anesthesia research

Article

Anesthesiologists Cross the Quality Chasm with Point of Care Ultrasound (POCUS) Among Perioperative Patients

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Abstract: Background/Objective: POCUS is an invaluable tool for anatomical variation assessment, guidance of invasive interventions, and diagnosis of critical conditions that may change the anesthesiologist's plan of care. This technology increases success rate, decreases time to surgery, and maximizes outcomes. The objective of this pilot program evaluation was to identify the anesthesiologists' systems and processes for utilizing POCUS in clinical decision-making for patients during the perioperative phases of care for improved outcomes. **Materials/Methods:** A Multivariate Analysis of Variance (MANOVA) was conducted to identify differences across groups (scan type). The independent variable was the type of POCUS examination. The dependent variables included the patient's: (1) Perioperative Status; (2) Cardiothoracic Anesthesiologist's Review of Patient History and Formulating the Clinical Question; (3) Overall Risk Potential; (4) Aspiration Potential; (5) Issues Related to Cardiovascular Hemodynamics; (6) Issues Related to Volume Status; (7) Clinical Question Answered by POCUS; (8) Change in Plan of Care; (9) Interventions; and (10) Pharmacological Interventions. **Results:** MANOVA findings (Wilks' λ) identified a statistically significant interaction between POCUS scan type and the cardiothoracic anesthesiologist's clinical decision-making ($p < 0.0001$). The following four criteria were statistically significant: (1) patients (64%) were examined with POCUS preoperatively ($p < 0.05$); (2) patients (95%) identified as having some type of overall risk potential ($p < 0.05$); (3) patients (36%) specifically identified as an aspiration risk ($p < 0.0001$); and (4) patients (41%) identified with issues related to cardiovascular hemodynamics ($p < 0.001$). **Conclusions:** POCUS is a proven imaging modality that is easy, portable, sensitive, and specific for identifying various anatomical landmarks. POCUS utilization in the perioperative setting has potential to have a profound impact on successful surgical completion.

Keywords: point of care ultrasound (POCUS); overall anesthesia risk; aspiration risk; cardiac hemodynamics; interventions

Citation: Ettel, G.L., III; Hughes, J.A.; Drago, K.N.; Jotch, E.F.-J. Anesthesiologists Cross the Quality Chasm with Point of Care Ultrasound (POCUS) Among Perioperative Patients. *Anesth. Res.* **2024**, *1*, 213–226. https://doi.org/10.3390/anesthres1030020

Academic Editor: Bogdan Socea

Received: 13 September 2024
Revised: 13 October 2024
Accepted: 1 November 2024
Published: 6 December 2024

1. Introduction

POCUS has become increasingly prevalent across many medical specialties, with one such specialty being anesthesiology. While many agree that POCUS provides a tremendous potential benefit to anesthesiology, many residency programs are in the preliminary stages of implementing a formal curriculum. The lack of a national standard for competence makes training difficult, as clinical proficiency has not yet been defined [1].

A study by Ramsingh et al. identified POCUS as an invaluable tool in the assessment of anatomical variation, the guidance of invasive interventions, and the diagnosis of critical conditions that may affect the anesthetist's plan of care [2]. POCUS is a safe, inexpensive, portable, and accessible tool. In their routine practice, anesthesiologists may benefit from this fast and accurate diagnostic tool. Using POCUS provides the anesthesiologist with real-time visualization of targeted anatomical structures, visualization of medication distribution within the tissues, and additional control of the needle position. This may improve the speed, success rate, and safety of patient procedures [1].

The following literature review focuses on ten critical data elements (criteria) that were identified as areas of opportunity for utilization of POCUS in this multi-hospital healthcare system: (1) Perioperative Status of the Patient; (2) Cardiothoracic Anesthesiologist's Review of the Patient's History and Formulating the Clinical Question; (3) Overall Risk Potential; (4) Aspiration Potential; (5) Cardiovascular Hemodynamics; (6) Issues Related to Volume Status; (7) Clinical Question Answered with POCUS; (8) Change to Plan of Care; (9) Interventions; and (10) Pharmacological Interventions. These critical data elements (criteria) provided the basis for this pilot program evaluation. Thus, this literature review emphasizes the importance of each criterion.

1.1. Perioperative Status of the Patient

The criterion '***Perioperative Status***' refers to the patient's perioperative status (preoperative, intraoperative, or postoperative). POCUS allows real-time imaging at the patient's bedside, enabling rapid assessment of cardiac and pulmonary conditions. POCUS is employed preoperatively to assess cardiovascular, pulmonary, airway, and abdominal systems, which aids in identifying potential complications. It helps detect hypovolemia, left or right ventricular dysfunction, pulmonary hypertension, pleural effusions, pneumothorax, and gastric contents. Additionally, POCUS may be used preoperatively to evaluate the quadriceps and rectus femoris muscles, providing a non-invasive method to assess patients' muscle mass and frailty status [3,4].

POCUS is utilized postoperatively to monitor and manage patients by providing real-time, bedside evaluation of gastric content and volume. In emergency abdominal surgeries, gastric ultrasound (GUS) helps assess the antral cross-sectional area (CSA) to detect gastric distension, which is associated with postoperative complications like nausea, vomiting, and ileus. Postoperative nausea, vomiting, and ileus are significant issues after major digestive surgery [1]. GUS has been performed pre- and postoperatively to assess the relationship between delayed gastric emptying and postoperative adverse events. Findings showed that a dilated gastric antrum is significantly linked to postoperative complications. Sensitivity of GUS varies with surgical technique, being higher in laparoscopic surgeries. GUS could help tailor postoperative care, such as nutrition and antiemetic therapy [1].

