A Quality Initiative to Improve Appropriate Use of Initial Outpatient Echocardiography Among Pediatric Cardiologists

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INTRODUCTION

Transthoracic echocardiography is a convenient, safe, and accurate imaging tool for delineating cardiac anatomy and function. It is the most commonly used imaging modality in pediatric cardiology clinics. Increasing trends in transthoracic echocardiogram (TTE) ordering over the past decade, and the high cost and low yield for TTE in common outpatient indications have led to initiatives focused on responsible TTE use.1–3 One such initiative is appropriate use criteria (AUC), which has been available for adults since 2007.4 Spurred by data from implementation studies of AUC, quality improvement (QI) projects in adult medicine have found success in improving TTE ordering appropriateness.5–8

In 2014, a multidisciplinary pediatric group published AUC for ordering initial TTE in the pediatric outpatient setting.9 The global aims of this initiative were to reduce the total costs and resource utilization associated with less-appropriate diagnostic testing. Our institution recently published an implementation study of AUC, wherein “rarely appropriate” indications comprised 14% of all TTE studies.10 As a result of this finding, the project aim was to improve overall TTE ordering appropriateness (ie, mean AUC score) by 10% through AUC based educational interventions. We also sought to identify barriers to implementing AUC.

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INTRODUCTION

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METHODS

Context
This QI initiative took place in the Heart Center at Seattle Children’s Hospital, an academic tertiary medical center located in Seattle, WA. The Heart Center is comprised of more than 40 cardiologists with practice locations spanning 3 states. We invited cardiologists practicing at the main campus in Seattle, WA, to participate in the QI initiative. The echocardiography lab at the main campus performs nearly 900 initial outpatient TTEs yearly.10

A pediatric cardiologist (B.D.S.) lead the project. Seattle Children’s Maintenance of Certification (MOC) Portfolio program provided QI consultation (J.S.T.), and participants were eligible for MOC part 4 credit. The Seattle Children’s American Board of Medical Specialties Multispecialty MOC Portfolio Program, accredited in 2012, maintains a portfolio of approved MOC projects.

Planning the Intervention
This initiative aimed to increase the group’s mean AUC score by 10% above the baseline. Primary drivers identified were participant knowledge of the 2014 pediatric TTE AUC (Fig. 1). Secondary aims included applying AUC to TTE ordering and improving provider skills in QI through focused educational interventions, assessed by pre- and post-project surveys. The project leader met with MOC Portfolio consultants to develop educational interventions to address the primary drivers.

Intervention
We obtained baseline data by reviewing the initial outpatient TTEs performed in our main campus echocardiography lab 4 months before the intervention. The 2014 TTE AUC encompasses initial outpatient TTE and assigns scores to each indication. A score of 1–3 carries a rating of “rarely appropriate,” “may be appropriate” 4–6, and “appropriate” 7–9. In our study, as in prior AUC implementation studies, specific indications are not encompassed by the AUC and receive an “unclassifiable” rating. We excluded initial studies for patients with known heart disease.

We launched the QI initiative during an initial meeting in November 2016, where we reviewed the 2014 TTE AUC and presented baseline data. We provided participants with a one-page double-sided handout with a complete list of indications for initial outpatient TTEs and their respective rating as well as the list of data elements required for each study (Fig. 2). Participants were instructed to refer to the AUC handout and assign a rating for initial outpatient echocardiograms they ordered during the study period. Participants recorded data including electrocardiogram (ECG) findings, TTE findings, follow-up recommendations, and specifics of ordering indications in a RedCap database. If the TTE indication was not included in the AUC, participants assigned an “unclassifiable” rating and provided indication details. TTE studies rated as “unclassifiable” by the participant were reviewed by a secondary observer to ensure that the study indication was not included in the AUC. If a study was inappropriately rated as “unclassifiable,” the study was rated accurately and included in the statistical analysis and control chart. We held 2 quarterly meetings (March 2017 and June 2017), where we reviewed the outcome, process, and balancing measures using a statistical process control (SPC) chart. We evaluated interventional effectiveness and identified and mitigated barriers to the application of AUC to TTE ordering. Cardiologists were
offered MOC part 4 credit as an incentive to participate in the QI initiative. To be eligible for MOC credit, attendance at the initial meeting and subsequent quarterly meetings were mandatory. In the instances where participants could not attend a quarterly meeting, the senior author (B.D.S.) met with individuals to review their progress. Additionally, participants were required to complete QI training, which was available by a variety of distance learning platforms (e.g., Institute for Healthcare Improvement Open School). Each participant completed pre- and post-participation surveys (MOC-PEAKS) to assess the impact of the QI initiative and educational activities.14

