

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

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Abstract

Introduction: Appropriate use criteria (AUC) guide initial transthoracic echocardiogram (TTE) use in outpatient pediatrics. We sought to improve pediatric cardiologist TTE ordering appropriateness (mean AUC score) with a quality improvement initiative. **Methods:** The outcome of interest was the prospective AUC score for all initial outpatient TTEs ordered between November 2016 and August 2017, categorized per the AUC: “appropriate” (score 7–9), “may be appropriate” (4–6), “rarely appropriate” (1–3). Interventions included a didactic review of 2014 AUC and participant documentation of AUC criteria for each TTE. Participants met quarterly to evaluate outcome, process, and balancing measures, intervention effectiveness, and to identify and mitigate barriers. **Results:** Twenty-two pediatric cardiologists participated. TTE appropriateness level before ($n = 216$) and after ($n = 557$) intervention was high. There was no significant difference in mean baseline and post-intervention AUC score (7.42 ± 1.87 versus 7.16 ± 2.87 , $P = 0.1$), nor in TTE sensitivity (27% versus 25%, $P > 0.1$) as a balancing measure. Among baseline studies, 81% were “appropriate,” and 6% “rarely appropriate.” Among post-intervention studies, 76% were “appropriate,” and 11% “rarely appropriate.” Barriers identified to implementing AUC include TTE indications not specified by current AUC, expectations of referring provider or parent to perform TTE, consistent provider application of AUC, and ability of AUC to capture comprehensive clinical judgment. **Conclusions:** Although the mean AUC appropriateness level was high, we were able to identify significant barriers to the implementation of AUC. Future efforts should focus on the reduction of “rarely appropriate” TTE ordering. (*Pediatr Qual Saf* 2020;4:e313; doi: 10.1097/pq9.0000000000000313; Published online 23 July, 2020.)

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 goal of this publication is to provide clinicians with a tool to improve patient care and health outcomes cost-effectively. The AUC publication provides 113 indications for TTE studies, rating each as “appropriate,” “may be appropriate,” or “rarely appropriate” with a corresponding score. Several implementation studies have evaluated the use of AUC in the pediatric clinical setting.^{10–13}

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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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 assign 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

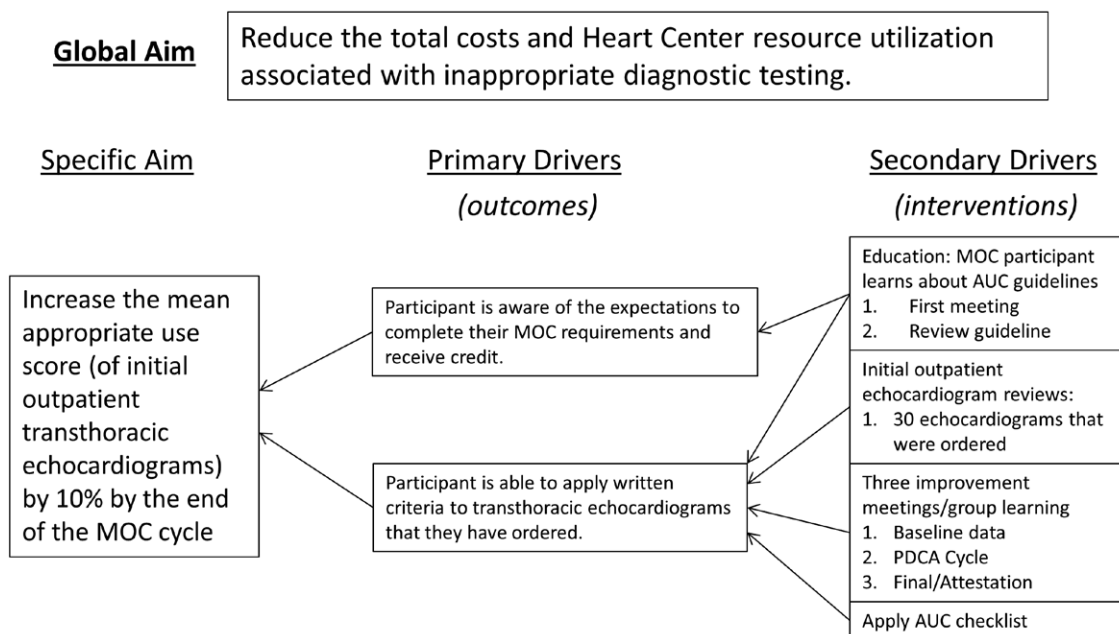


Fig. 1. Key driver diagram.