1.2. Anesthesiologist's Review of Patent History and Formulating the Clinical Question

The criterion '***Anesthesiologist's Review of Patient History and Formulating the Clinical Question***' refers to all the critical thinking processes that the anesthesiologist conducts. These include reviewing the patient's history, physical examination, review of previous imaging, identifying potential risks, and concludes with the formation of the clinical question. The clinical question may be defined as the clinical effectiveness of sedation/anesthesia for patients undergoing a diagnostic or surgical procedure. Currently, clinical history and physical examination are considered the standard of care for the perioperative evaluation of surgical patients. With increased use, a focused POCUS examination may emerge as a standard of care [5]. It is essential that the anesthesiologist be cognizant with the limitations of POCUS in the clinical setting. For example, identification of the appropriate POCUS should be based on the patient's clinical presentation and compared with previous images. For diagnostic purposes, clinicians who understand the sensitivity and specificity of each of the POCUS applications are more likely to be successful. It is always appropriate to request assistance and archive images for comparison to avoid clinical management errors and to ensure patient safety [6].

Another bedside option is a program called Gas Uptake Simulation (GUS), which may help the identification and measurement of gastric antral cross-sectional area to provide accurate measurements of gastric volume and contents in both the supine and right lateral decubitus positions [7]. 'Frailty' is a term some medical personnel use to describe older people who are weak, underweight, and often unsteady. This is a critical risk factor for the elderly population and needs to be evaluated by the anesthesiologist, as it is associated with high morbidity and mortality rates [8,9]. For these patients, POCUS is a valuable bedside tool for decision-making in anesthesia [6]. Individual patient factors and clinical context need to be considered rather than simply treating images obtained [10].

1.3. Overall Risk Potential

The criterion '***Overall Risk Potential***' refers to any type of anesthesia risk that may be prevented by proactive interventions to provide an uneventful procedure. Frailty is a pertinent risk factor in anesthesia. There are numerous screening tools for frailty, including a variety of questionnaires, extensive geriatric assessments, and measurement of functional parameters. These tests are frequently time-consuming and difficult to perform, depending on the mental and physical state of the patient [11,12]. Co-morbid conditions can cause issues during anesthesia and may cause harm if the anesthesiologist does not account for the existing conditions. Current practice requires a pre-anesthetic workup, but oftentimes the patient will go through the workup in the surgical department instead of the anesthesiology department [13].

Additionally, pneumothorax is a potential risk that can occur during the application of anesthesia. Pneumothorax is a condition where the lung collapses due to air entering the pleural cavity, creating pressure. Anesthetic administration has been documented to cause pneumothorax due to an interpleural puncture with an anesthesia needle [14].

Hypotension, or low blood pressure, is an additional risk posed by anesthesia. Anesthetics such as propofol have been documented to cause an abrupt decrease in blood pressure. This can lead to harmful effects such as heart failure and myocardial infarction during anesthesia. Recent research has been conducted to determine whether there is an indicator of whether hypotension might occur following the application of anesthesia. This information could be used to better predict adverse reactions to anesthesia and to plan accordingly [15].

As of 2020, obesity affects an estimated 38% of the population. Obese patients have a higher risk of complications while undergoing anesthesia, specifically in relation to their respiratory system. Special care should be taken with obese patients to ensure that their overall risks are addressed [16].

Polypharmacy is the practice of taking multiple medications. This raises the issue of drug-drug interactions that may lead to harmful, unintended effects. The issue is especially high-risk when the prevalence of polypharmacy is among older, frail patients [17,18].

1.4. Aspiration Potential

The criterion '***Aspiration Potential***' refers to any type of risk specific to patient aspiration. This includes a full stomach, semaglutide medications, and gastroparesis. Aspiration risk is particularly concerning in the context of procedures performed with moderate or deep sedation without an Endo-tracheal tube (ETT), such as transesophageal echocardiograph [TEE] examinations at the bedside. Another bedside option is a program called Gas Uptake Simulation (GUS), which may be helpful for the identification and measurement of gastric antral cross-sectional area. GUS provides accurate measurements of gastric volume and contents in both the supine and right lateral decubitus positions [19].

POCUS is a valuable tool for assessing the gastric contents of patients on GLP-1 agonists before surgery to prevent aspiration. Glucagon-like peptide-1 (GLP-1) agonists, such as semaglutide (Ozempic, Wegovy), are widely used for treating type 2 diabetes mellitus, as well as obesity, due to their effectiveness in controlling postprandial glycemia and in promoting weight loss by delaying gastric emptying [20]. Recent studies and case reports have highlighted these risks, prompting new guidelines that recommend the preoperative cessation of GLP-1 agonists. GLP-1 agonists mimic endogenous incretin hormones to stimulate insulin secretion, reduce glucagon secretion, and significantly slow gastric motility. While beneficial for diabetes and obesity management, delayed gastric emptying increases aspiration risk during general anesthesia. The American Society of Anesthesiologists (ASA) has issued new guidelines recommending a preoperative hold on GLP-1 agonists, but the precise timing for cessation is not well defined. Point-of-care gastric ultrasound is an effective tool for assessing gastric content preoperatively, helping to mitigate aspiration risks by informing anesthetic management decisions [20,21].

