Use of Cardiac Point-of-Care Ultrasound in the Pediatric Emergency Department

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Andrew Miller, MD, Piyawat Arichai, BS, Cynthia Gravel, MD, Rebecca Vieira, MD, Jeffrey Neal, MD, Mark Neuman, MD, MPH, Michael C. Monuteaux, ScD, Jason Levy, MD

Background

Point-of-Care Ultrasound (POCUS) has many uses at the bedside of patients seen in the emergency department (ED) including providing diagnostic information and procedural guidance. Cardiac POCUS is widely used in adults in the ED but its use in pediatric patients is less well-characterized despite endorsement from the American Academy of Pediatrics and American College of Emergency Physicians.

Objective

To evaluate how cardiac POCUS is utilized in the pediatric ED of a tertiary children's hospital including: indications for use, frequency of detecting pathology and of prompting cardiologist consultation, and test characteristics compared to expert sonographer review and/or echocardiogram.

Design/Methods

We performed a retrospective cohort study of patients seen in the pediatric ED between July 2015 and December 2017. A POCUS image storage and quality assurance (QA) database was queried for POCUS image interpretation and QA data for all patients who underwent clinically indicated cardiac POCUS. These POCUS exams were obtained by pediatric ED physicians who had undergone formal training on cardiac POCUS and completed at least 25 exams. Patients' charts were reviewed for demographic and clinical data. Expert POCUS reviewer and cardiologist review of echocardiogram were used as gold standards for the test characteristic analysis. STATA was used for descriptive statistics and analyses.

Results:

1,241 POCUS exams were performed, of which 558 (45%) were clinically indicated and included. 139 (25%) had a cardiac medical history and 95 (17%) were recently hospitalized. Chest pain, dyspnea, and tachycardia were the most common indications for POCUS. Compared to expert reviewer, sensitivity for pericardial effusion and decreased systolic function were

98.2% (95% CI 90.5-99.95) and 95.0% (95% CI 75.1-99.9) with specificity of 99.6% (95% CI 98.5-99.95) and 99.4% (95% CI 98.2-99.9), respectively. 234 (42%) underwent cardiology consultation, and 125 (22%) had echocardiograms. Compared to echocardiogram, sensitivity for pericardial effusion and decreased systolic function were 85.0% (95% CI 70.2-94.3) and 63.2% (95% CI 38.4-83.7) with specificity of 89.9% (95% CI 80.2-95.8) and 94.6% (95% CI 87.8-98.2), respectively.

Conclusion

Cardiac POCUS is sensitive and specific for pericardial effusion and global systolic function. A large proportion of patients undergoing cardiac POCUS ultimately undergo formal cardiology consultation and echocardiogram.

CONTENTS

GLOSSARY OF ABBREVIATIONS

POCUS – Point-of-Care Ultrasound

FOCUS – Focused Cardiac Ultrasound

FAST – Focused Assessment in Sonography with Trauma

ED – Emergency Department

PEM – Pediatric Emergency Medicine

STATEMENT OF THE SCHOLARLY PROJECT QUESTION

Point-of-Care Ultrasound (POCUS) is a focused ultrasonography performed and interpreted at the patient's bedside by a health care provider. POCUS is used in many ways in emergency medicine, primarily for procedural guidance or for answering a specific question. For example, the role of POCUS is well-established to aid in placement of a central venous catheter or to ascertain if there is free fluid in the abdomen after trauma through the focused assessment with sonography in trauma (FAST) exam. Cardiac POCUS evaluates the cardiovascular system for evidence of pericardial effusion, tamponade, left ventricular contractility, and cardiac arrest. In adult patients, cardiac POCUS has been shown to be helpful in narrowing differential diagnoses for scenarios such as undifferentiated shock, non-traumatic hypotension, chest pain, and dyspnea. It is being utilized in management of shock and evaluation of cardiopulmonary pathology in a variety of settings including emergency, perioperative, and in general practice[1–6]. The accuracy of cardiac POCUS by emergency physicians has been independently validated by cardiologist echocardiographers for findings including pericardial effusion, left ventricular systolic dysfunction, vascular filling[2,4,7–10]. In the adult population, many studies have also demonstrated that POCUS can expedite clinical decision-making, direct follow-up diagnostic imaging, aid in procedural guidance, and improve patient satisfaction[6,7].