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 (eg, 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

Indication for Initial Outpatient Echocardiography

Patient label (Name, MR, DOB): Date of study: Age (in days, months or years): Study location: Ordering physician name & initials: AUC Indication number: Unclassifiable indication (description):	ECG: <input type="checkbox"/> None <input type="checkbox"/> Normal <input type="checkbox"/> Abnormal findings _____ ECHO (if available): <input type="checkbox"/> Normal <input type="checkbox"/> Normal with PFO <input type="checkbox"/> Abnormal Primary Diagnosis _____ _____ (include severity eg: mild, moderate or severe PS; small, mod or large ASD or VSD)
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Table 1: Palpitations and Arrhythmias		AUC Rating
Indication #		
Palpitations		
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	M (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)
ECG Findings		
9.	PACs in the prenatal or neonatal period	R (3)
10.	PACs after the neonatal period	R (3)
11.	Supraventricular tachycardia	A (7)
12.	PVCs in the prenatal or neonatal period	M (6)
13.	PVCs after the neonatal period	M (6)
14.	Ventricular tachycardia	A (9)
15.	Sinus bradycardia	R (2)
16.	Sinus arrhythmia	R (1)

Table 2: Syncope		AUC Rating
Indication #		
17.	Syncope with or without palpitations and with no recent ECG	R (3)
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		AUC Rating
Indication #		
28.	Chest pain with no other symptoms or signs of cardiovascular disease, a benign family history, and a normal ECG	R (2)
29.	Chest pain with other symptoms or signs of cardiovascular disease, a benign family history, and a normal ECG	M (6)
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 (6)
37.	Reproducible chest pain with palpation or deep inspiration	R (1)
38.	Chest pain with recent illicit drug use	M (6)

Table 4: Murmur		AUC Rating
Indication #		
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 signs, 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).

Table 5: Other Symptoms and Signs		AUC Rating
Indication #		
42.	Symptoms &/or signs suggestive of congestive heart failure, including but not limited to respiratory distress, poor peripheral pulses, feeding difficulty, decreased urine output, edema, and/or hepatomegaly	A (9)
43.	Chest wall deformities and scoliosis pre-operatively	M (6)
44.	Fatigue with no other signs and symptoms of cardiovascular disease, a normal ECG, and a benign family history	R (3)
45.	Signs and symptoms of endocarditis in the absence of blood culture data or a negative blood culture	A (8)
46.	Unexplained fever without other evidence for cardiovascular or systemic involvement	M (5)
47.	Central cyanosis	A (8)
48.	Isolated Acrocyanosis	R (1)

Table 7: Systemic Disorders		AUC Rating
Indication #		
62.	Cancer without chemotherapy	M (5)
63.	Prior to or during chemotherapy in cancer	A (8)
64.	Sickle cell disease and other hemoglobinopathies	A (8)
65.	Connective tissue disorder such as Marfan, Loays Dietz, and other aortopathy syndromes	A (9)
66.	Suspected connective tissue disorder	A (7)
67.	Clinically suspected syndrome or extracardiac congenital anomaly known to be associated with congenital heart disease	A (9)
68.	Human immunodeficiency virus infection	A (8)
69.	Suspected or confirmed Kawasaki disease	A (9)
70.	Suspected or confirmed Takayasu arteritis	A (9)
71.	Suspected or confirmed acute rheumatic fever	A (9)
72.	Systemic lupus erythematosus and autoimmune disorders	A (7)
73.	Muscular dystrophy	A (9)
74.	Systemic hypertension	A (9)
75.	Renal failure	A (7)
76.	Obesity without other cardiovascular risk factors	R (2)
77.	Obesity with obstructive sleep apnea	M (6)
78.	Obesity with other cardiovascular risk factors	M (6)
79.	Diabetes mellitus	R (3)
80.	Lipid disorders	R (3)
81.	Stroke	A (8)
82.	Seizures, other neurologic disorders, or psychiatric disorders	R (2)
83.	Suspected pulmonary hypertension	A (9)
84.	Gastrointestinal disorders, not otherwise specified	R (2)
85.	Hepatic disorders	M (4)
86.	Failure to thrive	M (5)
87.	Storage diseases, mitochondrial and metabolic disorders	A (8)
88.	Abnormalities of visceral or cardiac situs	A (9)