Point-of-care gastric ultrasound (POCGUS) is used to evaluate stomach contents and volume, which influence airway management decisions. There is a plethora of evidence supporting the efficacy of POCGUS in assessing gastric contents for anesthetic management. POCUS is utilized to assess gastric fluid volume and content, primarily for evaluating the aspiration risk during sedation. This is particularly important in patients who are fasting or those for whom the fasting status is uncertain [21].

A study conducted by Asokan recommends POCGUS to assess aspiration risk in polytrauma patients undergoing emergency surgery. Many physicians use POGCUS to assess aspiration risk in traumatic surgery cases. POGCUS provides a reliable, real-time assessment of gastric content. Improved patient outcomes in emergency trauma surgeries confirm that it is a valuable tool for managing aspiration risks in polytrauma patients [22].

1.5. Issues Related to Cardiovascular Hemodynamics

The criterion '***Cardiovascular Hemodynamics***' refers to issues related to cardiovascular hemodynamics, including valve disease, shock, cardiac tamponade, and low ejection fraction. Evidence supports that Lung ultrasound (LUS) has greater sensitivity and specificity for certain lung conditions when compared to the traditional chest x-ray (CXR). Some of the most common lung conditions include pneumothorax (PTX), pulmonary edema (PE), lung consolidation, and pleural effusion (PE) [6].

Protocols like RUSH (Rapid Ultrasound in Shock) and SHoC (Shock Protocols) guide ultrasound examinations by focusing on different aspects of shock. The RUSH protocol, for instance, assesses the cardiac, abdominal, and venous systems to determine the shock type. The SHoC protocol adapts to the patient's clinical presentation through targeted ultrasound views to confirm tamponade. These views help detect pericardial effusion and signs of tamponade, such as diastolic collapse of the right ventricle and inferior vena cava changes [23].

POCUS plays a critical role in managing traumatic cardiac arrest (TCA). For instance, POCUS can quickly determine residual cardiac activity. Absence of cardiac motion often indicates a poor prognosis and a high likelihood of death. The presence of cardiac activity, even if minimal, may suggest some level of cardiac output, which can influence the decision to continue or modify resuscitation efforts. POCUS can forecast poor outcomes, including failure to achieve return of spontaneous circulation (ROSC), survival to hospital admission (SHA), survival to hospital discharge (SHD), and neurologically intact survival to hospital discharge (NISHD) [24].

POCUS is a valuable tool for accurately assessing heart failure (HF) due to its ability to provide real-time information on fluid status and cardiac function. Cardiac ultrasound evaluates the heart's pump function, focusing on parameters like left ventricular ejection fraction (LVEF), ventricular sizes, and wall motion abnormalities. POCUS offers a comprehensive, non-invasive approach to assessing heart failure. From cardiac function and fluid volume status to the impact on other organ systems, this informs clinical decisions for improved outcomes [25].

POCUS is increasingly recognized as a vital tool in the evaluation of hemodynamic status, particularly in critically ill patients. POCUS provides immediate visual feedback of anatomy and hemodynamic parameters, allowing clinicians to assess heart function, fluid status, and vascular dynamics. Doppler ultrasonography assesses blood flow patterns in veins like the inferior vena cava (IVC), hepatic vein (HV), portal vein (PV), and renal veins. Doppler ultrasound is a valuable tool for assessing venous congestion and its impact on organ function, especially in patients with heart failure or volume overload [26].

1.6. Issues Related to Volume Status

The criterion '***Volume Status***' refers to risks related to the patient's circulating blood volume (hypo/hypervolemia). Hemorrhage is a result of a ruptured blood vessel, which can result in large quantities of blood leaving the body. This leads to complications such as hypotension and organ failure, resulting in death if left untreated. Hemostatic powders and hydrogels are two common noncompressible hemorrhage treatments. New technologies include injectable, expanding hemostats such as ResQFoam and XStat. There are drawbacks such as the fact that they are both nondegradable, with the ResQFoam requiring surgical removal. They also require more time to take effect, which can lead to additional blood loss [27].

Hemorrhages are also treated by replacing the fluid that was lost in the blood with crystalloid fluid. Crystalloids maintain blood volume by expanding the blood already present [28]. Blood transfusions are common during cardiac surgery, but are associated with complications such as immunomodulation, acute lung injury, and infection. One potential workaround in the usage of autologous blood removal. Vasopressors can also be used alongside autologous blood removal. A retrospective study has shown that usage of autologous transfusion without fluid replacement can decrease the need for potentially harmful homologous transfusions [29].

POCUS is increasingly used to assess volume status in patients. A specific procedure called internal jugular vein ultrasound (IJV-US) is performed when assessing hypovolemia. In this test, the collapsibility of the internal jugular vein (IJV) during respiration is a key indicator. In hypovolemic patients, the IJV tends to collapse more readily with each breath due to reduced intravascular volume. A higher collapsibility index suggests hypovolemia. Although less sensitive, measuring the static diameter of the IJV can also provide information. A small or non-collapsing IJV may suggest reduced central venous pressure and hypovolemia. In hypervolemic patients, the IJV is less likely to collapse and may appear distended. Measuring the height of the IJV (distance from the sternal angle) can provide an indication of elevated central venous pressure and volume overload. The cross-sectional area of the IJV can also be used. An enlarged cross-sectional area might suggest hypervolemia [30].

