ORIGINAL ARTICLE

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Appropriateness and diagnostic yield of inpatient pediatric echocardiograms

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Abstract

Objective: Multiple reports have shown echocardiograms for certain indications are neither cost-effective nor of high diagnostic yield. Given the ease with which tests can be obtained at a tertiary academic children's hospital, our aims were to: (1) determine the diagnostic yield of inpatient studies by in-hospital location; (2) evaluate inpatient echocardiograms to determine indications and level of appropriateness; and (3) evaluate the frequency of cardiology involvement prior to those echocardiograms.

Design: All initial inpatient echocardiograms interpreted at our institution from February 2009 to December 2014 were reviewed retrospectively. Patient location was grouped as pediatric intensive care (PICU), emergency department (ED), and general floor.

Results: There were 727 first-time inpatient echocardiograms that met inclusion criteria. Pathology was identified in 25% of the study echocardiograms, with 11% of all studies demonstrating pathology that could alter patient management (moderate or severe pathology). The studies performed in the PICU and ED had more severe pathology compared with those from the general floor ($P < .001$, .003; respectively). Few echocardiograms were performed for rarely appropriate indications on the general floor (7%) and PICU (2.2%). Over 75% of general floor echocardiograms performed for a pathologic murmur yielded normal or incidental findings. Cardiology consultation was documented in only 7.5% of general floor studies.

Conclusion: The diagnostic yield of inpatient, first-time pediatric echocardiograms is relatively low. The majority of studies that identified pathology were performed on patients located in higher acuity units. General floor echocardiograms for murmurs had a low diagnostic yield, raising the question of cardiology consultation versus direct echocardiogram ordering for subjective physical exam signs.

KEYWORDS
cardiology consultation, general floor, echocardiogram indications, murmur

1 | INTRODUCTION

Echocardiography is the most commonly used cardiac imaging modality and remains a major tool in evaluating cardiac structure and function in the pediatric population. Echocardiography is safe, readily available, and quickly interpretable by trained echocardiographers.[1] These same attributes may also lead to its overuse in low diagnostic yield situations. Our group and others have shown that echocardiograms are neither

TABLE 1 Echocardiogram findings[6]

Normal	Normal cardiac structure and function (including patent foramen ovale)
Incidental	Findings not believed to necessitate cardiology follow-up (e.g., tiny PDA, physiologic peripheral pulmonary stenosis, left superior vena cava, tiny coronary fistula, anomaly of aortic arch without evidence of a vascular ring).
Pathologic	
–Minor	Findings other than incidental that may require follow-up without anticipated intervention (e.g., small ASD, VSD or PDA, greater than mild AV valve regurgitation, mild pulmonary stenosis, mitral valve prolapse, or bicuspid aortic valve without stenosis or insufficiency).
–Moderate	Findings that alter patient management but do not require urgent intervention (e.g., moderate to large septal defects or PDAs, bicuspid aortic valve with stenosis or insufficiency, anomalous aortic origin of a coronary artery).
–Severe	Findings that require urgent intervention (e.g., critical valve stenosis, moderate to severe coarctation, severely reduced cardiac function, large pericardial effusion, anomalous origin of coronary artery from the pulmonary artery).

ASD, atrial septal defect; AV, atrioventricular; PDA, patent ductus arteriosus; VSD, ventricular septal defect.

cost-effective nor of high diagnostic yield for a number of outpatient indications.[1–5] Recent appropriate use criteria (AUC) have been published regarding outpatient echocardiograms;[1] however, little has been done to evaluate inpatient echocardiogram ordering practices. Given the ease with which tests can be obtained at a tertiary academic children's hospital, and the continued emphasis to provide high quality, low cost medical care, this is an area of particular importance. Our study aims were to: (1) determine the diagnostic yield of inpatient studies as related to hospital location; (2) evaluate inpatient echocardiograms to determine common indications and level of appropriateness; and (3) evaluate the frequency of cardiology involvement prior to performed echocardiograms.