**Table 1: Palpitations and Arrhythmias**

| Indication # | AUC Rating |
|--------------|------------|
| 1. Palpitations with no other symptoms or signs of cardiovascular disease, a benign family history, and no recent ECG | R (2) |
| 2. Palpitations with no other symptoms or signs of cardiovascular disease, a benign family history, and a normal ECG | R (1) |
| 3. Palpitations with abnormal ECG | A (6) |
| 4. Palpitations with family history of a channelopathy | R (3) |
| 5. Palpitations in a patient with known channelopathy | M (4) |
| 6. Palpitations with family history at a young age (before the age of 50 years) of sudden cardiac arrest or death and/or pacemaker or implantable defibrillator placement | A (7) |
| 7. Palpitations with family history of cardiomyopathy | A (9) |
| 8. Palpitations in a patient with known cardiomyopathy | A (9) |

**Table 2: Syncope**

| Indication # | AUC Rating |
|--------------|------------|
| 17. Syncope with or without palpitations and with no recent ECG | R (5) |
| 18. Syncope with no other symptoms or signs of cardiovascular disease, a benign family history, and a normal ECG | R (2) |
| 19. Syncope with abnormal ECG | A (7) |
| 20. Syncope with family history of channelopathy | M (5) |
| 21. Syncope with family history at a young age (before the age of 50 years) of sudden cardiac arrest or death and/or pacemaker or implantable defibrillator placement | A (9) |
| 22. Syncope with family history of cardiomyopathy | A (9) |
| 23. Probable neurocardiogenic (vasovagal) syncope | R (2) |
| 24. Unexplained pre-syncope | M (4) |
| 25. Exertional syncope | A (9) |
| 26. Unexplained post-exertional syncope | A (7) |
| 27. Syncope or pre-syncope with a known non-cardiovascular cause | R (2) |

**Table 3: Chest Pain**

| Indication # | AUC Rating |
|--------------|------------|
| 29. Chest pain with no other symptoms or signs of cardiovascular disease, a benign family history, and a normal ECG | R (2) |
| 30. Exertional chest pain | A (8) |
| 31. Non-exertional chest pain with no recent ECG | R (3) |
| 32. Non-exertional chest pain with normal ECG | R (1) |
| 33. Non-exertional chest pain with abnormal ECG | A (7) |
| 34. Chest pain with family history of sudden unexplained death or cardiomyopathy | A (8) |
| 35. Chest pain with family history of premature coronary artery disease | M (4) |
| 36. Chest pain with recent onset of fever | M (5) |
| 37. Reproducible chest pain with palpation or deep inspiration | R (1) |
| 38. Chest pain with recent illicit drug use | M (5) |

**Table 4: Murmur**

| Indication # | AUC Rating |
|--------------|------------|
| 39. Presumptively innocent murmur with no symptoms, signs, or findings of cardiovascular disease and a benign family history | R (1) |
| 40. Presumptively innocent murmur with symptoms, or findings of cardiovascular disease | A (7) |
| 41. Pathologic murmur | A (9) |

Fig. 2. Handout given to participants at the first meeting detailing data elements required to be collected with each TTE study ordered as well as AUC reference tables (Courtesy of Dr. Ritu Sachdeva, Sibley Heart Center Cardiology).
Outcome Assessment

The primary outcome was the average AUC score for initial outpatient TTE post-intervention compared to baseline. Secondary outcomes included the proportion of studies rated as “appropriate,” “may be appropriate,” and “rarely appropriate” post-intervention compared to baseline. As a balancing measure, we recorded abnormal findings from each TTE to evaluate for a reduction in sensitivity of TTE following our intervention. Abnormal findings excluded incidental isolated patent foramen ovale, left superior vena cava, and right aortic arch with mirror image branching.