Hyponatremia, characterized by decreased plasma sodium concentration, is a multifactorial disorder that can lead to serious health issues. Diagnosing the underlying cause often requires assessment of extracellular volume (ECV). Traditionally, this relies on clinical history, vital signs, and laboratory tests. However, these methods can be imprecise, leading to misdiagnosis and inappropriate treatment. POCUS has emerged as a valuable tool in this context. By combining Lung Ultrasound (LUS), Venous Excess Ultrasound (VExUS), and Focused Cardiac Ultrasound (FoCUS), POCUS offers a comprehensive and accurate assessment of the patient's ECV. LUS identifies pleural effusions and B-lines to indicate fluid overload or lung congestion. VExUS evaluates venous congestion and assesses the diameter and collapsibility of the inferior vena cava (IVC), providing insights into the presence of venous excess. FoCUS, on the other hand, assesses cardiac function, including stroke volume and cardiac output, which are critical in understanding the fluid status and potential heart failure [31].

POCUS can aid significantly in diagnosing congestive heart failure (CHF) by evaluating various aspects of heart function and volume status. The IVC is a major vein returning blood to the heart. By measuring the IVC diameter and its collapsibility index (IVC-CI), clinicians can infer the patient's volume status. An enlarged IVC or low IVC-CI often indicates fluid overload, which is common in CHF. POCUS can estimate the left ventricular ejection fraction (LVEF) by visualizing the heart's chambers and assessing their movement. Reduced EF is a hallmark of systolic heart failure. POCUS utilization may assist in diagnosing and managing heart failure (HF), focusing particularly on the measurement of the inferior vena cava (IVC) as a central aspect [32].

POCUS is comparable or superior to traditional markers like proBNP in predicting outcomes. Incorporating POCUS, especially with IVC measurements, into standard care practices can improve HF management both in the emergency department and in outpatient and inpatient settings. In sum, POCUS is a quick, non-invasive tool that can enhance diagnosis, monitor treatment, and predict outcomes in HF patients [33].

1.7. POCUS Scan Answered Clinical Question

The criterion '***POCUS Scan Answered Clinical Question***' refers to whether the POCUS examination correctly answered the question posed. Clinical questions are healthcare issues that might need to be addressed for the patient. The portability of POCUS allows it to be used at the bedside, which could make diagnosis faster than X-Rays or CT scans. Thoracentesis was found to have a high number needed to scan with a range of 19 to 63. Avoiding complications confers a significant reduction in morbidity and avoids the need for additional procedures [34]. Evaluating the hemodynamic status of the patient through POCUS alongside basic evaluation can allow for a more complete evaluation of the patient's condition [35]. POCUS also has applications in neurosonology, which is the usage of ultrasound exams in the field of neurology. In events when the patient requires urgent diagnosis, such as in strokes, POCUS could be applied. POCUS can monitor the arterial recanalization, or reopening of the artery, in acute ischemic stroke patients. Usage in neurosonology is indicated to improve outcomes after stroke. POCUS can also be used on patients with acute neurological degradation, which can detect conditions that cause the degradation [36].

1.8. Changes to Overall Plan of Care

The criterion '***Change to Overall Plan of Care***' refers to any change in the patient's clinical management, including case cancellation. In one study, the examinations performed by cardiac anesthesiologists with formal transthoracic echocardiography (TTE) training were assigned for any required TTE duties that day. Substantial changes (84%) in patient management included: (1) obtaining a formal TTE; (2) addition or avoidance of invasive monitoring; (3) fluid or vasopressor administration; (4) changes in disposition; (5) change in anesthetic location; or (6) cancellation of case. While only TTE was performed, other examinations may be administered, including gastric, lung, and FAST [22].

Another study by Thanasriphakdeekul et al. examined the impact of the anesthesiologist performing a TTE in the preoperative clinic. In this study, one hundred patients who were suspected of having significant cardiovascular diseases had a TTE performed. They noted that the anesthetic plan changed in fifty-four patients, resulting in a step up in treatment in twenty patients and a step down in treatment in thirty-four patients. While cardiologists validated these examinations, this demonstrates the ability of anesthesiologists to detect significant hemodynamic diseases and alter the anesthetic management as a result [37].

1.9. Interventions

The criterion '***Interventions***' refers to the interventions made for the patient after reviewing the POCUS results. These included nasogastric tube insertion, insertion of a foley catheter, rapid sequence intubation, fluid management, or pharmacology such as inotropes. Evidence suggests that abnormal lung ultrasound findings among intensive care unit (ICU) patients post major surgery are associated with pulmonary complications. Detection of complications may predict the need for postoperative ventilatory support. POCUS has shown to be beneficial for patients and multi-disciplinary teams by creating opportunities for early interventions, improved clinical outcomes, decreased length of stay, and cost-effectively reducing medical referrals, and high-value tests and procedures [38].

Foley catheters drain urine from the bladder through the urethra and rarely result in bladder rupture. One study identified a patient with a ruptured bladder caused by a foley insertion that was detected by POCUS. In this case, POCUS helped obtain a diagnosis quickly and guided the clinical intervention [39].

