# Evaluation of a Focused Cardiac Ultrasound Protocol in a Pediatric Emergency Department

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**Objectives:** The objective of this study was to evaluate the implementation of a focused cardiac ultrasound (FoCUS) protocol in a pediatric emergency department (PED).

**Methods:** We conducted a cross-sectional, observational, quality improvement project in a PED of an urban tertiary care children's hospital. A FoCUS protocol was collaboratively developed by pediatric cardiology and pediatric emergency medicine. This included a reference document with definitions, indications, image acquisition guidelines, and interpretation expectations. We measured physician-sonographer performance against pediatric cardiologist interpretation of stored cine clips as our reference standard. Focused cardiac ultrasound interpretation was dichotomized for the presence or absence of pericardial effusion, depressed left ventricular function, and chamber size abnormalities. Run charts were used to compare the number FoCUS performed each month and the quality of captured cine clips with those from the previous year.

**Results:** Ninety-two FoCUSs were performed by 34 different physician-sonographers from January to December 2016. The prevalence of FoCUS abnormalities was 18.5%. For pericardial effusion, sensitivity was 100% (95% confidence interval [CI], 48%–100%) and specificity was 99% (95% CI, 94%–100%). For depressed function, sensitivity was 100% (95% CI, 54%–100%) and specificity was 99% (95% CI, 94%–100%). For chamber size abnormalities, sensitivity was 100% (95% CI, 54%–100%) and specificity was 95% (95% CI, 89%–99%). The median number of monthly FoCUS increased from 1 (preprotocol) to 5 (postprotocol), and the median rate of adequate studies increased from 0% to 55%.

**Conclusions:** We report the collaborative development and successful implementation of a PED FoCUS protocol. Physician-sonographer interpretation of FoCUS yielded acceptable results. Improvements in FoCUS utilization and cine clip adequacy were observed.

**Key Words:** ultrasound, focused cardiac ultrasound, quality improvement

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Focused cardiac ultrasound (FoCUS) aims to gather essential time-sensitive information to diagnose pericardial effusion, global cardiac function, and relative chamber size in symptomatic patients.[1] Core FoCUS applications are considered a minimum standard for emergency medicine,[2] competency training, and program accreditation.[2,3] In 2013, consensus educational guidelines were developed for focused cardiovascular applications pertinent to pediatric emergency medicine (PEM).[4] The 2015 American Academy of Pediatrics policy statement and technical report affirmed the importance of adequate training for PEM programs in point-of-care ultrasonography (POCUS).[5,6]

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FoCUS can facilitate a targeted, more precise approach to critically ill patients.[7] Literature on the use of FoCUS in children is limited. Case reports have described the value of FoCUS in the diagnosis of dilated cardiomyopathy and cardiac tamponade in the pediatric emergency department (PED).[8,9] Pediatric emergency medicine physicians undergoing goal-directed training can accurately diagnose systolic dysfunction and pericardial effusion.[10,11] Pediatric emergency medicine programs should seek ways to effectively integrate this vital POCUS application throughout their department.

In a collaboration between the sections of pediatric cardiology and PEM, we designed and implemented a FoCUS protocol at our institution with a quality assurance review process. Our FoCUS protocol established appropriate indications for use and provided trainees with a standardized approach for image acquisition and interpretation. The year before this intervention 14 total FoCUS examinations were performed by 8 different physician-sonographers in the PED. Of these, 44% of the cine clips reviewed were adequate in quality. To our knowledge, we present the first investigation that has assessed a department wide implementation and performance of a FoCUS protocol in a PED.

We hypothesized that the adoption and implementation of a FoCUS protocol would increase the number of these studies performed in our department. We aimed to measure physician-sonographer performance for the diagnosis of pericardial effusion, qualitatively depressed left ventricular function, and chamber size abnormalities. We sought to increase the adequacy of recorded cine clips and measure adherence to the protocol instructions. Our project intended to promote timely care and reduce time to imaging in cases of possible life-threatening illness by fostering the use of a screening examination by physician-sonographers.

## METHODS

### Study Design

This was a cross-sectional, observational study performed to evaluate a quality improvement initiative in our PED. The initiative met established criteria for a clinical quality improvement project and was exempt from review by our institutional review board.

### Setting and Study Population

We performed this project in an urban PED with roughly 35,000 annual patient visits at an academic tertiary care children's hospital between January 2016 and December 2016. Comparison data before FoCUS protocol adoption were obtained from January 2015 to December 2015. We evaluated data from a convenience sample of PED patients up to 21 years old who underwent FoCUS at the discretion of treating physicians. Eligibility and inclusion criteria were delineated in our FoCUS protocol document. No exclusion criteria were defined.

## FoCUS Protocol

Our protocol specified definitions, indications, image acquisition guidelines, interpretation expectations, and information related to quality assurance measures. It was prepared by the lead investigator (PEM physician and director of the POCUS program) and reviewed by the chief of pediatric cardiology. Consensus on indications was achieved by these 2 individuals. The protocol was disseminated via email to both PEM and emergency medicine (EM) residency programs and made accessible online, and a copy was kept in our PED.