In the pediatric population, POCUS has also shown to be a helpful tool to diagnose acute pathology in the pediatric ED when used by a single experienced provider[9]. Several studies indicate that cardiac POCUS may influence management decisions, including prompting referral to cardiology and formal echocardiogram and commencement of new treatments[6,11]. Pediatric emergency physicians can be trained to make accurate assessments of cardiac POCUS with reliable test characteristics[10]. There have been educational guidelines on how to teach and use cardiac POCUS[12]. Furthermore the use of cardiac POCUS has been widely supported by organizations including the American Academy of Pediatrics, American College of Emergency Physicians, American Society of Echocardiography, and international experts in critical care[13–17]. Many institutions have ultrasound training programs in place to create expertise in POCUS among various levels of providers. Despite its wider adoption, literature on POCUS in pediatric emergency is still largely based on results from experts who have extensive experience, training,

and research interest in POCUS. To our knowledge, there has not been a large-scale study examining the accuracy of cardiac POCUS done by clinicians who receive ultrasound training.

Our primary objective is to investigate the test characteristics of cardiac POCUS performed by PEM physicians who have gone through the POCUS credentialing process at Boston Children's Hospital. The aim is to extrapolate if similar training process is to be applied more broadly elsewhere in other PEM settings what test characteristics could we expect of cardiac POCUS done by practicing physicians with no in-depth expertise or interest in POCUS aside from the credentialing process. This information is important in evaluating the strengths and limitations of POCUS as it is being adopted more widely in many clinical settings.

I was involved with this research project from its inception to publication. I met Dr Miller who presented the research question and its initial study design around October 2017. We had meetings to discuss the study designs and create the electronic data capture database using RedCap. I wrote the study proposal and Dr Miller submitted the IRB research proposal to the Boston Children's Hospital internal IRB. I then conducted a pilot test of the database and made modifications. Over the course of the following few months, I conducted chart reviews of all the subjects in the study and entered the data into the database. I created a report summarizing the findings. We presented the findings to the pediatric emergency medicine ultrasound division for feedback. We worked with the division's statistician to further analyze the data and collate research results. I wrote the first draft of the research abstract. Dr Miller revised it and the division's members contributed edits and ideas. We submitted the abstract to the Pediatric Academic Society conference, which was accepted. I created the poster for the conference with Dr Miller's guidance. I rehearsed the poster presentation and practiced presenting at the division research meeting.

We then proceeded to write up the manuscript. This entailed performing additional data inquiries that were not included in the abstract. I acquired STATA knowledge and performed some analyses while learning from the division's in-house statistician, Dr Monuteaux who performed all analysis inquiries and was responsible for the integrity of the research analytic process. I drafted the manuscript contributing mainly to the introduction, results, and discussion sections. Dr Miller wrote the rest of the manuscript and provided oversight on the write-up

process incorporating insights from other division members. We are currently in the manuscript finalization process. The manuscript will be internally reviewed by members of the ultrasound division of the pediatric emergency department before being submitted for publication in a peer-reviewed journal. I am the second author of this publication.

Overall our study indicates that the test characteristics of cardiac POCUS is reasonably high for clinicians who underwent the credentialing process. Performance is particularly high for detecting pericardial effusion. Systolic function is much more challenging to evaluate in children given the small heart size, faster heart rate, and unique anatomy. This is reflected in its lower test characteristics compared to pericardial effusion. However, the test performance is still reasonable for higher cutoffs of systolic dysfunction, which are more clinically relevant. Additionally, many cardiac POCUS revealed other findings that were clinically significant such as presence of pathology in the mediastinum, valvular abnormality, pleural effusion, and cardiac anatomy anomaly. Although our study was not designed to evaluate the clinical impact of cardiac POCUS, we did find that there were high rates of cardiology referrals, echocardiogram within 96 hours, and initiation of cardiac treatment. Further study such as a prospective study of cardiac POCUS examination with a comparable control group without POCUS is needed to evaluate the impact of cardiac POCUS on the care process and outcome.

Ultrasound technology has astonishingly improved in recent years. It has become more portable, with higher image resolution, and able to emulate any type of transducers. These improvements have made ultrasound much more accessible to wider user groups in more diverse clinical practices at the point-of-care. With this evolution, it is important to establish ultrasound training and credentialing process that is effective in helping providers develop the ability to perform and interpret ultrasound with good accuracy. The point-of-care ultrasound program at the Boston Children's Hospital's pediatric emergency department is one model of POCUS credentialing process aimed at training PEM fellows and attendings with no background in ultrasound. The program creates a structured environment for providers to acquire ultrasound knowledge, practice, track progress, receive feedback, and improve their ultrasound skills. This model of interactive learning has showed to be effective in achieving reasonably high-test characteristics. It is our greatest hope that this model can be applied more broadly in other

institutions and practices to not only make point-of-care ultrasound more accessible but also higher quality everywhere.

