SYSTEMATIC REVIEW ARTICLE

CME

Intraoperative Focused Cardiac Ultrasound for Assessment of Hypotension: A Systematic Review

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Focused cardiac ultrasound (FoCUS) has become a valuable tool to assess unexplained hypotension in critically ill patients. Due to increasing availability of transthoracic echocardiography (TTE) equipment in the operating room, there is a widespread interest in its usefulness for intraoperative diagnosis of hypotension as an alternative to transesophageal echocardiography (TEE). The objective of this systematic review is to evaluate the utility of intraoperative FoCUS to assess patients experiencing unexplained hypotension while undergoing noncardiac surgery. We performed a systematic literature search of multiple publication databases for studies that evaluated the utility of intraoperative FoCUS for assessment and management of unexplained hypotension in patients undergoing noncardiac surgery, including retro- and prospective clinical studies. A summary of the study findings, study quality, and assessment of level of evidence is presented. We identified 2227 unique articles from the literature search, of which 27 were potentially relevant, and 9 were included in this review. The number of patients pooled from these studies was 255, of whom 228 had intraoperative diagnoses with the aid of intraoperative FoCUS. The level of evidence of all studies included was very low according to the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) guidelines. This systematic review has demonstrated that FoCUS may be a useful, noninvasive method to differentiate causes of intraoperative hypotension and guide correcting interventions, although the quality of evidence is very low. Further prospective high-quality studies are needed to investigate whether intraoperative FoCUS has a diagnostic utility that is associated with improved outcomes. (Anesth Analg 2021;133:852–9)

GLOSSARY

CI = confidence interval; **ED** = emergency department; **FoCUS** = focused cardiac ultrasound; **GRADE** = Grading of Recommendations Assessment, Development, and Evaluation; **ICU** = intensive care unit; **MeSH** = Medical Subject Headings; **PICO** = Population, Intervention, Comparison, and Outcomes; **PRISMA** = Preferred Reporting Items For Systematic Reviews and Meta-Analysis; **PROSPERO** = International Prospective Registry of Systematic Reviews; **SD** = standard deviation; **QUADAS-2** = Quality Assessment of Diagnostic Accuracy Studies-2; **RCT** = randomized controlled trials; **TEE** = transesophageal echocardiography; **TTE** = transthoracic echocardiography

Transthoracic echocardiography (TTE) is a noninvasive and portable technology used for assessment of cardiopulmonary pathophysiology states by the bedside physician and has the ability to improve outcomes in critically ill and surgical patients. The use of focused cardiac ultrasound (FoCUS) for cardiovascular evaluation has gained a broad adoption in the emergency department (ED) and intensive care unit (ICU).[1–3] A FoCUS examination can be rapidly performed by a noncardiologist with proper training and competency to diagnose and manage unstable patients in the ICU and ED.[4–6] Over the last decade, there has been a rising interest to incorporate this modality into the perioperative arena. Notably, it has been described that preoperative FoCUS examination by anesthesiologists has good interoperator reproducibility and may alter anesthetic management.[7,8]

It is paramount to distinguish the difference between FoCUS and focused TTE. The former entails a qualitative ultrasound assessment of the heart, performed and interpreted immediately, is goal-directed, performed using simple equipment and imaging modes, and involves a limited number of views for limited pathologies. In contrast, focused TTE encompasses a

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quantitative assessment of the heart, is more comprehensive, requires different imaging modes and more advanced equipment, and is not interpreted at the bedside by the operator, but separately.[9,10]

Historically, transesophageal echocardiography (TEE) has been used for intraoperative assessment of unexplained hypotension, also referred to as hemodynamic instability. Such "rescue echo" was applied initially for patients undergoing cardiac surgery, but subsequently has been expanded to use in noncardiac cases.[11–14] Intraoperative TEE in noncardiac cases has been reported to identify new findings in patients at high cardiac risk and to direct perioperative management changes.[15] However, a recent systematic review of effectiveness and harms of TEE for noncardiac surgery questions the expanded use of TEE as an intraoperative monitor as outcomes benefit compared to other monitoring modalities is not well supported.[16]

FoCUS is already common for assessment of unstable patients in the ED and ICU setting, hence support for its use as an intraoperative modality has started to emerge. We conducted a systematic review of the literature to assess utility of intraoperative FoCUS for diagnosis and management of unexplained hypotension in patients undergoing noncardiac surgery.