Data Analysis

Sample characteristics were summarized using appropriate descriptive statistics for quantitative and categorical...
variables. We calculated and compared the average baseline and post-intervention AUC scores using Student’s t test. To account for changes in ordering practices during the study period, we compared the mean AUC scores following the second quarterly meeting to baseline. We constructed a SPC chart with 1-month time intervals to visualize the effect of the intervention on AUC scores. The percentages of abnormal findings were compared at baseline and post-intervention using 2-proportion Z-test. We noted the percentage of unclassifiable indications at baseline and post-intervention. However, they were not included in descriptive or comparative statistics.

**Ethical Considerations**

There were no ethical objections to this QI initiative. The Seattle Children’s Hospital Institutional Review Board approved this study and waived participant consent.

**RESULTS**

Twenty-two cardiologists participated in the QI initiative, representing 73% of cardiologists who practice on the main campus. The baseline group consisted of 216 studies, with an average AUC score of 7.42 ± 1.87. Ninety-four percent of studies were classifiable by the AUC. Eighty-one percent (n = 175) of studies had an “appropriate” rating, 13% (n = 29) “may be appropriate,” and 6% (n = 12) “rarely appropriate.” The post-intervention group consisted of 557 studies. The average AUC score was 7.16 ± 2.87. Ninety-six percent of studies were classifiable. Seventy-six percent (n = 425) of studies had an “appropriate” rating, 13% (n = 71) “may be appropriate,” and 11% (n = 61) “rarely appropriate.”

The difference between baseline and post-intervention mean AUC score did not reach statistical significance (P = 0.1). The mean AUC score for studies ordered after the second quarterly meeting was 7.4 ± 2.4, which was also not significantly different from baseline (P = 0.4). The SPC chart displays mean AUC scores by month throughout the QI initiative (Fig. 3).

Balancing measures included the proportion of abnormal findings from all studies. Table 1 shows the percentage of abnormal findings by AUC classification in the post-intervention group compared to baseline, of which there was no significant difference (27% versus 25%, P > 0.05). We found abnormal findings in 30%, 18%, and 15% of “appropriate,” “may be appropriate,” and “rarely appropriate” rated studies, respectively. Table 2 details the abnormal results from studies with “rarely appropriate” ratings, including ECG findings and follow-up recommendations. Abnormal findings included small muscular ventricular septal defect (n = 2), Secundum atrial septal defect (n = 2), semilunar valve abnormality without significant dysfunction (n = 4), and mild aortic arch hypoplasia (n = 1). The majority (78%) had a normal ECG. In 89%, follow-up was recommended. Presumptively innocent murmurs represented the most frequent (56%) “rarely appropriate” indication for TTE. We compared the proportion of abnormal studies in the post-intervention group across all AUC ratings. We found that “appropriate” studies had higher diagnostic yield compared to “may be appropriate” studies (30% versus 18%,

![Fig. 3. SPC chart of mean AUC score for initial outpatient transthoracic echocardiogram studies ordered before and after the initial intervention and after each subsequent quarterly meeting. LCL, lower control limit; UCL, upper control limit.](image-url)
Table 1. Abnormal Findings on Transthoracic Echocardiogram by AUC Indication at Baseline and Postintervention

| AUC Rating       | Abnormal Findings (%) | P     |
|------------------|-----------------------|-------|
|                  | Baseline | Post-intervention |
| Appropriately    | 48 (27)  | 127 (30)          | >0.1  |
| May be appropriate | 3 (10)  | 13 (18)           | >0.1  |
| Rarely appropriate | 2 (17)  | 9 (15)            | >0.1  |

P < 0.05) or “rarely appropriate” studies (30% versus 15%, P < 0.01). When “appropriate” and “may be appropriate” studies were grouped and compared to “rarely appropriate” studies, diagnostic yield remained significant (28% versus 15%, P < 0.05). Diagnostic yield between “may be appropriate” and “rarely appropriate” studies was not significantly different (18% versus 15%, P > 0.1).