APPENDIX 1: MANUSCRIPT

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BACKGROUND

Point-of-Care Ultrasound (POCUS) is a focused ultrasonography performed and interpreted at the patient's bedside by a health care provider. POCUS is used in many ways in emergency medicine, primarily for procedural guidance or for answering a specific question. For example, the role of POCUS is well-established in aiding in placement of a central venous catheter or is ascertaining if there is free fluid in the abdomen after trauma through the focused assessment with sonography in trauma (FAST) exam. Cardiac POCUS evaluates the cardiovascular system for evidence of pericardial effusion, tamponade, left ventricular contractility, and cardiac arrest. In adult patients, cardiac POCUS has been shown to be helpful in narrowing differential diagnoses for scenarios such as undifferentiated shock, non-traumatic hypotension, chest pain, and dyspnea. It is being utilized in management of shock and evaluation of cardiopulmonary pathology in a variety of settings including emergency, perioperative, and in general practice[1–6]. The accuracy of cardiac POCUS by emergency physicians has been independently validated by cardiologist echocardiographers for findings including pericardial effusion, left ventricular systolic dysfunction, vascular filling[2,4,7–10]. In adult populations, many studies have also demonstrated that POCUS can expedite clinical decision-making, direct follow-up diagnostic imaging, aid in procedural guidance, and improve patient satisfaction.

In the pediatric population, cardiac POCUS has also shown to be a helpful tool to diagnose acute pathology in the pediatric ED when used by a single experienced provider[9]. Several studies indicate that cardiac POCUS may influence management decisions, including prompting referral to cardiology and formal echocardiogram and commencement of new treatments[6,11]. Pediatric emergency physicians can be trained to make accurate assessments of cardiac POCUS with reliable test characteristics, although this has not been demonstrated throughout a department[10]. There have been educational guidelines on how to teach and use cardiac POCUS [12]. Furthermore

the use of cardiac POCUS has been widely supported by organizations including the American Academy of Pediatrics, American College of Emergency Physicians, American Society of Echocardiography, and international experts in critical care[13–17]. Despite clinical utility and endorsement of cardiac POCUS, there have been no large-scale studies examining how it is being used in the pediatric emergency department (ED). This information is important in evaluating the strengths and limitations of POCUS as it is being adopted more widely in the pediatric emergency setting.

Objectives

To characterize POCUS utilization in a pediatric ED, and to assess the test characteristics of pediatric emergency medicine (PEM) physician-performed cardiac POCUS compared to expert sonographer review and cardiologist-performed echocardiogram.

Materials and Methods

Study Design and Setting

We performed a retrospective cohort study of patients presenting to the ED at a single tertiary care pediatric hospital.

Study Population

A POCUS image storage and quality assurance database, Q-path (Telexy Healthcare, British Columbia, Canada) was queried for cardiac POCUS performed from July 1, 2015 through December 31, 2017. All patients who underwent a clinically-indicated cardiac POCUS were eligible, which was defined by the sonologist indicating the study was clinically indicated in either the Q-path datasheet or in the electronic medical record (EMR). Image interpretation and quality assurance data were extracted from Q-path database including: operator name, clinical indication (chest pain, syncope, shortness of breath, tachycardia, palpitation, murmur, cyanosis, dyspnea, hypotension, shock, cardiac arrest, other), view (subxiphoid, parasternal long, parasternal short, apical four chamber), interpretation (gross ventricular function, pericardial effusion, cardiac stand still, other), clinical impact, and quality assurance (image quality, interpretation accuracy). Clinical data was then extracted from the patient's EMR for the corresponding clinical ED encounter, including age, sex, history of cardiac disease, significant

non-cardiac past medical history (defined as rheumatologic conditions, hematologic/oncologic conditions, renal disease, pulmonary disease), recent hospitalization within the last 3 months, performance of cardiology consultation during the ED encounter, performance of echocardiogram within 96 hours of the ED encounter, performance of a cardiac procedure (defined as pericardiocentesis, cardiac catheterization or cardiac surgery) within 96 hours of the ED encounter, ED disposition (discharged home, admission to floor, or admission to an intensive care unit).