METHODS

Study Design and Literature Search

Expert recommendations were followed to conduct this systematic review,[17] and it is in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement. A computerized search of electronic databases PubMed, MEDLINE (Ovid), EMBASE, Cochrane CENTRAL, Scopus, CINAHL, and WHO PAHO (VHL) was performed since the beginning date of databases to the date of search (ie, October 2019). A protocol for the review was registered in the International Prospective Registry of Systematic Reviews (PROSPERO) under the ID: CRD42020154825. Studies cited in a previous systematic review on a related topic were incorporated into the development of the search strategy and the authors were contacted for details of their strategies.[18]

The search strategy was developed by an academic health science librarian (J.R.) in consultation with members of the project team (J.R.N.-B. and J.L.) and was reviewed using the Peer Review for Electronic Search Strategies tool.[19] The search strategy was written for Ovid MEDLINE and translated using each database's syntax, controlled vocabulary, and search fields. Medical Subject Headings (MeSH) terms, EMTREE terms, CINAHL headings, and text words were used for the search concepts of point-of-care TTE, hemodynamic instability, and their synonyms.

The following MeSH terms were used in various combinations: "transthoracic echocardiography" ("TTE"), "perioperative care," "intraoperative care," "assessment," "cardiac," "ultrasound," "diagnosis," "point-of-care," "hemodynamic monitoring," "noncardiac surgery," "low left ventricular ejection fraction," "intracardiac air," "thrombus," "pulmonary embolus," "left Segmental Wall Motion Abnormality," "pulmonary embolism," "aortic valve disease," "mitral valve disease," "right ventricular failure," "pericardial effusion," "left ventricular outflow tract obstruction," and "systolic anterior motion of the mitral valve." For a full search strategy, see Supplemental Digital Content, Appendix 1, http://links.lww.com/AA/D295.

After the initial search, the academic health science librarian (J.R.) removed all duplicate studies and uploaded the results into an electronic repository (Covidence Software, Melbourne, Australia) for further screening. We only included studies focused on the use of FoCUS intraoperatively during unexplained hypotension, restricted to the adult human population (ie, ≥18 years old), and written in English. The summary of the study flow according to the PRISMA statement is presented in the Figure.

Selection Criteria

Two reviewers (J.R.N.-B. and J.L.) independently reviewed all citations. The Population, Intervention, Comparison, and Outcomes (PICO) framework was used to determine selection criteria focused to answer the main research questions: (1) Can FoCUS examination be performed intraoperatively during episodes of unexplained hypotension? This was expressed by the feasibility rate (defined as the number of times [expressed in percentage] that an acceptable quality image was obtained and allowed interpretation by the anesthesiologist). (2) Can anesthesiologist with the aid of FoCUS determine the cause of the unexplained hypotension and guide corrective intervention? This was expressed by the echocardiographic diagnoses of hypotension and the number of changes in management triggered subsequently. Relevant abstracts were evaluated independently and if there was a doubt regarding the relevance of the article, the full text was assessed. Additional references were screened for further articles not identified by the initial database search. Discrepancies were settled by discussion and consensus among both reviewers, and a third reviewer (R.D.) was contacted to adjudicate any disputes in interpretation. Case reports, case series, review articles, commentaries, abstracts, letter to the editor, and editorials were excluded.

Subsequently, a study quality assessment was performed by the same reviewers using the Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) critical appraisal tool.[20,21] The authors recognize that systematic reviews are best performed including randomized controlled trials (RCT);