Focused cardiac ultrasound indications included the following: (1) patients with undifferentiated shock, (2) patients with cardiopulmonary arrest and return of spontaneous circulation, (3) patients with concern for a pericardial effusion (examples provided), (4) patients with concern for a pulmonary embolus, (5) patients with unexplained dyspnea, and (6) patients with exertional syncope.

A complete FoCUS included the following views: (1) a parasternal long axis (PSLA), (2) a parasternal short axis (PSSA) at the papillary muscle level, (3) an apical 4-chamber (A4C), and (4) a subxyphoid inferior vena cava (IVC) seen entering the right atrium in long axis. A reference document available to the sonographers had pictures with examples of each view, the correct probe positioning, and a corresponding image as it should appear on the monitor.

The protocol described how quality control and oversight would be maintained. Any concern for an abnormal finding on FoCUS triggered consultation with pediatric cardiology. A comprehensive echocardiogram was performed at the discretion of the consultant. For stable established cardiology patients, it was requested that consultation with the primary service occurs before a FoCUS was performed. Information cards were provided to families. The cards explained the limited scope of the FoCUS examination goals, that the study was not billable to insurers, and that a follow-up echocardiogram could be necessary.

## Physician-Sonographer Training

Participating PEM fellows received an introductory FoCUS didactic lecture and hands-on training early in their first fellowship year. This was supplemented with dedicated FoCUS instruction at a regional PEM and critical care POCUS conference in September. Participation in a 4-week ultrasound rotation with our EM program is structured to occur during the early stages of their second fellowship year. Participating EM residents have integrated FoCUS education throughout training and frequently perform these scans on adult patients. Participating PEM attendings, when performing a FoCUS alone, had prior formal training experiences with FoCUS. When a FoCUS was performed by a trainee, a PEM attending was present on shift to provide supervision. The amount of POCUS experience and proficiency by supervising PEM attendings, however, was heterogeneous.

## Sonography and Cine Clip Reviews

Focused cardiac ultrasounds were performed using the phased-array S4-2 transducer (4–2 MHz) of a Philips Sparq ultrasound system (Philips, Bothell, Wash). Grayscale 2-dimensional images were obtained. Cine clip recordings were preset at 3 seconds. Acquired clips were uploaded to a secure POCUS workflow server where physicians could document their FoCUS interpretations using a templated worksheet. All studies were reviewed by a

