasound on mechanical ventilation is unreliable (20). Right heart dysfunction, arrhythmias and heart-lung interactions also closely affect IVC behavior as well. Elevated intra-abdominal pressure (IAP) can cause IVC collapse and limit venous return (19). Although we did not measure IAP in our post-operative lung transplant cohort, a high incidence of IAP exists in critically ill patients (21). Furthermore, the role of the IVC diameter as the 'gateway' step in the VExUS protocol may be fraught with interpretive pitfalls, as evidence of splanchnic congestion can potentially coexist with an IVC diameter measures < 2cm (19). Indeed, in this study, we did not apply the traditional VExUS score, as we elected to assess Doppler waveforms of all vessels included in the VExUS protocol even if the IVC diameter was initially < 2cm. This approach was taken as we have found in clinical practice that some patients have congested venous Doppler waveforms despite IVC size <2cm. Several of our post-operative patients had an IVC size <2cm on their final Doppler exam, yet continued to have a congested HV Doppler waveform (Figure 3). One patient who would have been classified as VExUS 0 per the original VExUS protocol, demonstrated continued portal and renal vein pulsatility on final Doppler exam (patient 8). These examples may represent instances where splanchnic congestion can coexist with an IVC diameter <2cm, potentially indicating early or subtle signs of venous congestion. Alternatively, this could potentially be explained by variations in intra-abdominal pressure between exams, IVC anatomic variation, or dynamic right heart physiologic changes after lung transplant. Regardless, this may present a limitation of the original VExUS protocol using IVC diameter as the first step, and requires further evaluation.

Compared to IVC measurements, HV Doppler waveforms, in contrast, can estimate CVP accurately in mechanically ventilated patients (20) and were reliably obtained in our patient cohort. However, HV waveforms provide insight into disorders of the right heart (22) and may not always be related to a patient's blood volume or NFB. Significant tricuspid regurgitation results in congested HV waveforms and may not represent volume-related venous congestion. Three patients in our cohort had mild-moderate or greater

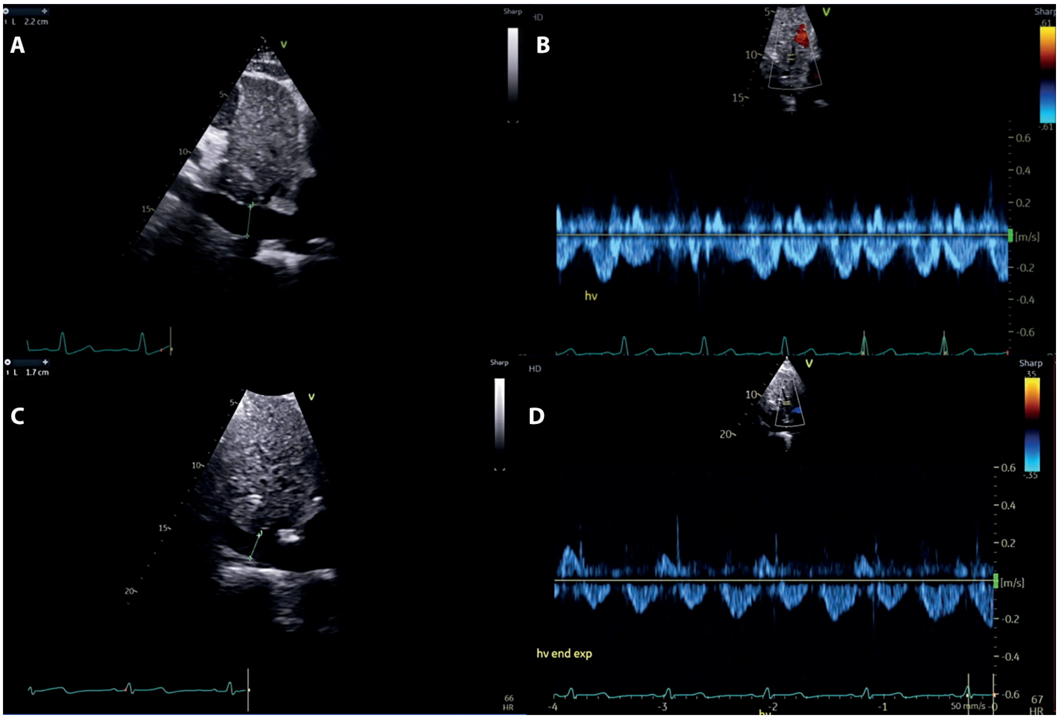

Figure 3. IVC diameter and HV waveform discordance in a representative patient. Panels A and B illustrate initial Doppler venous exam in a post-operative lung transplant patient, showing IVC diameter of 2.2 cm with diastolic predominant HV flow. Panels C and D demonstrate the final venous Doppler exam, showing an IVC diameter 1.7cm. However, diastolic predominant flow persists despite an IVC diameter <2cm.