Indications for “rarely appropriate” studies were evaluated separately. Fifty-six percent of “rarely appropriate” TTE study indications were for a “presumptively innocent murmur with no symptoms, signs, or findings of cardiovascular disease, and a benign family history.” “Syncope with no other symptoms or signs of cardiovascular disease, a benign family history, and a normal ECG” and “chest pain with no other symptoms or signs of cardiovascular disease, a benign family history, and a normal ECG” each represented 7% of “rarely appropriate” studies. Other indications each represented less than 5% of all “rarely appropriate” studies.

Thirty-eight TTEs were initially given an “unclassifiable” rating, meaning the indication for the study did not fall under the 2014 TTE AUC. Each TTE indication was reviewed independently, and 14 were inappropriately categorized as “unclassifiable.” Eleven would have fallen in the “appropriate” category and 3 in the “may be appropriate” category. Two studies were assigned an “unclassifiable” rating for obstructive sleep apnea but did not specify the presence of obesity (if obese, this is an “appropriate” rating). Two studies were ordered to rule out a vascular ring; only one indicated that a bicuspid aortic valve was abnormal (“appropriate” rating). Four orders were assigned an “unclassifiable” rating for presyncope with exertion (AUC give a “may be appropriate” rating to “unexplained presyncope”). The majority (n = 5) of unclassifiable indications were for abnormal heart sounds other than a murmur, including a click and split S1. Other indications included respiratory symptoms without heart failure findings, hemangioma, and history of chemotherpay.

**DISCUSSION**

**Summary**

The main finding from this QI initiative was that even at baseline, the mean AUC score was high (7.42), and 77% of study indications had an “appropriate” rating. We were not able to accomplish the primary aim of increasing the group mean AUC score by 10% from baseline, perhaps for this reason. In our cohort of pediatric cardiologists, an increase in the AUC score over time may not be a good metric to gauge improvement. This possibility is underscored by the fact that the baseline mean score was already within the “appropriate” (AUC score ≥ 7) range. An average score also does not highlight diagnostic yield between “appropriate” and “may be appropriate” indications, which may have a low yield of abnormal findings, may lead to further unnecessary testing or patient/parental anxiety, and may not be reimbursed by insurance providers. Focusing QI efforts on reducing the number of studies that are “rarely appropriate” is a preferred approach. QI initiatives focusing on TTE AUC in adults have used a percent change in rating classes as markers of improvement.

Our study did not experience a reduction in “rarely appropriate” studies (6% baseline versus 11% post-intervention). Explanations for this finding may include this not being the primary aim of the initiative, and so participants did not pay as much attention to this while ordering TTE studies. Providing each individual with a handout listing “rarely appropriate” indications (Fig. 4) to guide non-testing may be more effective. The high percentage of “appropriate” rated indications (77%) may have also contributed to our failure to increase the average AUC score. The percentage of “appropriate” rated studies is similar to previously published TTE AUC implementation studies (71%–77%). Because this QI initiative was