*S*onographers

All cardiac POCUS exams captured in the Q-path database are performed by a PEM attending physician or fellow under the supervision of a PEM attending. All of these providers have undergone didactic and hands-on education by PEM POCUS experts and performed at least 25 cardiac POCUS exams, followed by a proctored exam by a PEM POCUS expert. Echocardiograms are either obtained by a ultrasonographer technician or by a pediatric cardiology fellow. All echocardiograms are interpreted by an attending pediatric cardiologist.

Study scanning protocol

A cardiac POCUS study is considered adequate at our institution if it had good quality clips in at least two of the following views: parasternal long, parasternal short, subxiphoid, or apical four chamber. This definition was used for the study. The total number of views and the order in which they are obtained is left to the discretion of the scanning clinician. Captured images are assessed through a weekly quality assurance process by the expert POCUS faculty who are PEM POCUS experts – these individuals have either completed a POCUS fellowship and/or are Registered Diagnostic Medical Sonographer (RDMS) certified. This quality assurance process predated and continued throughout the study period. All study ultrasounds were performed on a TE-7 Mindray machine (Mindray, Shenzhen, China) or a Sonosite (FUJIFILM SonoSite, Inc., Washington, USA), with a 2-4 MHz phased array transducer. The hospital institutional review board approved this study.

Measurements and Outcome Measures

Our primary outcome measures were test characteristics (sensitivity, specificity) of the cardiac POCUS exam performed by an ED provider compared to expert POCUS review and to formal echocardiogram performed within 96 hours. Secondary outcome measures include descriptive

statistics of patient characteristics, cardiac POCUS indications, frequency of positive findings (defined as an exam concerning for pericardial effusion, decreased left ventricular systolic function, cardiac standstill), frequency of cardiology referral and echocardiogram within 96 hours, and initiation of new treatments.

Each of the cardiac POCUS findings is interpreted as either presence or absence. Echocardiogram qualitatively categorizes pericardial effusion as trace, mild, moderate, or severe. Global systolic dysfunction is categorized as normal, mild dysfunction, moderate dysfunction, and severe dysfunction. Left ventricular ejection fraction (LVEF) in echocardiogram reports was used to determine the corresponding category according to the following cut-offs: >50% normal, 40-49% mild, 30-39% moderate, and <30% severe. For echocardiogram reports without LVEF calculation, the qualitative report of systolic function was used.

Data Analysis

Demographic and clinical factors were analyzed with descriptive statistics (medians with interquartile ranges and frequencies with proportions for continuous and categorical variables, respectively).

RESULTS:

1,241 cardiac POCUS exams were performed between July 2015 and December 2017, of which 556 (45%) were clinically indicated and comprised the study sample (Figure 1). Median age was 13.5 years (interquartile range: 8.5, 17.5), 48% (n = 268) were female, 25% (n = 139) had a cardiac medical history, 50% (n = 279) had significant non-cardiac past medical history, 17% (n = 95) were recently hospitalized within 3 months, and 28% (n = 154) were transferred into the ED (Table 1). The most common indications for cardiac POCUS were chest pain (51%; n = 282), dyspnea (17%; n = 95), tachycardia (17%; n = 95), and syncope (8%; n = 47) (Table 2). Most of the studies, 98% (531/540), of the POCUS studies met the minimum quality criteria to make a diagnosis (Table 3).

Prevalence of pericardial effusion, global systolic dysfunction, and cardiac stand-still based on expert POCUS review were 11% (56/556), 4% (24/556), and 1% (4/556) respectively (Figure 1). Among patients undergoing cardiac POCUS, 42% (n = 234) received cardiology consultation, 22% (n = 125) had echocardiograms, and 14% (n = 79) were started on new treatments based on

the exam findings. Of all patients, 54% (302/556) were discharged home, 26% (143/556) were admitted to an inpatient unit, 19% (107/556) were admitted to the ICU, and 1% (4/556) were deceased.

The test characteristics of cardiac POCUS were calculated using two different gold standards: expert POCUS reviewer and echocardiogram within 96 hours (Table 4). For expert reviewer gold standard, the sensitivity and specificity of pericardial effusion were 98.2% (90.5%-99.9%) and 99.6% (98.5%-99.9%) respectively. The sensitivity and specificity of global systolic dysfunction were 95.0% (75.1%-99.9%) and 99.4% (98.2%-99.9%) respectively.