2 | METHODS

This study was approved by the University of Arkansas for Medical Sciences Institutional Review Board. Arkansas Children's Hospital (ACH) is a tertiary free-standing children's hospital with 15 529 inpatient hospitalizations in 2015. The echocardiogram laboratory is an open lab which allows all specialties to order echocardiograms. We retrospectively reviewed all first-time echocardiograms interpreted at our institution from February 2009 to December 2014 on patients from birth-to-19 years of age. The echocardiogram database included: study date, date of birth, weight, ordering physician, and location of the performed echocardiogram. We queried the database for all nonneonatology intensive care unit and noncardiology floor, first-time inpatient studies. By study design, we excluded neonatology intensive care unit echocardiograms due to difficultly classifying level of pathology in those situa-

tions. For example a patent ductus arteriosus, right ventricular hypertrophy, or elevated pulmonary vascular resistance likely represent different levels of pathology in a premature neonate compared with the patient population chosen in this study. Inpatient cardiology floor echocardiograms were excluded due to the predominance of patients with prior abnormal fetal echocardiograms. All echocardiogram reports were reviewed by a single investigator (S.M.L.). Studies were grouped according to patient location: pediatric intensive care unit (PICU), emergency department (ED), and general floor. Echocardiogram results were classified based on previously published ratings in the pediatric outpatient setting.[6] Echocardiogram findings were classified as normal, incidental or pathologic. Pathologic findings were graded as minor, moderate or severe (Table 1).[6] Based on the previous published ratings, moderate and severe findings were defined as pathology which may require future or urgent management or intervention.[6] An independent investigator (J.A.D.) reviewed 100 randomly selected echocardiograms to evaluate intra-observer agreement with regard to echocardiogram result.

Chart reviews were performed on patients who received echocardiograms on the general inpatient floor and PICU. ACH ED charts were transition to an electronic form in October of 2014 and therefore were not available for this subanalysis. Admission histories and physicals, progress notes prior to obtaining the echocardiogram, and discharge summaries were reviewed to determine the indication and appropriateness category using the 113 indications provided by the pediatric outpatient echocardiogram AUC document.[1] For the indication of murmur, documented description was evaluated to determine whether the provider suspected the murmur to be innocent or pathologic. Murmurs described as "soft," "intermittent," "positional," or less than 2/6 in intensity were deemed presumptively innocent. All others, including murmurs without description were classified as presumptively pathologic in quality. General floor charts were also reviewed to determine whether cardiology consultation occurred prior to obtaining the echocardiogram.

Data were analyzed using statistical software R v3.2.3 (R Foundation for Statistical Computing, Vienna, Austria). Summary statistics were expressed as median (1st quartile, 3rd quartile) for continuous variables, and count (proportion) for categorical variables. Pairwise comparisons were performed using Wilcoxon rank-sum tests for continuous/ordinal variables, and chi-square tests for categorical variables. The weighted kappa and its' 95% confidence interval (CI) were estimated to evaluate intra-observer agreement with regard to echocardiogram result.[7] P values $\leq .05$ were used to indicate statistical significance. Due to the exploratory nature of the study, no adjustment was made for multiple comparisons.

3 | RESULTS

There were 727 first-time inpatient echocardiograms that met inclusion criteria. Median patient age was 24.4 months (IQR 1.8, 159.1) (Table 2). Patients receiving echocardiograms in the ED were older ($P = .001$) and of greater weight ($P < .001$) compared with the general floor. There

TABLE 2 Patient demographics

	PICU (N = 145)	ED (N = 115)	General floor (N = 467)	Total (N = 727)
Age (months, IQR)	30.2 (2.1, 167.2)	117.5 (2.2, 183.9)*	13.4 (1.7, 140.3)	24.4 (1.8, 159.1)
Male (%)	84 (58%)	70 (61%)	273 (59%)	427 (59%)
Weight (kg)	13.8 (4.4, 48.5)	34.0 (4.9, 63.7)[†‡]	9.9 (4.3, 39)	12.8 (4.4, 46.3)

ED, emergency department; IQR, interquartile range; PICU, pediatric intensive care unit.
*Wilcoxon rank-sum tests were used for continuous variables. ED vs. general floor $P = .001$.
[†]ED vs. PICU $P = .02$.
[‡]ED vs. general floor $P < .001$.

was no difference in patient sex ($P = .57$). There was no difference between patients who received echocardiograms in the PICU compared with the general floor regarding age, weight, or sex ($P = .20, .19$, and .91; respectively).