Table 2. Abnormal Findings on Transthoracic Echocardiogram Studies With “Rarely Appropriate” Indication With Any Noted ECG Abnormalities and Recommendations for Follow-up

| TTE Findings                              | Indication                                      | ECG Abnormalities                  | Follow-up |
|--------------------------------------------|-------------------------------------------------|------------------------------------|-----------|
| Aortic insufficiency, mild                  | Non-exertional chest pain with normal ECG       | None                               | Yes       |
| Muscular VSD, small                        | Innocent murmur                                 | None                               | Yes       |
| Secundum ASD, moderate                      | Innocent murmur                                 | None                               | Yes       |
| Aortic hypoplasia, mild                     | Innocent murmur                                 | Right ventricular hypertrophy      | Yes       |
| Secundum ASD, small                        | Innocent murmur                                 | None                               | Yes       |
| Muscular VSD, small                        | Innocent murmur                                 | None                               | Yes       |
| Dysplastic pulmonary valve with trivial stenosis | Echogenic focus on fetal echocardiogram          | None                               | Yes       |
| Abnormal aortic valve morphology, normal function | Chest pain without signs/symptoms of heart disease, benign family history, and normal ECG | None                               | Yes       |
| Bicuspid aortic valve with mild insufficiency, no stenosis | PACs after the neonatal period                  | None                               | Yes       |

ASD, atrial septal defect; PACs, premature atrial complexes; VSD, ventricular septal defect.
Launched 1 year after the AUC publication, we cannot exclude whether the cohort's exposure to the publication altered their ordering behavior before the baseline study. However, a recent study by Sachdeva et al\textsuperscript{16} would argue against a significant impact of the AUC publication on ordering behavior.

The application of AUC to TTE ordering was a secondary aim of this QI initiative. The finding that the AUC

| Rarely Appropriate TTE Indications |
|-----------------------------------|
| **Palpitations**                  |
| 1 Palpitations with no other symptoms or signs of cardiovascular disease, a benign family history, and no recent ECG |
| 2 Palpitations with no other symptoms or signs of cardiovascular disease, a benign family history, and a normal ECG |
| 3 Palpitations with abnormal ECG |
| **ECG Findings**                  |
| 4 Premature atrial contractions in the prenatal or neonatal period |
| 5 Premature atrial contractions after the neonatal period |
| 6 Sinus bradycardia               |
| 7 Sinus arrhythmia                |
| **Syncope**                       |
| 8 Syncope with or without palpitations and with no recent ECG |
| 9 Syncope with no other symptoms or signs of cardiovascular disease, a benign family history, and a normal ECG |
| 10 Probable neurocardiogenic (vasovagal) syncope |
| 11 Syncope or pre-syncope with a known non-cardiovascular cause |
| **Chest pain**                    |
| 12 Chest pain with no other symptoms or signs of cardiovascular disease, a benign family history, and a normal ECG |
| 13 Non-exertional chest pain with no recent ECG |
| 14 Non-exertional chest pain with normal ECG |
| 15 Reproducible chest pain with palpation or deep inspiration |
| **Murmur**                        |
| 16 Presumptively innocent murmur with no symptoms, signs, or findings of cardiovascular disease and a benign family history |
| **Other Symptoms or Signs**       |
| 17 Fatigue with no other signs and symptoms of cardiovascular disease, a normal ECG, and a benign family history |
| 18 Isolated acrocyanosis           |
| **Prior Test Results**            |
| 19 Previously normal echocardiogram with no change in cardiovascular status or family history |
| 20 Elevated anti-streptolysin O titers without suspicion for rheumatic fever |
| **Systemic Disorders**            |
| 21 Obesity without other cardiovascular risk factors |
| 22 Diabetes mellitus              |
| 23 Lipid disorders                |
| 24 Seizures, other neurologic disorders, or psychiatric disorders |
| 25 Gastrointestinal disorders, not otherwise specified |
| **Family History of CV Disease in Patients without Signs or Symptoms and without Confirmed Cardiac Diagnosis** |
| 26 Premature coronary artery disease before the age of 50 years |
| 27 Channelopathy                  |
| 28 Unspecified cardiovascular disease |
| 29 Disease at high risk for cardiovascular involvement, including but not limited to diabetes, systemic hypertension, obesity, stroke, and peripheral vascular disease |
| 30 Pulmonary arterial hypertension other than idiopathic and heritable |
| 31 Consanguinity                  |
| **Outpatient neonates without post-natal cardiology evaluation** |
| 32 Isolated echocardiographic focus on fetal ultrasound |