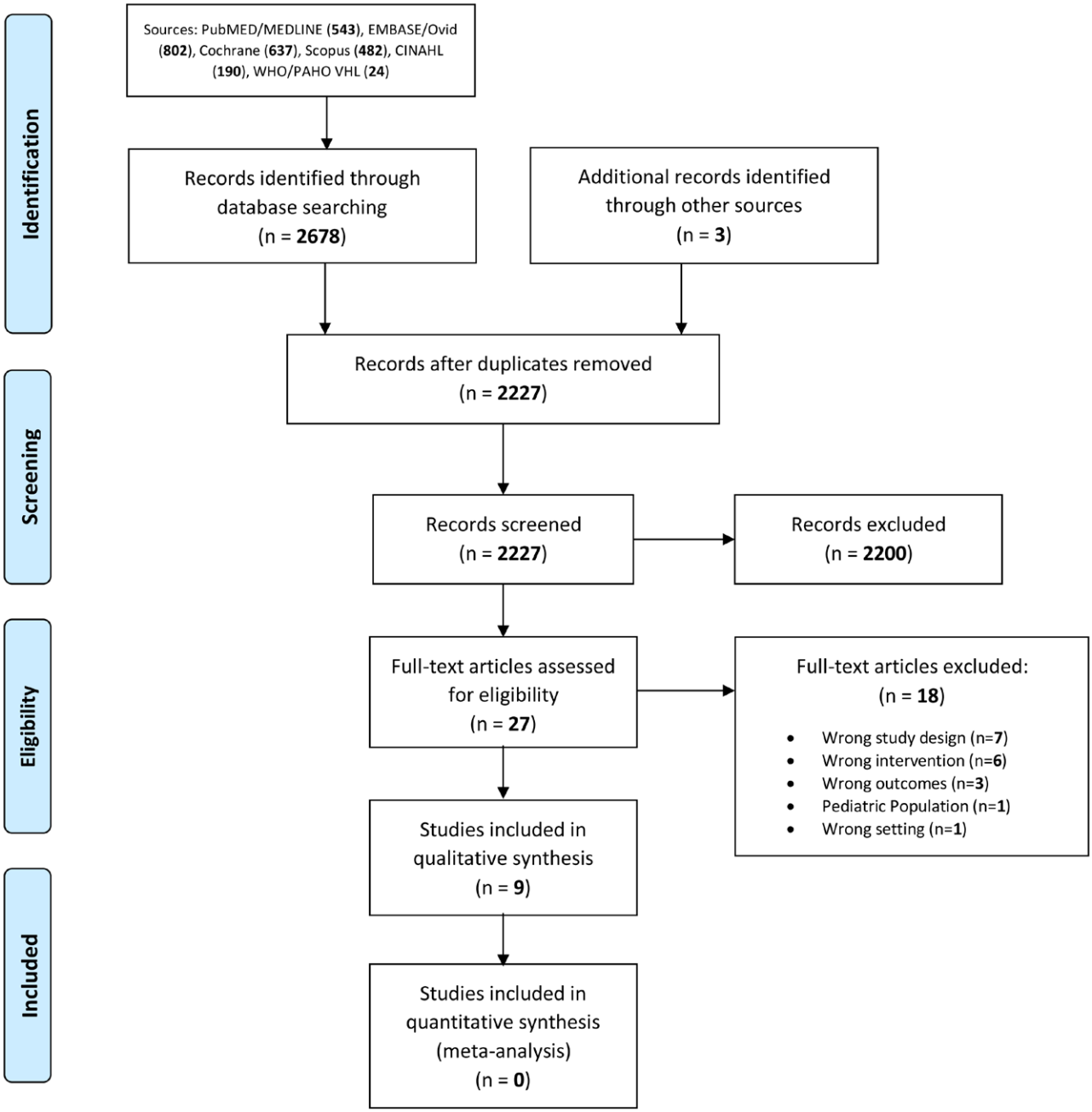

Figure. Study flow diagram.

although, due to lack of RCT on this topic, the consensus was to include prospective and retrospective, observational or descriptive studies that had >6 points in the QUADAS-2 tool. After this, the selected articles underwent data extraction. Assessment of the level of evidence of the studies included was done through the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) guidelines.[22]

Data Extraction and Statistical Analysis

Data extracted from the studies for final analysis included study authors, study design, country of origin, year of publication, number of patients included, number and percentage of acceptable quality images obtained and interpreted, number and percent of diagnoses made intraoperatively with FoCUS, and number of changes in anesthetic management derived from the results of examinations.

All data extracted were pooled and analyzed through an Excel datasheet (Microsoft Excel; Microsoft Corporation, Redmond, Washington). Incidence rates of the diagnoses encountered were analyzed through binomial confidence intervals. Weighted averages were calculated for the feasibility rates.

Risk of Bias

To avoid inclusion bias, 2 independent reviewers (J.R.N.-B and J.L.), after screening and assessing each title, applied the QUADAS-2 critical appraisal tool to each study included for the final review. This tool evaluates the presence of bias in each of its 4 domains (ie, patient selection, index test, reference test, and flow and timing).[20,21] In case of disagreement, the third independent reviewer (R.D.) adjudicated the interpretation.

RESULTS

A total of 2227 unique citations were identified (Figure). Based on the title and abstract, 2200 studies were discarded due to not meeting the inclusion criteria. Twenty-seven studies were selected for full-text assessment for final eligibility. Of these, 18 were excluded for not meeting inclusion criteria. Nine studies remained that met the prespecified inclusion criteria for data extraction and analysis.[12,14,23–29] No additional studies were identified from examination of the reference lists in the included manuscripts. All studies involved anesthesiologists who performed the FoCUS evaluation.