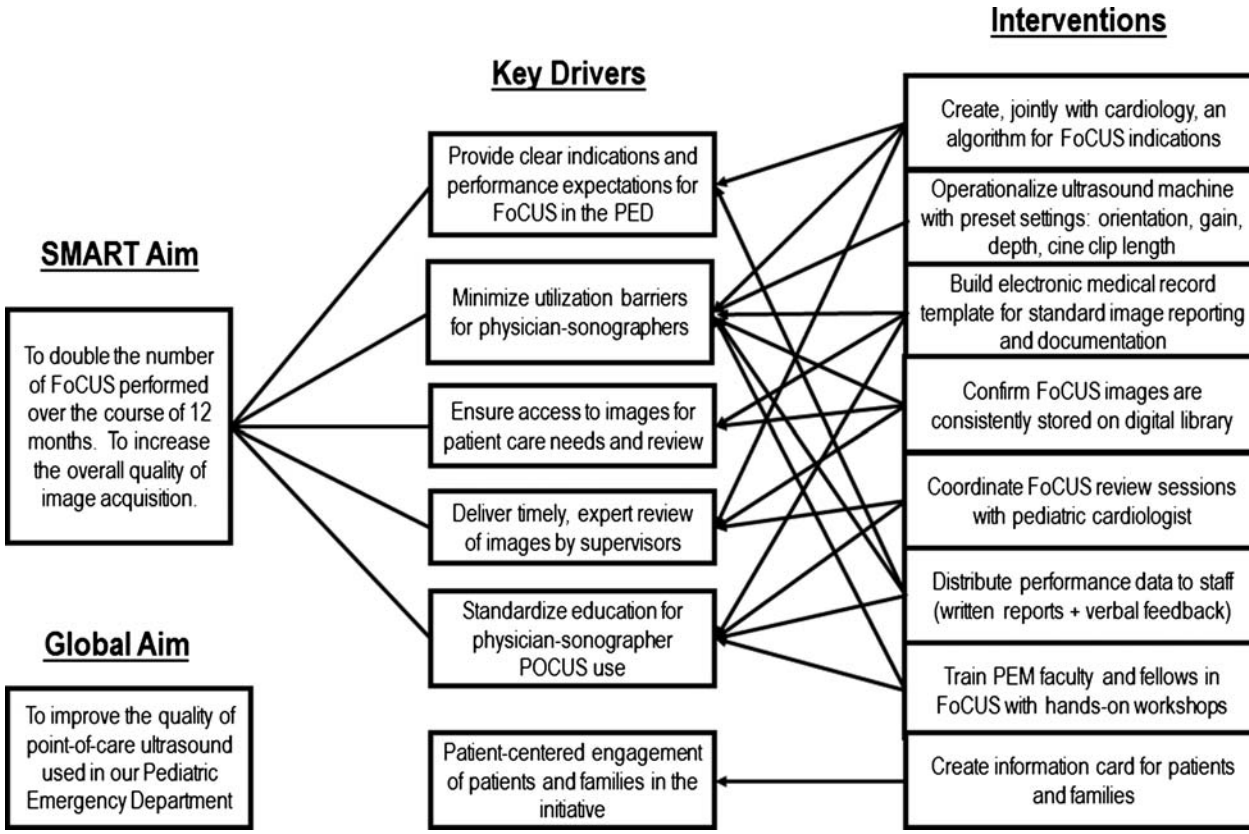


**FIGURE 1.** Key driver diagram for implementation of a FoCUS protocol.

pediatric cardiologist who was blinded to physician-sonographer findings. A brief clinical history that included the patient's age, sex, pertinent physical examination findings, and the FoCUS indication was provided.

## Data Analysis

Physician-sonographer FoCUS assessments at the time of the patient care encounter were compared with pediatric cardiologist interpretation of the recorded cine clips. The cardiologist's assessment for effusion, global function, and chamber size abnormalities was defined as our reference standard. Interpretation of the 3 main components of FoCUS were dichotomized as follows: (1) a pericardial effusion was present or absent, (2) the qualitative left ventricular function was normal or depressed, and (3) the relative chamber sizes were normal or abnormal. Test characteristics and likelihood ratios (LRs) were calculated. These calculations were performed using an online MedCalc statistical software.[12,13]

Each recorded PSLA, PSSA, and A4C video clip was independently inspected by the lead investigator and classified as *adequate* or *limited*. Cine clips were classified as adequate when all 3 of the following criteria were met: (1) the anatomy was recorded in the orientation outlined by the reference document; (2) the depth setting maximized and centered key structures on the monitor; and (3) the gain level used did not create cine clips that were too bright or too dark. A subset of cine clips was rated in this same fashion by our study's pediatric cardiologist. The interrater reliability of this assessment was tested with Cohen's $\kappa$ coefficient.

## Quality Improvement Measures

To improve FoCUS utilization in our PED, we aimed to double the number of scans performed over the course of 12 months compared with the previous year. An additional goal was to increase the overall quality of cine clips obtained by physician-sonographers. A structured improvement roadmap was developed (Fig. 1). Interventions leveraged towards these aims included "buy-in" from pediatric cardiology, process standardization for trainees, timely review of cases with ongoing feedback, and accessibility to the FoCUS protocol document. Baseline parameters were established by review of cine clips stored in our POCUS server from January to December 2015. Documentation of physician-sonographer FoCUS assessments during 2015 was not consistently available to allow for comparison of cine clip interpretation test characteristics before and after the protocol roll-out. Metrics tracked throughout the implementation period included FoCUS compliance with protocol indications and adherence to image acquisition guidelines. Medical record review was performed to track cardiology consultations, echocardiogram results, and patient disposition and ensure that appropriate follow-up care was obtained. Performance on key quality measures was tracked using run charts, and standard run chart rules were applied to demonstrate improvement.[14]

# RESULTS

Ninety-two FoCUS examinations performed by 34 different physicians were evaluated during our 1-year study period. Demographic information is listed in Table 1. The prevalence of abnormal findings on FoCUS was 18.5%. There were 13 patients with abnormal findings on FoCUS. These consisted of 5 cases of pericardial effusion (5.4%), 6 cases of depressed function (6.5%), and 6 cases of chamber size abnormalities (6.5%). In 2 patients, the FoCUS concurrently revealed a pericardial effusion, depressed function, and a chamber size abnormality. For detection of pericardial effusion, FoCUS had a positive LR of 87 (95% confidence interval [CI], 12–611), and the negative LR was 0 (95% CI, 0.01–1.20). For depressed function, FoCUS had a positive LR of 86 (95% CI, 12–604), and the negative LR was 0 (95% CI, 0.01–1.05). For chamber size abnormalities, FoCUS had a positive LR of 22 (95% CI, 8–60), and the negative LR was 0 (95% CI, 0.01–1.09). Overall test characteristics and subgroup analysis of cases with follow-up echocardiograms are shown in Table 2.

Adequate cine clips (80%) were most commonly recorded on the PSLA view (91%), whereas limited clips (20%) were most commonly recorded on the A4C view (40%). Cine clip categorization by view is provided in Table 3. The interrater reliability of clip categorization as either *adequate* or *limited* between POCUS director, and pediatric cardiologist was very good ($\kappa$ = 0.90; 95% CI, 0.71–1.0) with 95% agreement.