Central venous catheter placement is another technique that may be aided by POCUS. Central venous catheters are often used to infuse fluids and nutrients into preterm infants. Improper central line tip placement is common and can lead to medical complications, creating a need to verify that the line is correctly placed. Amer (2023) reported that usage of POCUS to detect improper central line tip position has a sensitivity of 83% and a specificity of 96%. This indicates that POCUS could be used as a reliable tool to verify that venous catheters are properly inserted, ensuring that the intervention was performed correctly [40].

1.10. Pharmacological Interventions

The criterion '***Pharmacological Interventions***' refers to the administration of medications in general and specifically with the initiation/increase of inotropic medications.

Highly skilled anesthesiologists utilize transesophageal echocardiography (TEE) in the cardiothoracic surgical suite. This expertise has not been extended to other perioperative settings due to the limitations of placing these probes, compounded by the need for specialized training. Recently, attention has been placed on whole body POCUS in daily anesthesia practice as an adjunct diagnostic tool. This use may aid the anesthesiologist in identifying causes in rapid changes in hemodynamic status [21].

When the patient is not intubated, or there is a contraindication to TEE, transthoracic echocardiography (TTE), a form of POCUS, may aid the evaluation of hemodynamic and volume status. In high-risk patients with established cardiovascular pathology, TTE may be an extension of the physical examination for monitoring the status of cardiac structures and cardiovascular diseases. TTE utilization allows for real time feedback and diagnosis of cardiovascular pathology and hemodynamics. This information is critical for decisions regarding pharmacologic interventions, such as inotropic medications, vasopressor infusions, and intravenous fluids [41].

2. Materials and Methods

Initially, students and faculty at the University of South Florida's Honors College met with a cardiothoracic anesthesiologist from a 479-bed, acute care facility that is within a multi-hospital system in the southeastern United States. A partnership was formed for a pilot program evaluation of POCUS utilization among anesthesiologists.

2.1. Population Demographics

The sample (n = 22) was limited to a retrospective review of discharged patients who had a POCUS examination during their perioperative period.

The population was obtained by a convenience sample of every patient who had a POCUS examination by the supporting cardiothoracic anesthesiologist over a four-month period. Patients who did not need a POCUS examination were excluded. The cardiothoracic anesthesiologist provided these redacted data for analysis. No additional data are available.

These discharged patients included the following patient demographics: (1) young adult patients (n = 5); (2) adult patients (n = 11); (3) elderly patients (n = 5); and (4) pediatric patients (n = 1). The providing cardiothoracic anesthesiologist defined the following age groups for analysis: Pediatric patients ranged from two to eighteen (2–18) years of age; Young adult patients ranged from nineteen to twenty-nine (19–29) years of age; Adult patients ranged from thirty to sixty-nine (30–69) years of age; Elderly patients were greater than seventy (>70) years of age. Half of the data were from male (50%) patients. The breakdown of the patient's phase of perioperative care was: Preoperative (64%); Intraoperative (4%); and Postoperative (32%).

2.2. Treatment of These Data

Prior to this pilot program evaluation, a task force was convened to review the tool for appropriateness and use. All experts received a copy of the tool. After the panel sufficiently reviewed the material, the members discussed the strengths and weaknesses of the criteria.

Members of the panel deemed that the criteria were appropriate, supporting the claim for content validity.

Ten critical data elements (CDE) were identified and examined: (1) Perioperative Status; (2) Cardiothoracic Anesthesiologist's Review of Patient History and Formulating the Clinical Question; (3) Overall Risk Potential; (4) Aspiration Potential; (5) Issues Related to Cardiovascular Hemodynamics; (6) Issues Related to Volume Status; (7) Clinical Question Answered by POCUS; (8) Change in Plan of Care; (9) Interventions; and (10) Pharmacological Interventions.

The data collection procedure included a retrospective review of information collected in an Excel spreadsheet by the attending cardiothoracic anesthesiologist. This spreadsheet listed the previously described CDE. Separate team members double-verified data to ensure accuracy. All analyses were computed in SAS (9.4) Cary, North Carolina. Statistical significance was considered when $p < 0.05$.

2.3. Institutional Review Board

This quality improvement project was not classified as "research" according to 45 CFR 46; thus, this project did not fall within the scope of IRB. Nonetheless, collected data were non-identifiable and known risks to patients were minimal.

2.4. Statisitcal Analyses

A quantitative, causal, comparative approach identified differences across groups (scan type). The independent variable was the type of POCUS scan the patient received during the perioperative period. The dependent variables were the cardiothoracic anesthesiologist's clinical assessments and decision-making processes, as measured by the ten CDE. A Multivariate Analysis of Variance (MANOVA) was conducted to compare differences across groups. For significant findings, Univariate Analysis of Variance (ANOVA) contrasts were conducted on each dependent variable.

3. Results

Descriptive statistics were calculated and are visually displayed in Table 1. There were statistically significant findings (Wilks' λ) between scan type and clinical decision-making ($p < 0.0001$). After rejecting the null hypothesis, univariate Analysis of Variance (ANOVA) contrasts were conducted on each of the ten CDE. The following four CDE were found to be statistically significant: (1) Perioperative Status of the Patient; (2) Overall Risk Potential; (3) Aspiration Risk; and (4) Cardiovascular Hemodynamics.

Table 1. Summary statistics of all scan types, presented as proportions.