A total of 255 patients underwent intraoperative FoCUS for unexplained hypotension (Table 1). Correspondingly, 228 diagnoses of hypotension causes were made intraoperatively. Additionally, we extracted the type of diagnoses encountered on each study. Two studies described performing intraoperative examinations for intraoperative hypotension although no diagnoses were specified and were therefore excluded from final analysis.[14,25] Within the studies analyzed in our review, the feasibility rate of adequate quality images acquisition, when reported,

Table 1. Database Search Results Demonstrating Overview of Publications Reporting the Role of Intraoperative Focused Cardiac Ultrasound During Hemodynamic Instability for Patients Undergoing Noncardiac Surgery

Study author(s) (year)	Study design (location)	Number of patients	Diagnoses (n)	Changes in management (n)	Feasibility rate[a]	QUADAS-2 score—grade quality[b] (reason)
Canty and Royse[23] (2009)	Prospective cohort (Australia)	10	10 (hypovolemia [4]; vasodilation [2]; LV failure/low EF [1]; RV failure [1]; WMA [1]; severe PR [1])	8 (alter anesthesia [8])	100%	8—very low (observational, no control group)
Cowie[24] (2009)	Prospective cohort (Australia)	6	7 (vasodilation [7])	42 (changes nonspecified in manuscript)	98%	6—very low (observational, no control group)
Cowie[25] (2011)	Prospective cohort (Australia)	22	Nonreported	Nonreported	98%	6—very low (observational, no control group)
Shillcutt et al[12] (2012)	Retrospective cohort (United States)	7	8 (LV failure/low EF [4]; RV failure [3]; hypovolemia [1])	10 (postoperative mechanical ventilation [1]; fluid resuscitation [4]; inotropic support [3]; cancel surgery [1]; transfusion [1])	Nonreported	8—very low (observational, no control group)
Markin et al[14] (2015)	Retrospective cohort (United States)	3	Nonreported	Nonreported	Nonreported	9—very low (observational, no control group)
Kratz et al[26] (2015)	Prospective cohort (Germany)	60	61 (hypovolemia [45], LV failure [7], pulmonary HTN [7], RV failure [2])	Nonreported	91%	7—very low (observational, no control group)
Li et al[27] (2017)	Retrospective cohort (China)	7	9 (vasodilation [3]; hypovolemia [2]; WMA [2]; MS [1]; AI [1])	7 (surgery cancelled [6]; transfer to ICU [1])	Nonreported	6—very low (observational, no control group)
Kratz et al[28] (2017)	Prospective interventional (Germany)	50	72 (hypovolemia [32]; RV failure [23]; WMA [6]; LV failure [3]; pericardial effusion [7]; pulmonary HTN [1])	46 (vasopressors/ inotropics support [21]; fluid administration [19]; anti-ischemics [2]; upgrade monitoring [2]; upgrade postop level of care [2])	90%	6—very low (observational, nonrandomized, no control group)
Kratz et al[29] (2018)	Prospective cohort (Germany)	90	61 (LV failure [24]; RV failure [24]; hypovolemia [13])	24 (inotropic support [16]; fluid administration [6]; transfer to ICU [2])	98%	8—very low (observational, no control group)
Total		255	228	137		

Abbreviations: AI, aortic insufficiency; EF, ejection fraction; GRADE, Grading of Recommendations Assessment, Development, and Evaluation; HTN, hypertension; ICU, intensive care unit; LV, left ventricle; MS, mitral stenosis; PR, pulmonary regurgitation; QUADAS-2, Quality Assessment of Diagnostic Accuracy Studies-2; RV, right ventricle; WMA, wall motion abnormality.

aDefined as the number of times (expressed in percentage) that an acceptable quality image was obtained and allowed interpretation by the anesthesiologist.

[b]Level of evidence based on GRADE guidelines.