A shift in the median number of FoCUS performed by month from 1 to 5 was observed. This is calculated based on 8 sequential data points (January 2016 to August 2016), all above the baseline median from the preceding year in 2015 (Fig. 2). When compared with the previous year, an improvement in the median rate of adequate cine clips obtained by month was observed from 0% to 55%. Improvements were observed across each cardiac view. The median adequate PSLA improved from 0% to 100% (Fig. 3). The median adequate PSSA improved from 0% to 80% (Fig. 4). The median adequate A4C improved from 0%

**TABLE 1.** Demographic Data

| Study Population | N = 92 |
|---|---|
| FoCUS indications | |
| Concern for pericardial effusion | 46 (50%) |
| Unexplained dyspnea | 21 (23%) |
| Concern for pulmonary embolus | 11 (12%) |
| Undifferentiated shock | 8 (9%) |
| Cardiopulmonary arrest* | 2 (2%) |
| Exertional syncope | 1 (1%) |
| Other (eg, vasovagal syncope) | 3 (3%) |
| Sex of patient | |
| Male | 49 (53%) |
| Female | 43 (47%) |
| Age of patient | |
| 0–2 mo | 3 (3%) |
| 2–12 mo | 3 (3%) |
| 1–3 y | 6 (7%) |
| 4–12 y | 20 (22%) |
| 13–21 y | 60 (65%) |
| Physician-sonographer level of training | |
| EM-1 | 4 (4%) |
| EM-2 | 24 (26%) |
| EM-3 | 11 (12%) |
| EM-4 | 4 (4%) |
| PEM-1 | 12 (13%) |
| PEM-2 | 18 (20%) |
| PEM-3 | 13 (14%) |
| PEM attending | 6 (7%) |
| Preexisting heart condition | |
| Yes | 12 (13%) |
| No | 80 (87%) |

*Patients evaluated for cardiac standstill with a single view during cardiopulmonary resuscitation were not analyzed.

**TABLE 2.** Overall Performance of FoCUS and Comparison With 24-Hour Follow-up Echocardiogram

| N = 92 | Cardiologist + | Cardiologist − | Test Characteristics | % (CI) |
|---|---|---|---|---|
| Pericardial effusion | | | | |
| FoCUS + | 5 | 1 | Sensitivity \| specificity | 100 (48–100) \| 99 (94–100) |
| FoCUS − | 0 | 86 | NPV \| PPV | 100 \| 83 (42–97) |
| Depressed function | | | | |
| FoCUS + | 6 | 1 | Sensitivity \| specificity | 100 (54–100) \| 99 (94–100) |
| FoCUS − | 0 | 85 | NPV \| PPV | 100 \| 86 (46–98) |
| Abnormal chamber size | | | | |
| FoCUS + | 6 | 4 | Sensitivity \| specificity | 100 (54–100) \| 95 (89–99) |
| FoCUS − | 0 | 82 | NPV \| PPV | 100 \| 60 (37–80) |
| **N = 23** | **Echo Report +** | **Echo Report −** | **Test Characteristics** | **% (CI)** |
| Pericardial effusion | | | | |
| FoCUS + | 5 | 0 | Sensitivity \| specificity | 100 (48–100) \| 100 (81–100) |
| FoCUS − | 0 | 18 | NPV \| PPV | 100 \| 100 |
| Depressed function | | | | |
| FoCUS + | 6 | 0 | Sensitivity \| specificity | 100 (54–100) \| 100 (80–100) |
| FoCUS − | 0 | 17 | NPV \| PPV | 100 \| 100 |
| Abnormal chamber size | | | | |
| FoCUS + | 4 | 1 | Sensitivity \| specificity | 100 (40–100) \| 95 (74–100) |
| FoCUS − | 0 | 18 | NPV \| PPV | 100 \| 80 (37–96) |

NPV indicates negative predictive value; PPV, positive predictive value.

to 50% (Fig. 5). These improvements over time were evident using standard run chart rules.

Overall adherence to protocol indications was high at 97%. Protocol deviations included a 16-year-old female with vasovagal syncope, a 15-year-old female with costochondritis, and a 10-year-old girl with a murmur and a fixed split S2 on heart examination. This latter patient had been referred to our PED to get intravenous fluid therapy for gastroenteritis symptoms. The FoCUS revealed a markedly enlarged right ventricle and suggested that an atrial septal defect was present. The findings subsequently led to cardiology consultation, and the diagnosis was confirmed with an echocardiogram performed as an outpatient.