Fig. 4. Proposed handout with a compiled list of “rarely appropriate” TTE indications according to the 2014 appropriate use criteria for initial transthoracic echocardiography in outpatient pediatric cardiology.\textsuperscript{9}
encompassed 36% of initially “unclassifiable” indications provides an opportunity for improvement in future PDSA (Plan-Do-Study-Act) cycles. Only TTE indications rated as “unclassifiable” were audited. In future QI, auditing and providing focused participant feedback may prove useful. At each quarterly meeting, the SPC chart was reviewed with the entire group, which may not have been as effective as providing each participant with their AUC score or AUC rating breakdown as a form of peer benchmarking.

**Participant Education and Feedback**

Likert-scaled averages (data not shown) showed increased agreement with the statement, “the MOC experience is an important tool in improving the delivery of healthcare as well as the ability to use and interpret run charts to improve patient care, and the ability to apply QI methods to improve healthcare delivery for patients.” Despite the perceived obstacles of part 4 MOC,17 MOC is essential in demonstrating expertise in the field, keeping medical knowledge up to date, and demonstrating competency in providing medical care.18 Our study shows that multidisciplinary groups can create projects to capture the interest of subspecialty providers. Physician leaders can be coached by QI consultants to deliver quality projects that provide MOC part 4 credit.

This project was generally well-received among the participants. Reflections elicited were particularly telling of their experience. “I am more thoughtful about why I order an echo on a patient,” wrote one participant. Another noted that “I learned more factual information regarding practice patterns and the data supporting appropriate TTE indications.” Another went so far as to say, “the list of AUC for TTEs now lives on my home page and is something I refer to at each clinic to minimize unnecessary testing.” During the final meeting, participants discussed ways to integrate AUC into the daily workflow to reduce TTEs ordered for “rarely appropriate” indications. The group discussed the integration of AUC indications and corresponding ratings into the electronic medical system at the time of TTE ordering and discussed its feasibility. Point-of-care testing algorithms integrated into the electronic medical record system have been reported as modestly successful at improving the application of AUC.19 Participants also noted that referring provider and parental expectation for testing can be an influential factor in TTE ordering. This aspect was not explored in this QI initiative. A recent study showed that parental anxiety was reduced by performing a TTE for an innocent murmur, an indication considered “rarely appropriate” by the current AUC.20 Additionally, prior studies have shown a discrepancy in TTE ordering appropriateness between primary care providers and cardiologists.10,21 To what degree referring provider and parental/patient expectation of TTE does and should influence TTE ordering is an interesting question and deserving of future study, particularly in the setting of cost-conscious medicine and value-based reimbursement.

**Limitations of Current Appropriate Use Criteria**

We reviewed TTE orders for indications not classified by the current AUC. From a review of the literature, a recurrent theme among unclassifiable indications is that for an abnormal heart sound other than a murmur, such as a valvular click or split first or second heart sound, which represented the majority (n = 5) of the unclassifiable indications for a TTE in our cohort. The diagnostic yield for TTE in “rarely appropriate” indications was surprising to us. We observed abnormal echocardiographic findings in 15% of studies assigned a “rarely appropriate” rating. None of these findings were critical, although the majority elicited cardiology follow up (Table 2). Other pediatric TTE AUC studies have observed diagnostic yield for “rarely appropriate” indications of 2%–9%.10,11 In our study, “appropriate” studies had higher diagnostic yield than “rarely appropriate” studies (30% versus 15%, P < 0.01), however, the diagnostic yield of “may be appropriate” and “rarely appropriate” studies were not significantly different (18% versus 15%, P > 0.1). The latter finding is quite interesting and questions the AUC distinction between indications that are considered “rarely appropriate” and those that “may be appropriate.” All abnormal results discovered during “rarely appropriate” TTE were mild, but follow up was recommended in 89%.