Pathology was identified in approximately 25% of all studies, with 2.6% of studies resulting in urgent changes to management. Moderate or severe pathology was present in 11% of studies (Table 3). About 64% of studies were from the general floor, 20% from the PICU, and 16% in the ED. Pathology was less common, and less severe, on general floor echocardiograms, compared with those in the PICU and ED ($P < .001, .003$; respectively). Severe pathology was rarely found on echocardiograms from the general floor (2 patients, 0.43%). Intra-observer agreement was performed on 100 randomly selected echocardiograms. The weighted kappa and 95% CI were estimated to be 0.85 (0.75, 0.94) indicating almost perfect agreement.[8]

A flow chart of general floor inpatient echocardiograms is shown in Figure 1a. During this time period, ACH switched to an electronic medical record with prior documentation scanned to the medical record. Sixty-nine studies (15%) had inadequate information to determine AUC indication. About 81% of studies where classified as appropriate (A), 6.5% were classified as may be appropriate (M), 7.0% as rarely appropriate (R), and 5.5% as unclassifiable (U). Of the echocardiograms rated U, the most common indication was for apnea or Apparent Life Threatening Event (ALTE) (20, 91%). Of the echocardiograms rated A, the most common were pathologic murmur (39%), hypertension (11%), positive blood cultures suggestive of endocarditis (8.0%),

abnormal EKG (7.5%), and symptoms and/or signs of congestive heart failure (5.5%). Of note, assessment of ventricular function prior to chemotherapy represented 1.8% of first-time general floor echocardiograms. Of the echocardiograms rated R, the most common was presumptively innocent murmur (12, 3.0% total, 43% of all R echocardiograms), followed by syncope without signs or symptoms of cardiovascular disease (3), probable neurocardiogenic (vasovagal) syncope (3), nonexertional chest pain without mention of a previous EKG (3), and reproducible chest pain with palpation or deep inspiration (3).

A flow chart of PICU echocardiograms is shown in Figure 1b. Six percent of those studies had inadequate information to determine an AUC indication. About 94% of studies were classified a A, and 2.2% were classified as R (all for presumptively innocent murmurs without signs or symptoms of cardiovascular disease). The most common indications were symptoms and/or signs of congestive heart failure (38%), pathologic murmur (22%), hypertension (8.8%), and positive blood cultures suggestive of endocarditis (8.1%).

For general floor echocardiograms there was a significantly higher likelihood of finding pathology with A classified indications compared with indications classified as either M or R ($P = .002$) (Figure 2). Description of R classified indications which yielded pathology is shown in Table 4. The single patient with moderate pathology had symptoms consistent with vasovagal syncope, and the initial echocardiogram raised concerns for anomalous origin of the left main coronary artery arising from the noncoronary sinus of Valsalva. A gated cardiac computed tomography scan with angiography confirmed normal coronary artery origins in the patient. None of the 3 PICU echocardiograms classified as R yielded pathology.

Diagnostic yields for the most common general floor echocardiogram indications are shown in Figure 3. Murmurs believed to be pathologic found none or incidental findings in 75% of patients. Fifteen patients (9.7%) were found to have moderate pathology, and one patient (0.66%) was found to have severe pathology (coarctation of the aorta and severe branch pulmonary artery hypoplasia in a patient later found to have Alagille syndrome). Of patients with hypertension, 1 was found to have severe pathology in the form of coarctation of the aorta. In patients with blood cultures suggestive of endocarditis, 81% of those echocardiograms were normal, and the remainder showed mild pathology. In patients with an abnormal EKG without symptoms, 83% of those echocardiograms yielded normal findings. PICU diagnostic yields per indication are shown in Figure 4.