**TABLE 3.** Assessment of FoCUS Completeness and Cine Clip Adequacy

| PSLA Window | N = 92 |
|---|---|
| Adequate | 84 (91%) |
| Limited | 8 (23%) |
| Omitted | 0 |
| PSSA Window | N = 89 |
| Adequate | 77 (87%) |
| Limited | 12 (13%) |
| Omitted | 3 |
| A4C Window | N = 82 |
| Adequate | 49 (60%) |
| Limited | 33 (40%) |
| Omitted | 10 |
| IVC Window | N = 65 |
| Adequate | 54 (83%) |
| Limited | 11 (17%) |
| Omitted | 27 |

A complete FoCUS with 3 cardiac views plus IVC assessment occurred 61% of the time. Findings were documented by the physician-sonographer before the end of shift in 92% of cases. In all 7 cases with documentation omissions, the physician-sonographer was contacted by the lead investigator and cine clip interpretations were recorded before review by our pediatric cardiologist. Patients with preexisting heart conditions included cases of patent ductus arteriosus, mitral valve insufficiency, pulmonary valve insufficiency, hypertrophic cardiomyopathy, heart transplant, hypoplastic left heart syndrome after surgical palliation, and 2 cases each of Duchenne muscular dystrophy, dilated cardiomyopathy, and tetralogy of Fallot after surgical repair. Cardiology consultation was performed in 52% of cases when a FoCUS was performed. Follow-up echocardiograms performed within 24 hours occurred 25% of the time and the admission rate for patients that received a FoCUS was 39%.

## DISCUSSION

After the implementation of a FoCUS protocol that was collaboratively derived, physicians in our PED were observed to satisfactorily perform FoCUS studies and provide useful real-time interpretations. This adds to the existing body of literature that has shown that focused pediatric echocardiography can be accurately performed and interpreted by emergency physicians after receiving dedicated training.[10,11,15] Our findings are unique in that we did not evaluate the performance[10,11,15] of individually trained physician-sonographers but rather the global training received as part of the PEM fellow and EM residency POCUS curriculums.

In our study, FoCUS exhibited high specificity for the diagnosis of pericardial effusion and depressed global function, with narrow confidence intervals, making it an excellent test to rule in these conditions. Physician-sonographer assessment of chamber size abnormalities exhibited similar performance, except for a

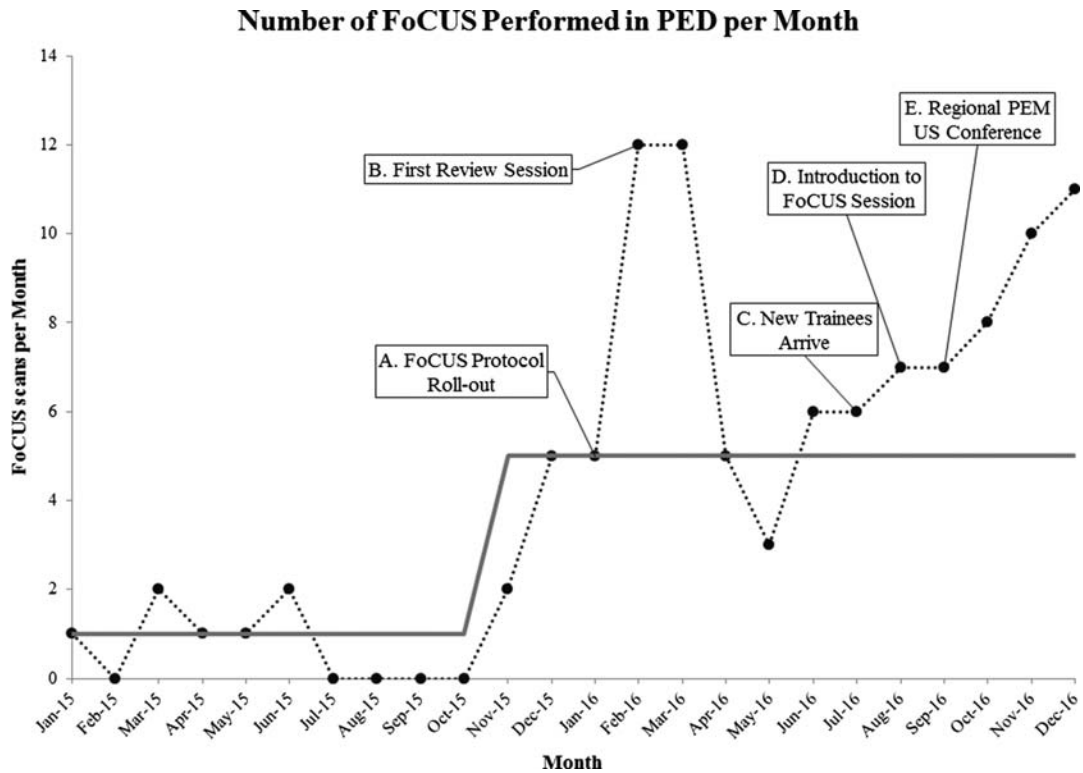


**FIGURE 2.** Number of FoCUS performed by month before and after protocol implementation.

notably lower positive predictive value. This finding coincides with the lowest adequate quality designation (60%) associated with the A4C view. The A4C is typically considered the most useful window to make chamber size determinations, as all 4 cardiac chambers can be compared in relation to one another.[16] Obtaining adequate A4C views may be a more operator-dependent assessment that depends on patient positioning and the physician-sonographer's level of skill and experience.