Several studies have reported on diagnostic yield by AUC appropriateness level. Diagnostic yield for “appropriate” rated TTE indications ranges from 20% to 23%, with overall yield ranging from 13% to 19%.10,13 In our study, diagnostic yield for “appropriate” TTE was 30%, which we suspect is because the most significant proportion of “appropriate” studies were for the indication “pathologic murmur.” An indication of pathologic murmur has been shown to have the highest yield of abnormal findings.11,13 Diagnostic yield of TTE also varies across age groups. Safa and colleagues examined the diagnostic yield of TTE across children of all ages. Age less than 1 year was a significant risk factor for having an abnormal finding (odds ratio 15, P < 0.001).13 We did not study diagnostic yield by age, but modifications to AUC in the future may consider including patient age when rating TTE appropriateness.

The most common indication for “may be appropriate” studies was a family history of congenital left-sided heart lesions, including mitral stenosis, left ventricular outflow tract obstruction, bicuspid aortic valve, aortic coarctation, and/or hypoplastic left heart syndrome, which represented 30% of these studies. A family history of sudden unexplained death before 50 years represented 17% of all “may be appropriate” study indications, and palpitations with abnormal ECG represented 13%. The most common indication for “rarely appropriate” studies was a presumptively innocent murmur, which represented 56% of all “rarely appropriate” studies. The distinction between innocent and potentially pathologic murmurs involves a degree of subjectivity on behalf of the practitioner,
Despite characteristics of pathologic murmurs published broadly,22 additionally, the decision to perform an echocardiogram for a murmur most certainly considers other factors besides cardiac auscultation, including parental or referring provider expectations and clinical gestalt, which were not evaluated in this QI initiative but are deserving of future investigation. Differences in clinical opinion exist when addressing “innocent murmurs,” especially in infants, when murmurs may reflect a normal transition from fetal to postnatal physiology rather than pathology (such as in peripheral pulmonic stenosis). In this instance, rather than making the choice to perform or not perform a TTE, one may consider a follow-up in the future to relisten. It is difficult, if not impossible, to encompass every clinical decision in AUC. AUC seeks to be comprehensive to guide the practitioner’s use of cardiovascular tests, which the current AUC seems to do well.

CONCLUSIONS
Although TTE appropriateness level before and after the intervention was high, we were able to identify significant barriers to implementation of AUC by pediatric cardiologists at an academic children’s hospital. Future interventions should focus on reducing “rarely appropriate” TTE studies, integrating AUC into the electronic medical system, and investigating factors outside of the history and physical that affect TTE ordering practices.

DISCLOSURE
The authors have no financial interest to declare in relation to the content of this article.