TABLE 3 Inpatient diagnostic yield

	PICU (N = 145)	ED (N = 115)	General floor* (N = 467)	Total (N = 727)
Normal	82 (57)	71 (62)	339 (73)	**492 (68)**
Incidental	13 (9)	6 (5.2)	34 (7.3)	**53 (7.3)**
Minor	25 (17)	15 (13)	58 (12)	**98 (13)**
Moderate	18 (12)	13 (11)	34 (7.3)	**65 (8.9)**
Severe	7 (4.8)	10 (8.7)	2 (0.43)	**19 (2.6)**

Data expressed as number (%).
ED, emergency department; PICU, pediatric intensive care unit.
*Wilcoxon rank-sum tests were used in all analyses. There was significantly more severity in the PICU and ED group compared with general floor ($P < .001, .003$; respectively).
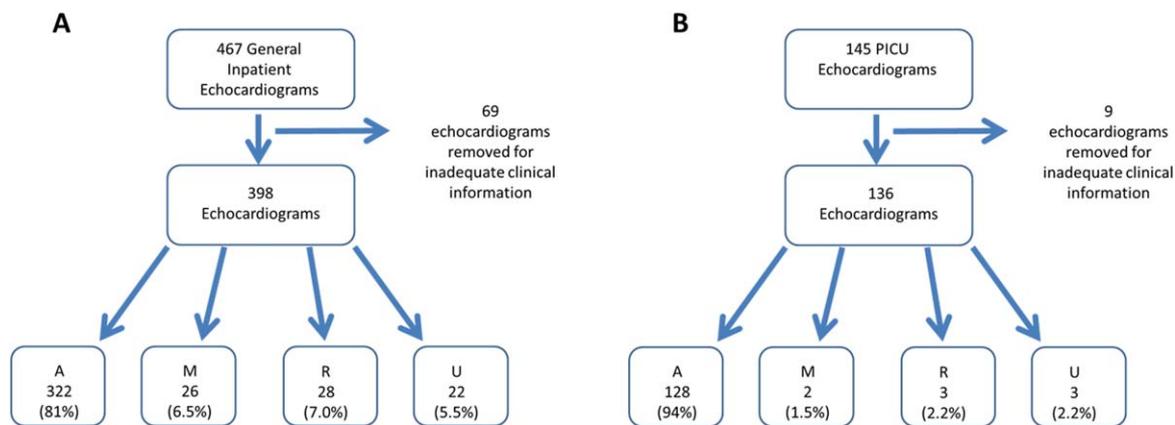
FIGURE 1 General floor **(A)** and PICU **(B)** echocardiogram flow chart. A, appropriate; M, may be appropriate; R, rarely appropriate; U, unclassifiable.