	GU		Cardio		Gastric		Pulmonary	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Pre-Op	0.00	0.00	0.44	0.53	1.00	0.00	0.67	0.58
Clinical Q/Hx	0.00	0.00	0.78	0.44	0.63	0.52	0.67	0.58
Overall Risk	0.50	0.71	1.00	0.00	1.00	0.00	1.00	0.00
Aspiration	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Hemodynamics	0.00	0.00	0.78	0.44	0.00	0.00	0.67	0.58
Volume Status	0.00	0.00	0.44	0.53	0.00	0.00	0.00	0.00
Scan Answered	1.00	0.00	1.00	0.00	0.88	0.35	1.00	0.00
Change POC	0.50	0.71	0.22	0.44	0.50	0.53	0.33	0.58
Intervention	1.00	0.00	0.67	0.50	0.50	0.53	0.33	0.58
Inotropic meds	0.00	0.00	0.22	0.44	0.00	0.00	0.00	0.00

3.1. Perioperative Status

For the criterion '***Perioperative Status of the Patients***', over half of the patients (64%) received scans during the pre-operative stage. Differences by scan type showed that patients in the pre-operative stage were more likely to undergo a GI scan (100%) than

Pulmonary (66%), Cardiac (45%), or GU (0%) scans ($p < 0.05$). For the purposes of the results section, "scan" refers to the respective POCUS type.

There were eight (8) patients who had a GI POCUS scan performed by the cardiothoracic anesthesiologist:

- The first patient was a young adult male with a history of gastroparesis and morbid obesity. Despite the completion of GI scan, the results were unacceptable due to the patient's obesity. This patient's plan of care was changed to include rapid sequence intubation, and surgery proceeded uneventfully.
- The second patient was an adult male. He was diagnosed with a small bowel obstruction and received a GI scan to rule out a full stomach. The scan found the patient's gastric contents to be over 800 mL. Based on this real-time information, the cardiothoracic anesthesiologist performed a pre-induction nasogastric tube (NG) to prevent aspiration. Similarly, this case was uneventful
- The third patient was an adult male with a history of severe gastroparesis. Like with the second patient, the cardiothoracic anesthesiologist performed a GI scan to rule out a full stomach. Results showed an empty stomach, and the surgery was uneventful.
- The fourth patient was a young adult female. She also received a gastric scan to rule out a full stomach. The scan revealed an empty stomach, and the surgery was uneventful.
- The fifth patient was a young male. The cardiothoracic anesthesiologist performed a GI scan to rule out a full stomach for an elective procedure. The scan revealed considerable amounts of liquid and solids. In this case, the surgery was cancelled and rescheduled.
- The sixth patient was a young adult female. Five hours prior, a CT scan showed a full stomach with considerable liquid. The scan confirmed there was still considerable stomach content, and an NG tube was placed, and the surgical course was uneventful.
- The seventh patient had ongoing gastro-enteritis with nausea. The cardiothoracic anesthesiologist performed a GI scan to rule out a full stomach. Results identified minimal to moderate fluid in the stomach. As a result, the anesthetic plan changed from sedation to rapid sequence intubation (RSI).
- The eighth patient was an adult female who presented with an acute abdomen. The cardiothoracic anesthesiologist performed a GI scan to rule out a full stomach. Findings showed an empty stomach, which allowed this patient to undergo surgery faster.

There were four (4) patients who had a Cardiac POCUS scan performed preoperatively:

- The first patient was an elderly adult female who required valve surgery. The cardiothoracic anesthesiologist performed a Cardiac TEE to rule out aortic stenosis. The scan showed aortic valve sclerosis without stenosis. This patient moved to surgery faster, and the case was successfully completed.
- The second patient was an adult female with multiple comorbidities, including ischemic cardiomyopathy and diabetes. This patient also presented with urosepsis. The cardiothoracic anesthesiologist also performed a Cardiac TEE, which showed a combination of septic and cardiogenic shock. Full preparation for aggressive pressor and inotropic support were initiated. The subsequent surgery proceeded uneventfully.
- The third patient was a pediatric male with a parental history of obstructive cardiomyopathy. The cardiothoracic anesthesiologist performed a cardiac scan to rule out cardiomyopathy. The scan results were normal.
- The fourth patient was an elderly male with a bowel perforation and septic shock. The cardiothoracic anesthesiologist performed a Cardiac TEE to assess volume status. Results showed a severely reduced preload. The resulting anesthetic plan of care consisted of aggressive hydration prior to induction.

There were two (2) patients who had both Cardiac and Pulmonary POCUS scans:

- The first patient was a young adult male. These scans assessed fluid status related to congestive heart failure (CHF). Results revealed no pleural effusions and the surgery was uneventful.
- The second patient was an adult male with decompensated CHF. The cardiothoracic anesthesiologist noted that the patient was severely dyspneic and orthopneic during the preoperative evaluation. The examinations revealed large, bilateral, pleural effusions. The patient underwent emergency surgery. The anesthetic plan included fluid restriction and diuretics. Refer to Figure 1.