Table 9: Outpatient Neonates without Post-Natal Cardiology Evaluation		AUC Rating
Indication #		
106	Suspected cardiovascular abnormality on fetal echocardiogram	A (9)
107	Isolated echogenic focus on fetal ultrasound	R (2)
108	Maternal infection during pregnancy or delivery with potential fetal/neonatal cardiac sequelae	A (7)
109	Maternal diabetes with no prior fetal echocardiogram	M (6)
110	Maternal diabetes with a normal fetal echocardiogram	M (4)
111	Maternal phenylketonuria	A (7)
112	Maternal autoimmune disorder	M (5)
113	Maternal teratogen exposure	M (6)

Table 6: Prior Test Results		AUC Rating
Indication #		
49.	Known channelopathy	M (4)
50.	Genotype positive for cardiomyopathy	A (9)
51.	Abnormal chest X-ray findings suggestive of cardiovascular disease	A (9)
52.	Abnormal ECG without symptoms	A (7)
53.	Desaturation based on pulse oximetry	A (9)
54.	Previously normal echocardiogram with no change in cardiovascular status or family history	R (1)
55.	Previously normal echocardiogram with a change in cardiovascular status and/or a new family history suggestive of heritable heart disease	A (7)
56.	Elevated anti-streptolysin O titers without suspicion for rheumatic fever	R (3)
57.	Chromosomal abnormality known to be associated with cardiovascular disease	A (9)
58.	Chromosomal abnormality with undefined risk for cardiovascular disease	M (5)
59.	Positive blood cultures suggestive of infective endocarditis	A (9)
60.	Abnormal cardiac enzymes	A (9)
61.	Abnormal barium swallow or bronchoscopy suggesting vascular ring	A (7)

Table 8: Family History of CV Disease in Patients without Signs or Symptoms and without Confirmed Cardiac Diagnosis		AUC Rating
Indication #		
89.	Unexplained sudden death before the age of 50 years	M (6)
90.	Premature coronary artery disease before the age of 50 yrs	R (2)
91.	Channelopathy	R (3)
92.	Hypertrophic cardiomyopathy	A (9)
93.	Non-ischemic dilated cardiomyopathy	A (9)
94.	Other cardiomyopathies	A (8)
95.	Unspecified cardiovascular disease	R (3)
96.	Disease at high risk for cardiovascular involvement, including but not limited to diabetes, systemic hypertension, obesity, stroke, and peripheral vascular disease	R (2)
97.	Genetic disorder at high risk for cardiovascular involvement	A (7)
98.	Marfan or Loays Dietz syndrome	A (7)
99.	Connective tissue disorder other than Marfan or Loays Dietz syndrome	M (6)
100.	Congenital left-sided heart lesion, including but not limited to mitral stenosis, left ventricular outflow tract obstruction, bicuspid aortic valve, aortic coarctation, and/or hypoplastic left heart syndrome	M (6)
101.	Congenital heart disease other than the congenital left-sided heart lesions	M (5)
102.	Idiopathic pulmonary arterial hypertension	M (5)
103.	Heritable pulmonary arterial hypertension	A (8)
104.	Pulmonary arterial hypertension other than idiopathic and heritable	R (3)
105.	Consanguinity	R (3)

Table 9: Outpatient Neonates without Post-Natal Cardiology Evaluation		AUC Rating
Indication #		
106	Suspected cardiovascular abnormality on fetal echocardiogram	A (9)
107	Isolated echogenic focus on fetal ultrasound	R (2)
108	Maternal infection during pregnancy or delivery with potential fetal/neonatal cardiac sequelae	A (7)
109	Maternal diabetes with no prior fetal echocardiogram	M (6)
110	Maternal diabetes with a normal fetal echocardiogram	M (4)
111	Maternal phenylketonuria	A (7)
112	Maternal autoimmune disorder	M (5)
113	Maternal teratogen exposure	M (6)