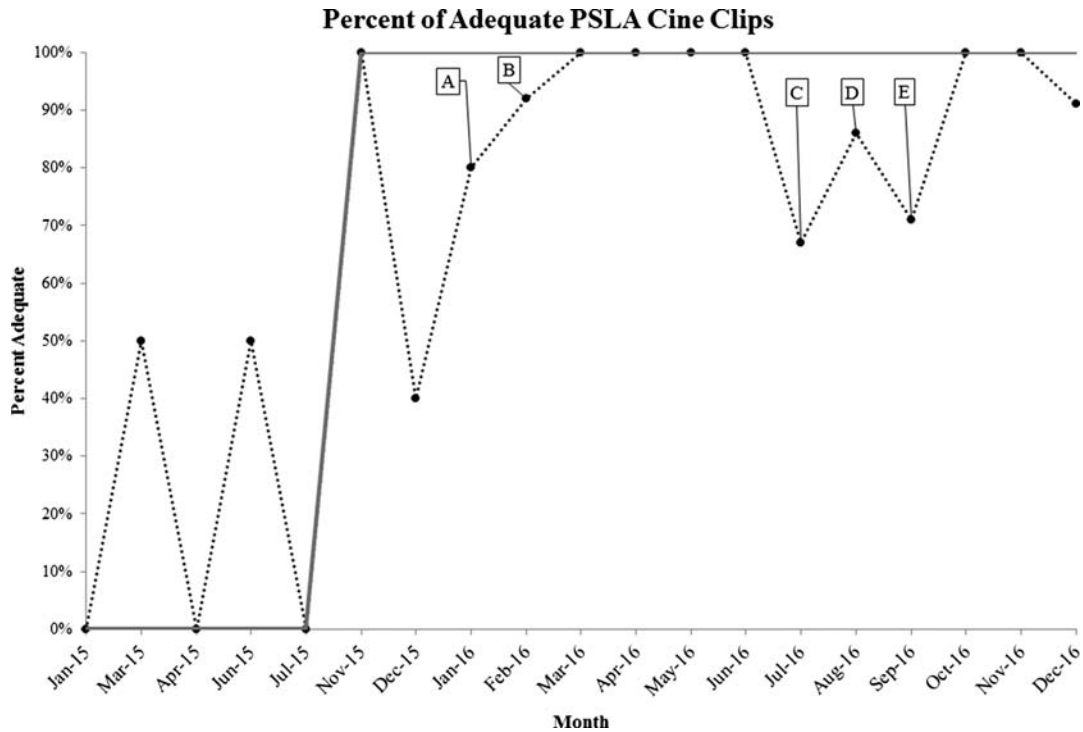


**FIGURE 3.** Parasternal long axis quality by month before and after protocol implementation.

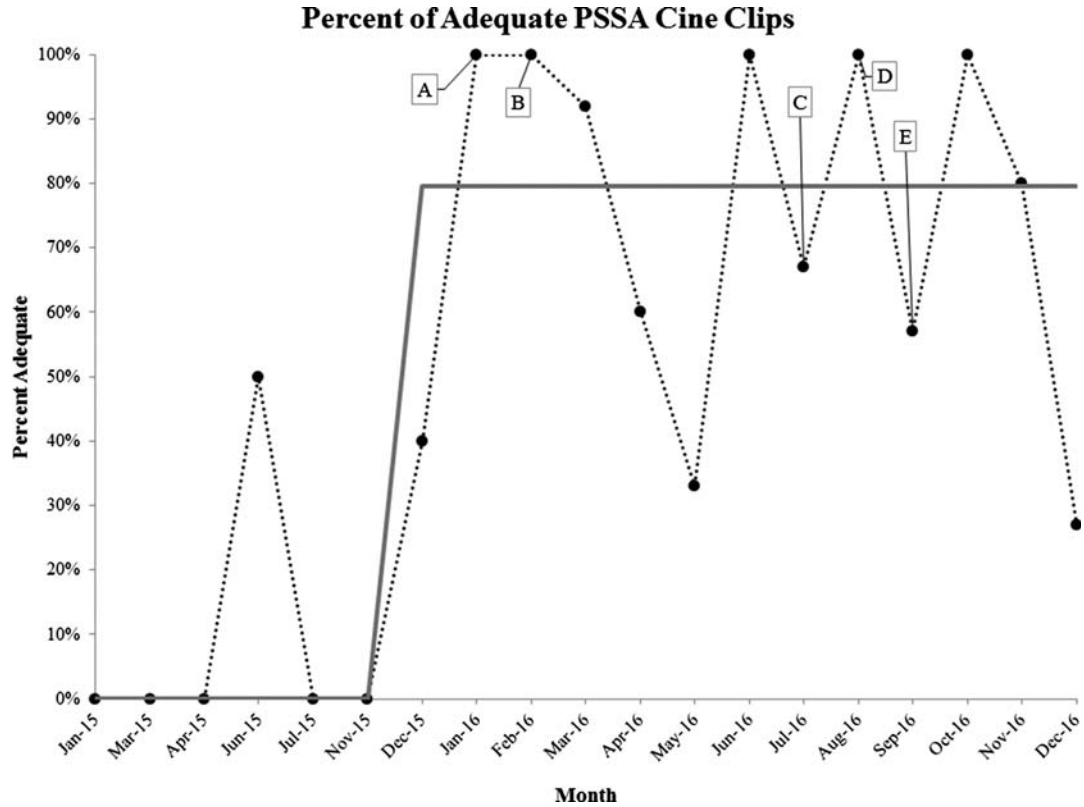


**FIGURE 4.** Parasternal short axis quality by month before and after protocol implementation.

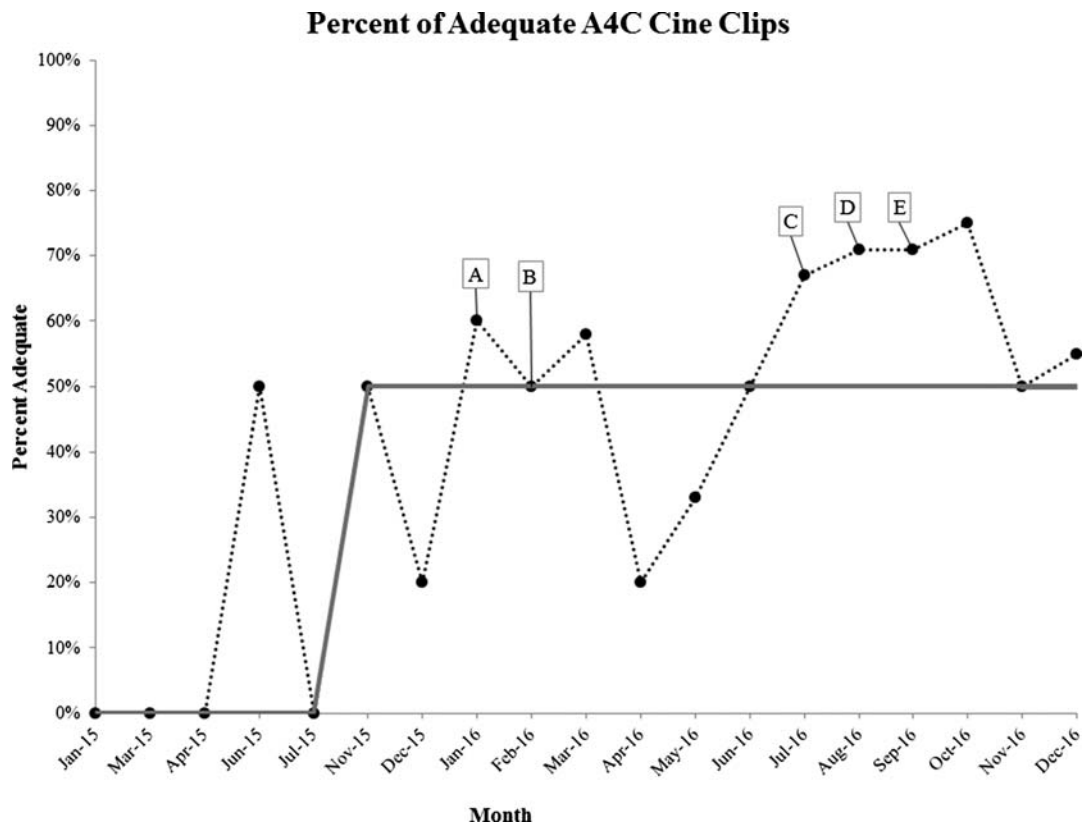


**FIGURE 5.** Apical 4-chamber quality by month before and after protocol implementation.

Findings related to protocol adherence will help inform future directions for our program. At the outset, we hoped that setting indications for appropriate use would reach a conciliatory balance between clinical care needs and trainee education. We planned to create appropriate indications so that patients with concerning cardiac complaints were candidates for FoCUS. Performing FoCUS when symptoms and physical examination were consistent with more benign causes like gastroesophageal reflux, costochondritis, and vasovagal syncope could lead to overutilization of resources and unnecessary testing. When our protocol was applied to a 1-year convenience sample, the prevalence of abnormal findings was 18.5%. At this rate of pathology, the developed protocol indications seemed to generate an appropriate level of FoCUS utilization.