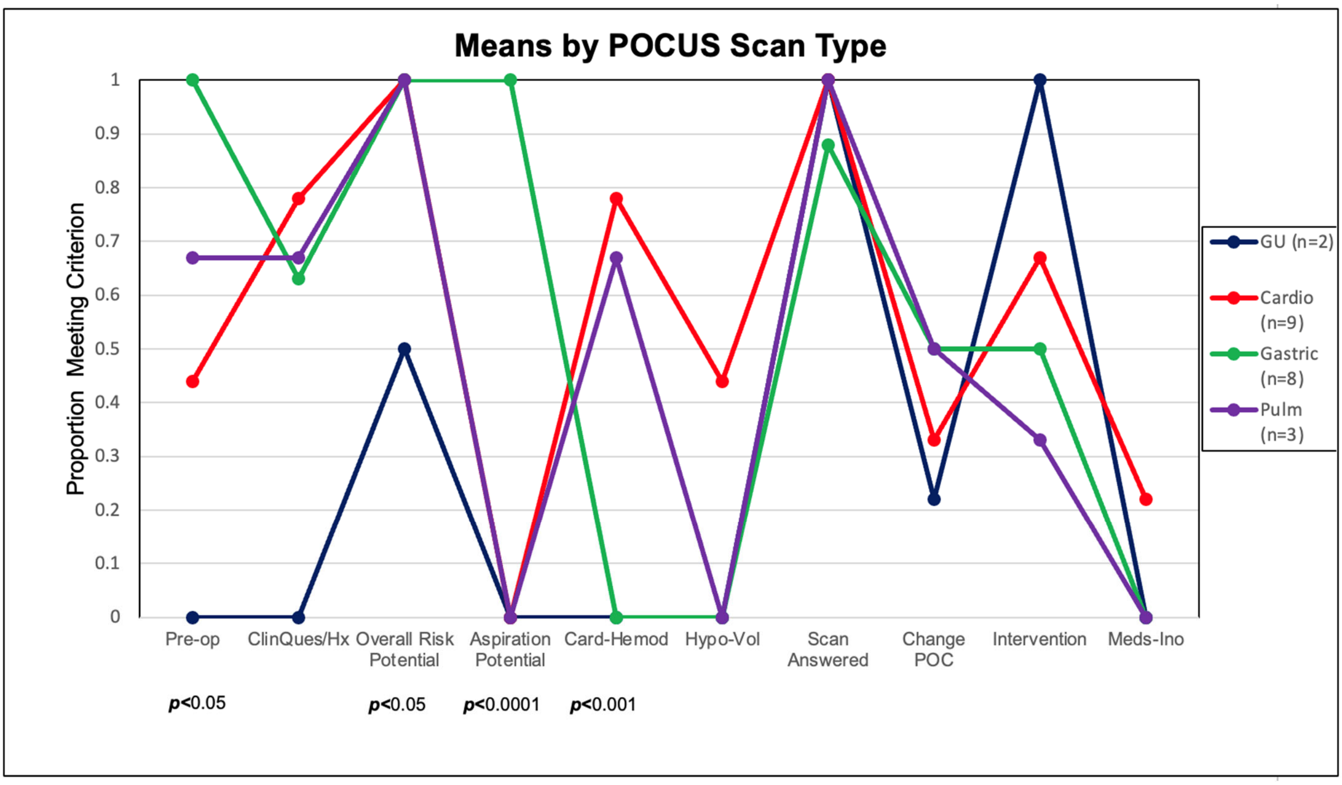

Figure 1. Means by POCUS Scan Type.

3.2. Overall Risk Potential

For the criterion '***Overall Risk Potential***', most patients (95%) possessed some type of overall risk. As described above, all the patients who underwent POCUS pre-operatively were the same patients identified to have some type of 'overall risk'. Of those, differences by scan type showed that patients were more likely to have a GI/Cardiac/Pulmonary scan (100%) than a GU scan (50%) post-operatively ($p < 0.05$). Refer to Figure 1.

3.3. Aspiration Potential

For the criterion '***Aspiration Potential***', the cardiothoracic anesthesiologist identified around one-third of patients (36%) as being at risk for aspiration specifically ($p < 0.0001$). In this pilot program evaluation, only three patients received a pulmonary POCUS scan. The first two patients were those also identified and discussed above in both Criterion 1 and Criterion 3.

The third patient had a pulmonary scan performed by the cardiothoracic anesthesiologist during the intraoperative phase. This adult female patient had a sudden rise in inspiratory pressures. The cardiothoracic anesthesiologist immediately performed a pulmonary scan to rule out a pneumothorax. Fortunately, the scan was normal, and the case was completed uneventfully. Refer to Figure 1.

3.4. Cardiovascular Hemodynamics

For the criterion '***Cardiovascular Hemodynamics***', less than half of the patients (41%) were identified with issues related to cardiovascular hemodynamics. There were only nine (9) patients who underwent Cardiac POCUS examinations ($\boldsymbol{p} < 0.001$). Of those, differences by scan type showed that patients who had potential for cardiovascular hemodynamic complications either had a Cardiac scan (78%) or both Cardiac and Pulmonary (67%) scans ($\boldsymbol{p} < 0.001$). The first six patients were identified and discussed in Criterion 1. The remaining three patients received a Cardiac scan during the post-operative phase:

- The first patient was an adult female with postoperative hypotension. Major findings included hyperdynamic systolic function with a severely underfilled heart. Interventions included volume replacement, and the surgery was uneventful.
- The second patient was an elderly female, post coronary artery bypass graft (CABG) with an etiology of hypotension. A Cardiac TEE was performed to rule out cardiac tamponade. Fortunately, the scan was normal. Increased inotropic agents and pressure support helped the patient's course.
- The last patient was an adult male with post operative hypotension and an ongoing urinary tract infection. A cardiac scan was performed with normal results. The patient remained on pressor agents. The hypotension was likely due to vasodilatory shock. Refer to Figure 1.