Fig. 2. (Continued)

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%,

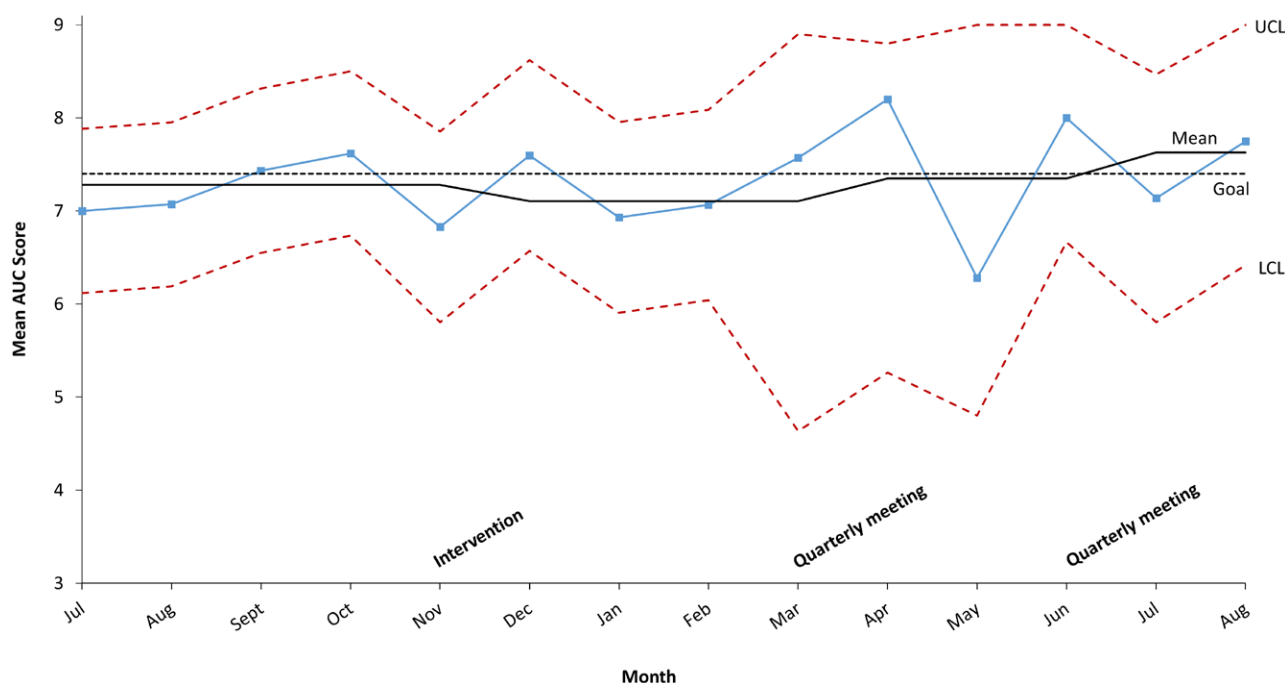


Fig. 3. SPC chart of mean AUC score for initial outpatient transthoracic echocardiogram studies ordered before and after the initial intervention and after each subsequent quarterly meeting. LCL, lower control limit; UCL, upper control limit.

Table 1. Abnormal Findings on Transthoracic Echocardiogram by AUC Indication at Baseline and Postintervention

AUC Rating	Abnormal Findings (%)		P
	Baseline	Post-intervention	
Appropriate	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 barium swallow 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 chemotherapy.

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 the percentage of studies ordered for “rarely 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.^{6,15}

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%).^{10–12} 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	No
Secundum ASD, moderate	Innocent murmur	None	Yes
Aortic hypoplasia, mild	Innocent murmur	None	Yes
Secundum ASD, small	Innocent murmur	Right ventricular hypertrophy	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.

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 echogenic 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.⁹

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 al¹⁶ 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

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.

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