For echocardiogram gold standard, the sensitivity and specificity of pericardial effusion were 82.1% (67.3%-91.0%) and 91.3% (83.0%-95.7%) respectively. After increasing the cut-off point of detection to mild to large pericardial effusion, the sensitivity and specificity were 82.4% (66.5% - 91.7%) and 87.1% (78.3% - 92.6%) respectively (Table 5). The sensitivity and specificity of global systolic dysfunction were 54.5% (34.7%-73.1%) and 93.2% (86.6%-96.7%) respectively. After adjusting the cut-off point of systolic dysfunction to moderate to severe, the sensitivity and specificity were 60.0 % (35.7% - 80.2%) and 90.9% (84.1% - 95.0%) respectively (Table 6).

DISCUSSION

Cardiac point-of-care ultrasound is a useful tool in the pediatric emergency setting. Pediatric emergency physicians can obtain high quality images and make accurate interpretations at bedside. Test characteristics are highly reliable compared to readings of the POCUS images by expert reviewers. The examination is particularly highly sensitive and specific in detecting pericardial effusion. Assessment of systolic dysfunction is less accurate particularly when attempting to rule this out, however when it is seen it is highly accurate. This is sensible as the interpretation of global systolic dysfunction is more complex requiring judgment of dynamic movement including wall motion abnormalities and contractility. This is particularly challenging in pediatric patients due to rapid heart rate, small heart size, and anatomic anomalies from congenital heart disease and surgery. Furthermore, due to the small frequency of systolic dysfunction, the sensitivity calculation has significantly wide confidence interval.

Using echocardiograms as gold standard, the cardiac POCUS test characteristics are less robust. Sensitivity and specificity of detecting pericardial effusion remain high among all levels of effusions. However, the sensitivity of detecting systolic dysfunction is significantly lower compared to POCUS expert reviewer gold standard. This could partially be explained by the time lapse between POCUS and echocardiogram. Patient's physiologic state and medication effect among other factors can influence the dynamic cardiac function.

The cardiology consult rate is high in this cohort (42%; 234/556). This may be due to the readily available cardiology service, large proportion of patients with prior cardiac medical history and primary cardiologist. Correspondingly a significant proportion of patients had echocardiogram within 96 hours and commencement of new treatment. Further study is needed to evaluate how cardiac POCUS examination may influence these rates.

This is a single center study therefore may not be generalizable to other pediatric EDs. This is a retrospective study, which prevents real-time data collection on provider decision-making. However, QPath is populated by having providers complete a worksheet that is intended to be filled out at the time of the study regarding how the results affected the care provided. The Qpath database have data fields not completely filled out or entered in error. These concerns were minimized by confirming these fields through chart review. In addition, the quality assurance portion of Qpath (the portion completed weekly by the ultrasound division) is based on what is entered in the data fields, with no chart review formation.

Overall, cardiac POCUS is both sensitive and specific for pericardial effusion, which is prevalent in pediatric patients. Cardiac POCUS can rapidly identify pericardial effusion and global systolic cardiac dysfunction, making it a useful diagnostic tool in the PEM setting.

TABLE 1: Demographic characteristics (n = 556)

Demographic characteristic	n (%)
Median (or mean) Age in years [IQR]	13.5 [8.5, 17.5]
Sex (female)	268 (48.2)
Past medical history (non-cardiac)	279 (50)
Rheumatologic	20 (4)
Oncologic	32 (6)
Renal	26 (5)
Pulmonary	105 (19)
Chronic Inflammation	10 (2)
Other	168 (30)
Cardiac past medical history	139 (25)
Congenital	87 (16)
Acquired	26 (5)
Arrhythmia	16 (3)
Prior Cardiac Arrest/ECMO Cannulation	2 (0.4)
Prior DVT/PE	3 (0.5)
Other	14 (3)
Hospitalization within last 3 months	95 (17)
Transferred into ED	154 (28)
Outside Hospital	105 (19)
Cardiology Clinic	5 (1)
Non-Cardiology Clinic	44 (8)
Cardiac Interventions	
Cardiology consultation within 24 hours	234 (42)
Echocardiogram within 96 hours	125 (22)
Disposition from ED	
Discharged Home	302 (54)
Admission to floor	143 (26)
Admission to ICU	107 (19)
Deceased	4 (1)