Table 2. Summary of Total Most Frequent Diagnoses Encountered for Intraoperative Focused Cardiac Ultrasound During Hemodynamic Instability

Diagnosis	Incidence rate	95% Confidence intervals
Hypovolemia	97	43 (36-49)
RV failure	53	23 (17-29)
LV failure/low EF	39	17 (12-22)
Vasodilation	12	5 (2-9)
WMA	9	4 (1-7)
Pulmonary hypertension	8	4 (1-6)
Pericardial effusion	7	3 (1-6)
Valvulopathy	3	1 (0.2-3)
Total	228	

Values are obtained from Clopper-Pearson exact binomial confidence intervals.
Abbreviations: EF, ejection fraction; LV, left ventricle; RV, right ventricle; WMA, wall motion abnormality.

ranged between 90%-100% (94% weighted average, standard deviation [SD] ±3%).[23–26,28,29]

The most commonly encountered diagnoses were hypovolemia (95% confidence interval [CI], 43 [36-49]), right ventricular failure (95% CI, 23 [17-29]), and left ventricular failure/low ejection fraction (95% CI, 17 [12-22]) (Table 2). However, the echocardiographic criteria for those diagnoses were not described. Other diagnoses included vasodilation, segmental wall motion abnormalities, pulmonary hypertension, and pericardial effusion. The term "valvulopathy" encompassed all 4 cardiac valves (ie, tricuspid, pulmonary, mitral, and aortic) with either stenosis or regurgitation. Three valvular issues (ie, 1 severe pulmonary regurgitation, 1 severe mitral stenosis, and 1 aortic insufficiency) were identified as a cause for the intraoperative hypotension in the studies identified.

A total of 137 changes in anesthetic management derived from the results of the intraoperative FoCUS were made; though, not all the studies reported or specified such changes.[14,24–26] From those studies that report changes in anesthetic management, the most common ones were administration of vasoactive drugs (40 of 137, 29%) and fluid management (29 of 137, 21%). Other changes in management included changes to the anesthetic being administered; postoperative mechanical ventilation; surgery cancellation; blood transfusion; postoperative transfer of care to the ICU; and escalation, intraoperatively, of invasive monitoring. The quality of the studies based on the QUADAS-2 critical appraisal questions is reported in Table 3. Quality of evidence of all studies included was very low as per GRADE guidelines, since no control groups or randomized groups were present in the studies that were evaluated.

Table 3. Quality of Studies

	Patient selection			Index test		Reference test		Flow and timing			
Study author(s)	Was a consecutive or random sample of patients enrolled?	Was a case-control design avoided?	Did the study avoid inappropriate exclusions?	Were the index test results interpreted without knowledge of the results of the reference standard?	If a threshold was used, was it prespecified?	Is the reference standard likely to correctly classify the target condition?	Were the reference standard results interpreted without knowledge of the results of the index test?	Was there an appropriate interval between index test and reference standard?	Did all patients receive the same reference standard?	Were all patients included in the analysis?	Total QUADAS-2 score
Canty and Royse[23]	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Unclear	Yes	8
Cowie[24]	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	6
Cowie[25]	Yes	Yes	Yes	Yes	No	Yes	Unclear	Unclear	No	Yes	6
Shillcutt et al[12]	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	8
Markin et al[14]	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	9
Kratz et al[26]	Yes	Yes	Yes	Yes	Yes	Yes	No	Unclear	No	Yes	7
Li et al[27]	Yes	Yes	Yes	Yes	No	Unclear	Yes	Unclear	Yes	No	6
Kratz et al[28]	Yes	Yes	Yes	Yes	No	Yes	Unclear	Unclear	No	Yes	6
Kratz et al[29]	Yes	Yes	Yes	Yes	Yes	Yes	No	Unclear	Yes	Yes	8

Abbreviation: QUADAS-2, Quality Assessment of Diagnostic Accuracy Studies-2.

DISCUSSION

This systematic review of intraoperative FoCUS during episodes of unexplained hypotension for patients undergoing noncardiac surgery found a high feasibility rate of adequate echocardiographic image

acquisition, and the ability to determine the cause of hypotension and guide-corrected intervention.

Preoperative FoCUS has been advocated for the qualitative evaluation of the gross cardiovascular status of the patient shortly before going to the operating room with particular benefit in emergent situations and for assessment of elderly patients.[7] Logistically, preoperative FoCUS is more accessible as the patient may still cooperate with the examiner; positioning is usually not an issue; and the patient is not currently undergoing a sterile procedure. While FoCUS may have some advantages intraoperatively when compared to TEE, due to availability and noninvasive nature, it also has major limitations related to necessity of sterile field preservation in thoracic and upper abdominal procedures, including the need to occasionally reposition the patient for image optimization, limited ability to perform a comprehensive examination, and patient factors influencing quality of examination (eg, emphysema or body habitus).