A few poignant cases where our FoCUS pathway led to improved patient care and staff education warrant further discussion. The first case was that of a 4-year old Nigerian girl who presented with dyspnea. The parents reported cough, grunting noises, and difficulty sleeping. At triage, the patient was categorized as a "work of breather," and a nebulizer treatment was requested. On physical examination, she was found to have mild tachypnea, a heart murmur, lung crackles, and wheezing. Focused cardiac ultrasound performed 8 minutes after her triage found a pericardial effusion, qualitatively depressed left ventricular function, a dilated right atrium, and a plethoric IVC, as interpreted by the treating team. Pediatric cardiology was consulted immediately and subsequently diagnosed mitral valve insufficiency secondary to rheumatic heart disease. The second case was a 13-year-old female with longstanding chest pain. She was transferred to our PED with a diagnosis of pericarditis and a low voltage electrocardiogram. Her vital signs consisted of a fever to 38.1°C, a heart rate of 95 beats per minute, and a blood pressure of 107/47. On physical examination, heart sounds were described as "muffled." A FoCUS performed immediately after arrival revealed a large pericardial effusion as interpreted by the treating team. Pediatric cardiology and the intensive care unit were notified immediately. She subsequently underwent sedated pericardiocentesis, which aspirated close to 1 L of blood. This was felt to have been caused by an indolent accumulation of fluid after blunt trauma during a cheerleading injury several months before presentation. Finally, we report the case of a 2-week old who had a FoCUS performed after a cyanotic spell attributed as a possible brief resolved unexplained event. The FoCUS was interpreted by the treating team as having no significant or abnormal findings. During the review session, our pediatric cardiologist pointed out the appearance of air bubbles seen in the left atrium on the PSLA view. The infant was getting a normal saline bolus at the time the FoCUS was performed. The patient was found to have a small secundum atrial septal defect on echocardiogram. This layer of expertise allowed us to review our departmental protocols and perform reeducation related to filtering intravenous lines in patients with congenital heart disease.

Goals for future improvement were identified. The first was to attain a higher rate of complete FoCUS evaluations. Analysis of monthly trends over time did not reveal any improvement with this metric. The omission of IVC windows may suggest either a lack of familiarity or comfort level with this POCUS application. A second area was to increase the rate of adequate cine clip archiving, especially for the A4C view. One key driver for this process may be hands-on instruction during clinical shifts. Dedicated POCUS scanning shifts with real-time mentorship may increase the number of adequate scans. When real-time guidance is not possible, timely cine clip review and feedback for physician-sonographers are advisable. This quality assurance step should identify individual areas for improving subsequent FoCUS assessments.

Our study has several limitations. Individual goal-directed training before protocol roll-out was not done. The protocol was integrated with regular clinical activities, and awareness of the practice change was raised at the outset. Our patient population was mainly adolescents with normal anatomy. There were few cases of children younger than 12 months or with preexisting cardiac disease included for analysis, making our study findings less generalizable to infants or children with known congenital heart disease. In addition, we did not track cases where patients that met FoCUS eligibility criteria did not have scans performed. We also did not assess whether technical difficulties led to incomplete or aborted FoCUS scans. We acknowledge that our FoCUS pathway may have impacted resource utilization, and we did not measure balancing metrics for its potential impact on interventions or costs. Review of annual trends with our pediatric cardiology division, however, did not reveal any measurable increase in echocardiograms, PED consultation requests, or admissions.

Our test characteristic findings should be interpreted with caution. The reference standard used was pediatric cardiologist interpretation of a PEM or EM physician-sonographer FoCUS. Test characteristics may have been different if we had compared physician-sonographer FoCUS with a study obtained by a certified echocardiogram technician or pediatric cardiologist. The wide sensitivity confidence intervals reflect the relatively low number of positive findings. Of the 5 patients diagnosed with a pericardial effusion, 1 had this finding on a prior echocardiogram. Of the 6 patients diagnosed with depressed function, 3 had this finding on a prior echocardiogram. Of the 6 patients diagnosed with chamber size abnormalities, 3 had this finding on a prior echocardiogram. Physician-sonographer knowledge of these prior results through our electronic medical record system could have biased their FoCUS interpretation. For FoCUS negative patients discharged from our PED, medical record review did not reveal any missed cases of pathology based on a subsequent ED visit or hospitalization at our same institution.

We did not assess the accuracy of physician-sonographer evaluation of the IVC. Several methods have been described to estimate volume status based on IVC measurements. Pediatric studies have included different patient populations, transducer orientations, modes of measurement, and locations where the IVC diameter was measured.[17–20] Given this heterogeneity in the literature, we felt that a reliable reference standard measurement was more difficult to define and would add to the complexity of the FoCUS protocol. Because of these issues related to measurement certainty and additional training requirements, we did not compare physician-sonographer assessment with pediatric cardiologist interpretation of IVC volume status. We encouraged IVC assessment, however, as this is an important POCUS skill to learn and considered part of the focused cardiovascular assessment in consensus educational guidelines.[4]

## CONCLUSIONS

We report the collaborative development and successful implementation of a FoCUS protocol in a PED. Physician-sonographer interpretation of FoCUS yielded acceptable results. Improvement in FoCUS utilization and cine clip adequacy was observed. Pediatric emergency department programs should consider collaborative implementation of FoCUS protocols tailored to trainee, patient care, and institutional needs.

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