Values in table represent median [interquartile range] or frequency (percent)

TABLE 2: Sonography indication (n = 556)

Sonography indication	n (%)
Chest pain	282 (51)
Shortness of breath	95 (17)
Tachycardia	95 (17)
Syncope	47 (8)
Hypotensive	25 (5)
Palpitations	24 (4)
Dyspnea	19 (3)
Shock	17 (3)
Murmur	10 (2)
Cyanosis	6 (1)
Cardiac arrest	4 (1)

TABLE 3: Cardiac POCUS quality assessment (n = 540)

Quality	n (%)
5 - Minimal criteria met for diagnosis, all structures imaged with excellent image quality and diagnosis completely supported	72 (13)
4 – Minimal criteria met for diagnosis, all structures imaged well, and diagnosis easily supported	346 (64)
3 – Minimal criteria met for diagnosis, recognizable structures but with some technical or other flaws	113 (21)
2 – Minimal recognizable structures but insufficient for diagnosis	9 (2)
1 – No recognizable structures, no objective data can be gathered	0

TABLE 4: Test characteristics of cardiac POCUS in detection of pericardial effusion and systolic dysfunction

Gold standard	Pericardial effusion			Global Systolic Dysfunction		
	n	Sensitivity (95% CI)	Specificity (95% CI)	n	Sensitivity (95% CI)	Specificity (95% CI)
Expert POCUS Reviewer*	519	98.2% (90.5%-99.9%)	99.6% (98.5%-99.9%)	508	95.0% (75.1%-99.9%)	99.4% (98.2%-99.9%)
Echocardiogram	119	82.1% (67.3%-91.0%)	91.3% (83.0%-95.7%)	111	54.5% (34.7%-73.1%)	93.2% (86.6%-96.7%)

*Physicians with POCUS Fellowship training or RDMS certification
CI = confidence interval

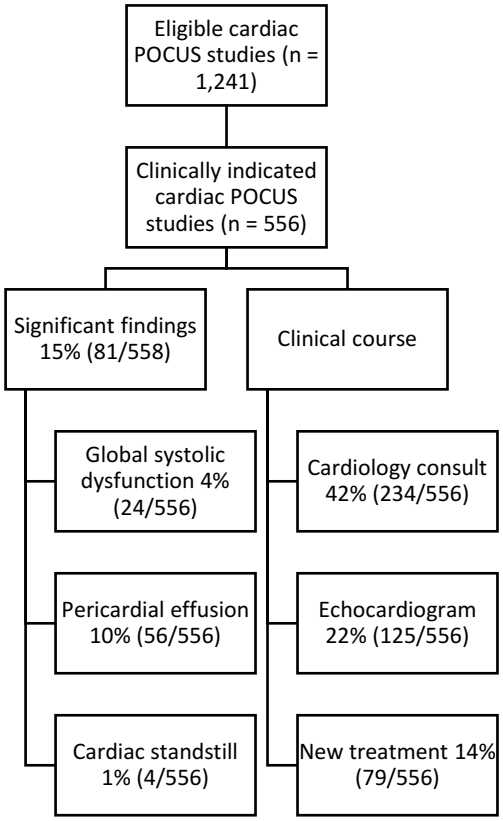
TABLE 5: Test characteristics of cardiac POCUS in detection of varying levels of pericardial effusions using echocardiogram as the gold standard

Pericardial effusion severity	n	Sensitivity (95% CI)	Specificity (95% CI)
Trace to large	119	82.1% (67.3%-91.0%)	91.3% (83.0%-95.7%)
Mild to large	119	82.4% (66.5% - 91.7%)	87.1% (78.3% - 92.6%)
Moderate to large	119	100% (78.5% - 100%)	76.2% (67.2% - 83.3%)
Large	119	100% (56.6% - 100%)	70.2% (61.2% - 77.8%)

TABLE 6: Test characteristics of cardiac POCUS in detection of mild to severe compared to moderate to severe systolic dysfunction using echocardiogram as the gold standard

Systolic dysfunction severity	n	Sensitivity (95% CI)	Specificity (95% CI)
Mild to severe	125	54.5% (34.7%-73.1%)	93.2% (86.6%-96.7%)
Moderate to severe	125	60.0 % (35.7% - 80.2%)	90.9% (84.1% - 95.0%)
Severe	125	50.0% (21.5% - 78.5%)	87.2% (79.9% - 92.1%)

FIGURE 1: Summary of study and results



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