4. Discussion

This pilot program evaluated the utility of POCUS in anesthesiology. ANOVA contrasts found significance in the following variables: (1) Perioperative status of the patient; (2) Overall risk potential; (3) aspiration risk; and (4) cardiovascular hemodynamics. In the present study, preoperative POCUS examination identified gastric contents, reduced cardiovascular load, pleural effusions, and causes related to hypotension. At the preoperative stage, POCUS prevented risky procedures from proceeding. Additionally, the cardiothoracic anesthesiologist implemented measures such as NG tubes, RSI, and volume replacement at various stages to increase patient safety. In the gastric realm, POCUS provided an additional layer of airway protection. The ability to assess gastric contents prior to anesthesia reduced aspiration risk in patients with delayed gastric emptying, or with unknown fasting times. From the cardiovascular perspective, POCUS provided real-time data on cardiac function and volume status. This allowed the cardiothoracic anesthesiologist to initiate intravenous fluids and pressure support for patients at risk. Additionally, POCUS enabled the cardiothoracic anesthesiologist to examine a potential pneumothorax in patients who displayed respiratory distress. At this facility, this study found that POCUS examination throughout the perioperative phases translated into enhanced patient safety and improved postoperative outcomes.

A prior study by Ramsingh et al. [1] explored the utility of POCUS in the post-anesthesia care unit (PACU). Like the present study, Ramsingh et al. identified hypovolemia, reduced ejection fraction, and pleural effusions through cardiac and pulmonary POCUS scans. Unlike Ramsingh et al., the present study did not measure length of stay as a dependent variable. Rather, the present study was exploratory, with the ten CDE designed to identify the most significant areas in which POCUS may be utilized. The results from the present study indicate that further research into POCUS for reduced aspiration risk and for comprehensive hemodynamic assessment is warranted. Areas of future research for POCUS examinations in the perioperative setting require healthcare systems to assess issues of timeliness of information exchanges, human resources, cost, technology, interdisciplinary involvement, and reimbursement. Answering these questions would allow anesthesiologists to assume a key role by providing essential health information required for quality patient care.

This pilot program evaluation has limitations related to methodological bias. First, we studied patients from a single, secular regional hospital in the southeastern United States. The patients seen at this hospital do not represent the patient population at large.

Second, due to the small sample size of patients, the authors are reluctant to infer that these findings are generalizable. Third, sampling was non-random and limited to the patients seen by a single cardiothoracic anesthesiologist. Despite these limitations, the present study supported POCUS as an essential tool for improved safety and outcomes in anesthesia.

5. Conclusions

A system of reliable and accurate POCUS resources may improve issues relating to healthcare quality, safety, and efficiency. The certifying body for anesthesiology, the American Board of Anesthesiology (ABA), includes POCUS on the content outline for certification in anesthesiology. Furthermore, content on POCUS is tested on the applied examination [2]. The American Society of Anesthesiology (ASA) has also introduced a diagnostic POCUS course. This course features lung, gastric, cardiac, and Focused Assessment with Sonography for Trauma (FAST) examinations [42]. The addition of anesthesiologists trained in POCUS could expand residency training through a focus on clinical applications. This initiative could offer POCUS expertise to all providers, thus benefitting patients. Meanwhile, providers who are not formally trained in POCUS could improve their skillset. Thus, the importance of POCUS skills has been established, but the path to get there has not.

All in all, POCUS is a proven imaging modality that is easy to use, sensitive, and specific for the identification of multiple anatomical landmarks, conditions, and pathologies. Evidence shows that this tool progresses patients to surgery faster and decreases the need for CT scans in trauma patients. POCUS is beneficial for patients and multi-disciplinary teams by aligning opportunities for early interventions, improving clinical outcomes, decreasing lengths of stay, and reducing the costs of medical referrals, high-value tests, and procedures. POCUS enables the anesthesiologist to act during the management of various emergencies and redirect the patient's plan of care.

Author Contributions: Conceptualization, G.L.E.III and J.A.H.; methodology, G.L.E.III, J.A.H., K.N.D. and E.F.-J.J.; software, G.L.E.III, J.A.H., K.N.D. and E.F.-J.J.; validation, G.L.E.III, J.A.H., K.N.D. and E.F.-J.J.; formal analysis, G.L.E.III, J.A.H., K.N.D. and E.F.-J.J.; investigation, G.L.E.III, J.A.H., K.N.D. and E.F.-J.J.; resources, G.L.E.III, J.A.H., K.N.D. and E.F.-J.J.; data curation, G.L.E.III, J.A.H., K.N.D. and E.F.-J.J.; writing—original draft preparation, G.L.E.III, J.A.H., K.N.D. and E.F.-J.J.; writing—review and editing, G.L.E.III, J.A.H., K.N.D. and E.F.-J.J.; visualization, G.L.E.III, J.A.H., K.N.D. and E.F.-J.J.; supervision, G.L.E.III, J.A.H., K.N.D. and E.F.-J.J.; project administration, G.L.E.III, J.A.H., K.N.D. and E.F.-J.J.; funding acquisition, not applicable. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that supports the findings of this study are available from the corresponding author, K.N.D., upon reasonable request.

Acknowledgments: This manuscript is dedicated to Robert J Rosen, who practices the science of the anesthesiology discipline with the magnificence of its art.

Conflicts of Interest: The authors declare no conflicts of interest.

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