degrees of pre-operative tricuspid regurgitation and six patients had evidence of preoperative right ventricular dysfunction. Right heart pathology is common in lung transplant candidates due to preexisting pulmonary hypertension, and although pulmonary artery pressures typically improve quickly after lung transplant, right ventricular remodeling is slower and can take months (23). This may partly explain why we did not see immediate improvement in HV waveforms in many of our patients in the post-operative period. Furthermore, in some patients with severe tricuspid regurgitation, despite aggressive diuresis, HV waveforms may remain congested, whereas PVP can still normalize (11), with one study demonstrating that PVP tracks volume removal even in severe tricuspid regurgitation (24). As an example, patient 7 in our cohort experienced normalization of PVP from initial to final exams (33.9 to 13.5%), despite HV waveforms remaining congested (D>S). From a technical standpoint, HV acquisition is also more complex, requires concurrent EKG tracing for interpretation, and can be challenging to interpret without experience.

RV Doppler evaluation has important limitations to note as well, primarily being the ability to acquire high-quality images in postoperative lung transplant patients, wherein the right flank region is commonly obscured with adjacent chest tubes and bandages. The target interlobar renal veins are small in caliber, making tracings more susceptible to respiratory motion, compared to the other venous congestion Doppler waveforms (25). A failure rate of 25% for RV Doppler acquisition has been reported (26), and in our cohort, two of the nine patients had unobtainable RV Doppler waveforms. A modified delta VExUS protocol omitting RV Doppler, but retaining the other original Doppler parameters has shown prognostic significance in the acute decompensated heart failure population, and may provide one avenue when it is difficult to obtain RV Doppler tracings (27).

Significant limitations of the study are noted. Firstly, the very small sample size does not allow conclusions to be drawn; and the results aim to be primarily descriptive in nature and hypothesis-generating. However, as a pilot study in lung transplant recipients, the feasibility and early experience data may be helpful to guide future research. Secondly, undetected factors could have contributed to a decreased PVP in our patients, including undocumented fluid output and insensible losses, which are common in ICU patients. Intake and output data was recorded from the electronic health record, which may be unreliable in the postoperative ICU setting, and weights were not included as bed weights are commonly inaccurate in the ICU setting. Furthermore, the time between initial and final venous Doppler exams was variable in our study (between 1 and 15 days, mean 5.89), as this was a retrospective data review. Prospective studies with standardized exams on specified postoperative days are necessary. There was a lack of severe congestion Doppler waveforms in our patient population. Despite significant intra-operative fluid resuscitation in most of our patients, only three out of nine patients had an initial VExUS of >1, and no patients demonstrated VExUS grade 3. This may be partly explained by restrictive fluid practices in contemporary intraoperative lung transplantation and lack of severe TR and severe RV dysfunction, although other studies of hospitalized patients also showed an overall low incidence of severe congestion via venous Doppler exams (28). Technical aspects of performing venous congestion Doppler pose challenges as well, given the multitude of surgical dressings located in the right flank region (Figure 4). We excluded three patients due to poor imaging quality or incomplete Doppler exam data. A single experienced clinician performed all the ultrasound exams in our cohort, and thus inter-rater reliability was not assessed, although this has been shown to be adequate in other studies (29). Finally, we assessed only venous congestion Doppler parameters in our cohort, while a more complete hemodynamic picture would likely be clinically useful. Future prospective studies focusing on a combination of venous Doppler waveforms, lung ultrasound B-line burden, and non-invasive estimates of left and right sided filling pressures may help paint a more useful comprehensive picture during care of the post-operative lung transplant patient.

Figure 4. Location of potential transducer placement to perform venous Doppler ultrasound assessment in an immediate post-operative lung transplant recipient. The space just below the costal margin in the mid axillary region is accessible (red asterisk), although common imaging barriers adjacent to the site are visible; a chest tube exiting the skin, diaphragmatic suture with clamp, and bandages over the surgical clamshell incision site (yellow asterisks).

Conclusions

Venous Doppler ultrasound congestion assessment appears feasible in a cohort of immediate post-operative lung transplant patients. Observations from this study may serve as a foundation for future prospective research to help delineate clinical roles of venous Doppler ultrasound in the complex hemodynamic milieu after lung transplantation surgery.

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Competing Interests: The authors declare that they have no competing interests.

Declaration on the Use of AI: No artificial intelligence tools were used in the preparation of the manuscript.

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