Cardiology consultation was confirmed prior to 29 general floor echocardiograms (7.5%). This increased to 74 cases (19%) when accounting for patients who had EKGs read by cardiology as abnormal. Of the 29 cases where an echocardiogram was performed after cardiology consultation, 9 were for abnormal EKG without symptoms, 5 were for syncope with abnormal EKG, and 3 were for pathologic murmur. The diagnostic yield of the 29 cardiology consults were similar to the entire cohort (17%, $P = .91$). For the murmur indication, 1 echocardiogram demonstrated pathology, 1 demonstrated an incidental finding of peripheral pulmonic stenosis in a newborn, and 1 echocardiogram was normal. Only 1 cardiology consultation echocardiogram (3.4%) was classified with an R indication. This is compared with 27 cases of indications classified as R in the 356 cases (7.6%) where no documented cardiology consultation occurred ($P = .41$).
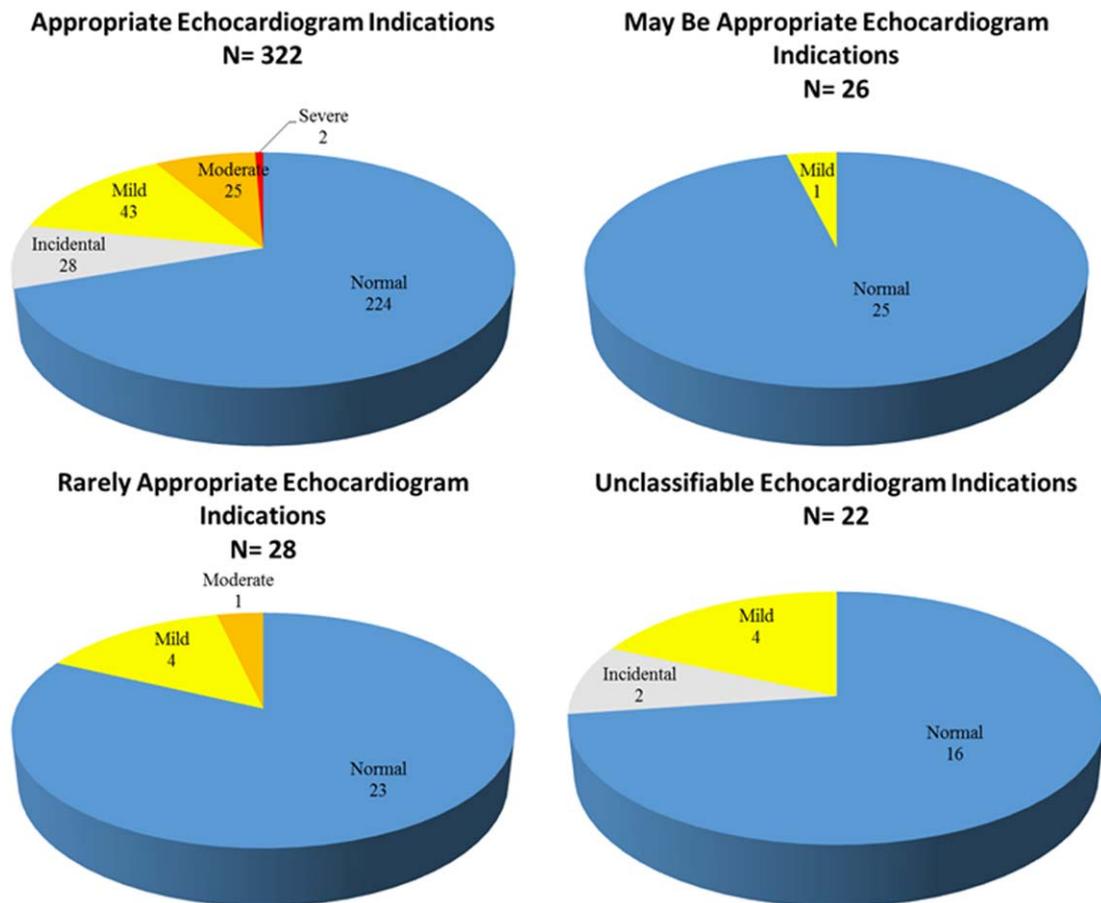

FIGURE 2 General floor echocardiogram findings by level of appropriateness.

TABLE 4 Rarely appropriate echocardiograms with pathology

Description with indication (AUC indication number)[1]	Pathology
16 yo with syncopal episodes consistent with vasovagal syncope. Probable neurocardiogenic syncope (23)	Bicuspid aortic valve without stenosis or insufficiency
14 yo with syncopal episode in setting of asthma attack. Syncope with known noncardiovascular cause (27)	Mild concentric left ventricular hypertrophy
1 month old with described intermittent, blowing murmur. Presumptively innocent murmur without symptoms, signs, or findings of cardiovascular disease (39)	Small secundum atrial septal defect
3 month old with described soft murmur. Presumptively innocent murmur without symptoms, signs, or findings of cardiovascular disease (39)	Small muscular ventricular septal defect
14 yo with nonexertional syncope believed secondary to vasovagal syncope. Probable neurocardiogenic (vasovagal) syncope (23)	Echocardiography concern for anomalous left coronary artery origin from the noncoronary cusp. Later confirmed normal by CT angiogram