REFERENCES
1. Shaw LJ, Marwick TH, Zoghbi WA, et al. Why all the focus on cardiac imaging? JACC Cardiovasc Imaging. 2010;3:789–794.
2. Caddell AJ, Wong KK, Barker AP, et al. Trends in pediatric cardiology referrals, testing, and satisfaction at a Canadian tertiary centre. Can J Cardiol. 2013;31:95–98.
3. Lang SM, Bolin E, Hardy S, et al. Diagnostic yield of outpatient pediatric echocardiograms: impact of indications and specialty. Pediatr Cardiol. 2017;38:162–169.
4. Douglas PS, Khandheria B, Stainback RF, et al. ACCF/AHA/ASE/ASNC/SCAI/SCCT/SCMR 2007 appropriateness criteria for transthoracic and transesophageal echocardiography: a report of the American College of Cardiology Foundation Quality Strategic Directions Committee Appropriateness Criteria Working Group, American Society of Echocardiography, American Society of Emergency Physicians, American Society of Nuclear Cardiology, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, and the Society for Cardiovascular Magnetic Resonance. Endorsed by the American College of Chest Physicians and the Society of Critical Care Medicine. J Am Soc Echocardiogr. 2007;20:787–805.
5. Kossaify A, Grollier G. Echocardiography practice: insights into appropriate clinical use, technical competence and quality improvement program. Clin Med Insights Cardiol. 2014;8:1–7.
6. Johnson TV, Rose GA, Fenner DJ, et al. Improving appropriate use of echocardiography and single-photon emission computed tomographic myocardial perfusion imaging: a continuous quality improvement initiative. J Am Soc Echocardiogr. 2014;27:749–757.
7. Bhata RS, Milford CE, Picard MH, et al. An educational intervention reduces the rate of inappropriate echocardiograms on an inpatient medical service. JACC Cardiovasc Imaging. 2013;6:545–555.
8. Bhata RS, Dudzinski DM, Malhotra R, et al. Educational intervention to reduce outpatient inappropriate echocardiograms: a randomized control trial. JACC Cardiovasc Imaging. 2014;7:857–866.
9. Campbell RM, Douglas PS, Eidem BW, et al. ACC/AAP/AHA/ASE/HRS/SCAI/SCCT/SCMR/SP 2014 appropriate use criteria for initial transthoracic echocardiography in outpatient pediatric cardiology: a report of the American College of Cardiology Appropriate Use Criteria Task Force, American Academy of Pediatrics, American Academy of Cardiovascular and Interventional Pulmonologists, American Society of Echocardiography, Heart Failure Society of America, Society for Cardiovascular Magnetic Resonance, and Society of Pediatric Echocardiography. J Am Soc Echocardiogr. 2014;27:1247–1266.
10. Kourtidou S, Evers PD, Jorgensen NW, et al. Pediatric appropriate use criteria for outpatient echocardiography: practice variations among pediatric cardiologists, noncardiologist subspecialists, and primary care providers. J Am Soc Echocardiogr. 2017;30:1214–1224.
11. Sachdeva R, Allen J, Benavidez OJ, et al. Pediatric appropriate use criteria implementation project: a multicenter outpatient echocardiography quality initiative. J Am Coll Cardiol. 2015;66:1132–1140.
12. Rose-Felker K, Kelleman MS, Campbell RM, et al. Appropriateness of outpatient echocardiograms ordered by pediatric cardiologists or other clinicians. J Pediatr. 2017;184:137–142.
13. Safa R, Aggarwal S, Misra A, et al. Application of appropriate use criteria for initial transthoracic echocardiography in an academic outpatient pediatric cardiology program. Pediatr Cardiol. 2017;38:1282–1287.
14. Tieder JS, Prall SP, Beck J, et al. A survey of perceived effectiveness of part 4 maintenance of certification. Hosp Pediatr. 2017;7:642–648.
15. Bhata RS, Ivers NM, Yin XC, et al. Improving the appropriate use of transthoracic echocardiography: the Echo WISELY trial. J Am Coll Cardiol. 2017;70:1135–1144.
16. Sachdeva R, Douglas PS, Kelleman MS, et al. Effect of release of the first pediatric appropriate use criteria on transthoracic echocardiogram ordering practice. Am J Cardiol. 2016;118:1545–1551.
17. Cook DA, Holmboe ES, Sorenson KJ, et al. Getting maintenance of certification to work: a grounded theory study of physicians’ perceptions. JAMA Intern Med. 2015;175:35–42.
18. Bower EA, Choi D, Becker TM, et al. Awareness of and participation in maintenance of professional certification: a prospective study. J Contin Educ Health Prof. 2007;27:164–172.
19. Bogdan JC, Shulteis RD, Donahue M, et al. Guideline-based decision support has a small, non-sustained effect on transthoracic echocardiography ordering frequency. BMJ Qual Saf. 2016;25:57–62.
20. Ip FH, Hay M, Menahem S. Impact of echocardiography on parental anxiety in children with innocent murmurs. J Paediatr Child Health. 2020. Epub ahead of print.
21. Lang SM, Daily JA, FitzGerald MR, et al. Knowledge of appropriate outpatient pediatric echocardiogram ordering in primary care physicians and trainees. Am J Cardiol. 2017;120:1209–1213.
22. McGrindle BW, Shafter KM, Kan JS, et al. Cardinal clinical signs in the differentiation of heart murmurs in children. Arch Pediatr Adolesc Med. 1996;150:169–174.