Since FoCUS is still not officially part of the anesthesiology curricula, external validation of the images by an expert may be necessary in selected cases before a clinical decision is made. Kratz et al[26] explored this concern throughout all the studies performed and involved a cardiologist as part of the study team.[28,29] Our results reveal 137 changes in management, and even though this correlates with the existing data that suggest that FoCUS may modify clinical decisions, there is still lack of evidence to suggest that it improves patients' outcomes.[18,30,31]

To our knowledge, this is the first systematic review of FoCUS for diagnosis of intraoperative hypotension. Previously, Jasudavisius et al[18] performed a review of echocardiography in the operating room; though, the study was heavily focused on TEE rather than FoCUS and did not define the purpose of the examination. Similarly, Heiberg et al[32] systematically explored the impact of TTE in clinical decision-making both in the perioperative and the critical care environment, but intraoperative settings are distinctly different. Similar to the findings of these studies, our review found hypovolemia and right and left ventricular failure as the major culprits for hemodynamic instability. On the contrary, this is the first systematic review to provide feasibility rates of image acquisition and detail changes in management derived from the intraoperative FoCUS findings.

The use of ultrasound within the practice of anesthesia has been confined mostly to vascular access and nerve blockade, leaving the use of TEE for intraoperative evaluation of hemodynamic crisis and assessment of cardiac and valvular function during cardiac surgery.[3,18] TTE has been a key tool of the cardiology practice, but given its noninvasive nature and wide equipment availability, it has gained an expanded role in the perioperative setting, critical care and the ED. Within the field of anesthesiology, the lack of formal training in FoCUS continues to be the main obstacle for the implementation of such skill into residency training as clinical competency. Definition of such competency and expected pathway, including numbers of examination performed, should be drafted by professional societies. The increasing availability of hand-held ultrasound devices suggests that basic principles of ultrasound should be introduced into the core curriculum of medical school and anesthesiology residency programs.[33] As the number of anesthesiology practitioners with FoCUS training continues to grow, more studies describing its role in the perioperative setting and its overall utilization are expected to increase.[3,10]

As the number of anesthesiology practitioners with FoCUS training continues to grow, studies describing its role in the perioperative setting and its overall utilization are expected to increase.[14,18] Implementation of a FoCUS curricula for the anesthesiologist has been investigated with favorable results, and basic competency in FoCUS is considered to be incorporated into the American Board of Anesthesiology certification process.[3,34,35] The ultimate decision in regards to the appropriate diagnostic tool to be used, in the case of an intraoperative episode of unexplained hypotension (FoCUS versus TEE), should be made in a case-by-case basis guided by patient and procedure factors.

This review has several limitations. First, all studies included in the analysis were from single centers, and even though the majority (6 of 9) were prospective in nature, the level of evidence based on the GRADE guidelines was very low since no control groups or randomized groups were involved in any study. This strongly suggests the need for future randomized controlled studies to corroborate the findings from the studies analyzed.[22] Second, based on the QUADAS-2 critical appraisal tool, there was a high risk for bias in the studies included.[20] The authors decided to incorporate these as part of the systematic review, given the paucity of studies dedicated to intraoperative FoCUS. Third, similar to other ultrasound imaging modalities, FoCUS remains heavily operator-dependent. Fourth, the FoCUS examination may be affected by multiple factors (eg, patient's body habitus and comorbidities, operative positioning, and avoidance of surgical field to preserve sterility) resulting in acquisitions of a limited number or nonstandard view of images and contributing to a vast variability of interpretations and subsequent clinical decisions. Sixth, neither study uniformly describes the type of surgery in which FoCUS diagnosed the cause of the hypotension, nor the type of anesthetic used (eg, general versus neuraxial anesthesia). Additionally, there

are no details regarding specific echocardiographic views/windows used by the authors to reach the diagnosis. Seventh, no details are given regarding the type of FoCUS certification or training the anesthesiologists involved in the studies.

In summary, FoCUS may be a useful, noninvasive, readily available method to diagnose cause of unexplained intraoperative hypotension and guide management, when used in the context of clinical presentation and data from standard monitors. Nevertheless, the existing reports have a significant bias and results should be interpreted with caution. Further prospective high-quality studies are needed to assess the diagnostic ability of intraoperative FoCUS and its association with outcomes.

DISCLOSURES

Name: Jose R. Navas-Blanco, MD.
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Contribution: This author helped with main conceptualization of this project, data search and analysis, manuscript drafting, editing, and final review.
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