4 | DISCUSSION

This study is the first, of our knowledge, to evaluate pediatric inpatient echocardiograms using the recent pediatric echocardiogram outpatient appropriate use guidelines.[1] This is particularly important given the ease with which studies can be performed in a tertiary children's hospital. The principal finding of our study is the relatively low diagnostic yield of inpatient first-time echocardiograms. Overall, 25% of first-time echocardiograms yielded pathology with 2.6% of these studies finding severe pathology requiring urgent intervention. Pathology, and in particular more severe pathology, was increasingly found in hospital locations with higher acuity (i.e., PICU and ED) compared with the general floor. The increased incidence of pathology in higher acuity areas is understandable given that patients in those locations are more likely to have hemodynamic or respiratory compromise which may be secondary to, or directly affecting, the cardiovascular system. Not surprisingly, the most common indication in PICU studies was for symptoms and or signs of congestive heart failure. Most frequently these represented studies performed on patients in shock with escalation of inotropic medications, occasionally before or during the process of extracorporeal membrane oxygenation
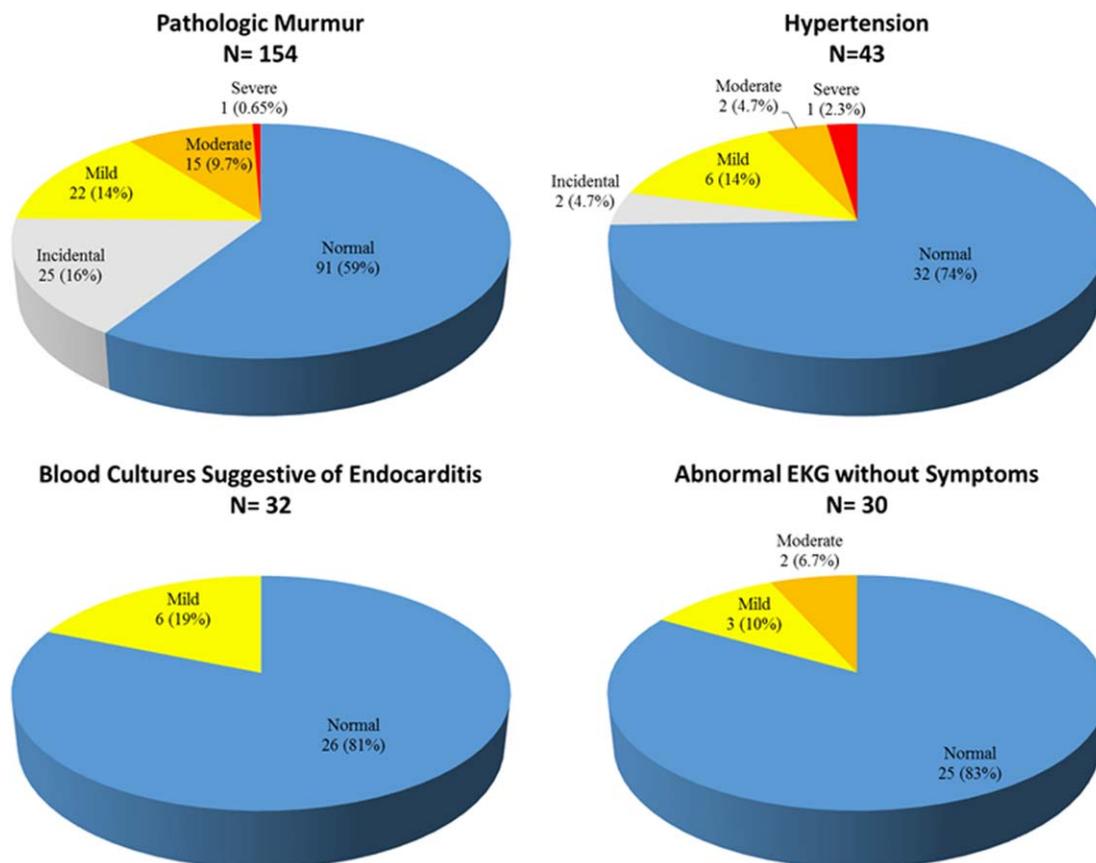

FIGURE 3 General floor echocardiogram findings by indication.

Symptoms and/or Signs of CHF
N=51

![Pie chart: Normal 22 (43%), Incidental 3 (5.9%), Mild 10 (20%), Moderate 10 (20%), Severe 6 (12%)]

Pathologic Murmur
N= 30

![Pie chart: Normal 12 (40%), Incidental 8 (27%), Mild 3 (10%), Moderate 7 (23%)]

Hypertension
N=12

![Pie chart: Normal 9 (75%), Mild 3 (25%)]

Blood Cultures Suggestive of Endocarditis
N= 11

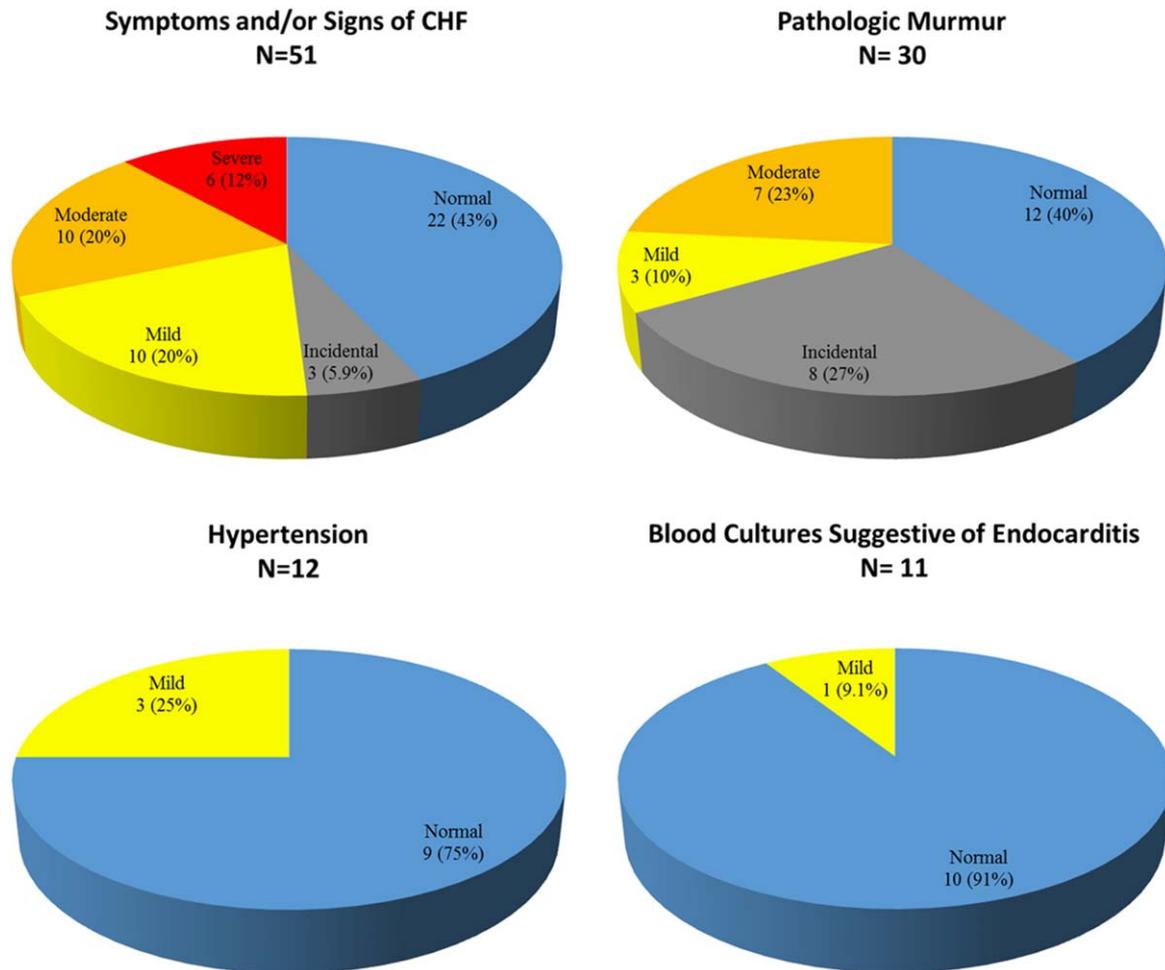![Pie chart: Normal 10 (91%), Mild 1 (9.1%)]

FIGURE 4 PICU echocardiogram findings by indication. CHF, congestive heart failure.

(ECMO) cannulation. Compared with the prior outpatient AUC implementation project,[6] our inpatient diagnostic yield was higher (25% vs. 10%). This is likely due to the higher acuity level of patients requiring inpatient care. There was a greater percentage of pathologic murmurs, and signs and symptoms of congestive heart failure in our cohort compared with the outpatient study. In addition, our cohort represented a younger age group (median age 24.4 months vs. 10 years),[6] increasing the likelihood of finding previously undiagnosed congenital heart disease.

Congenital heart disease is relatively rare, with incidences ranging from 6 to 75 per 1000 depending on the inclusion of hemodynamically insignificant abnormalities.[9] Despite the rarity, timely diagnosis of structural or functional cardiac abnormalities requires clinical suspicion and can be lifesaving. In addition, in high acuity situations where the etiology of a patient's clinical course is ambiguous, quickly ruling out a cardiac cause can be essential in the patient's care. There are also situations where echocardiograms are performed for initial surveillance without the expectation of finding cardiac pathology. Examples include assessing for ventricular hypertrophy in hypertensive patients, and assessing for ventricular function in patients exposed to cardiotoxic chemotherapy medications. Therefore, the rate of pathology is not an ideal method for evaluating appropriate echocardiogram ordering but rather provides an estimate of pretest probability.

The second aim of our study was to evaluate the indications of inpatient echocardiograms. Overall, the frequency of R classified echocardiograms was relatively low, and comparable to previous evaluations in the outpatient pediatric cardiology setting.[6] Our results suggest there is good conceptual agreement between pediatric cardiologists and pediatric inpatient providers from tertiary academic centers with regard to appropriate echocardiogram ordering. An ALTE was the most common unclassifiable indication using the pediatric outpatient AUC document. Prior research has shown less than 1% of ALTE patients are found to have significant heart disease.[10] Patients with ALTE and an abnormal EKG, or other signs/symptoms or findings of cardiovascular disease represent examples where an echocardiogram would likely be appropriate.

Appropriate echocardiograms identified pathology at a much higher rate compared with those indications classified as M, or R. In addition, the pathologic findings in echocardiograms ordered for R-classified indications were likely unrelated to the initial indication. The example of the patient with vasovagal syncope and concern for a coronary anomaly demonstrates the dangers of ordering echocardiograms with low pretest probability. That patient required a computed tomography scan with angiography adding extra medical cost, subjecting the patient to ionizing radiation, and likely increasing patient/family anxiety secondary to a low-yield echocardiogram indication.

Evaluating indications separately, the most common indication was a pathologic murmur, and presumptively innocent murmurs made up the most common rarely appropriate indication. The large majority of presumptively pathologic murmurs on the general floor demonstrated normal or incidental findings. The diagnostic yield for these studies was notably lower compared with that of the pediatric cardiologists in the outpatient AUC implementation project (25% vs. 40%).[6] In a prior study, 62% of general medical ward consultations were for innocent murmurs.[11] High output states brought on by fever, pain, anxiety, and dehydration may accentuate or bring on innocent flow murmurs not usually apparent.[12] In addition, previously discussed issues of decreased auscultatory skills of general pediatricians and trainees may also play a role in the low rate of pathology found in echocardiograms performed for murmur indications.[12,13]

Our final aim was to evaluate the prevalence of cardiology consultation prior to performed echocardiograms in our tertiary academic children's hospital. The ACH echocardiogram laboratory is an open laboratory which does not require cardiology consultation prior to obtaining an echocardiogram. Cardiology consultations prior to ordering an echocardiogram were relatively rare, and only improved modestly when a cardiologist's official read of an EKG as abnormal was considered to be a form of consultation. While unlikely, the frequency of consultations may be an underestimate due to incomplete documentation. The diagnostic yield of cardiology consultation echocardiograms did not differ from the entire sample, however the small number of consultations were predominantly for abnormal EKG without symptoms, and syncope with an abnormal EKG. Although appropriate, these indications are known to have a low yield of uncovering cardiac pathology.[6,14] Although our data did not have the power to meet statistical significance, we believe that cardiology involvement would further decrease low-yield, rarely appropriate echocardiogram ordering. It is therefore the practice at some tertiary children's hospitals to require a cardiology consultation prior to obtaining an echocardiogram.[11] Such a practice would require agreement between both the inpatient teams and the cardiology group, as it would depend upon cardiology availability to evaluate the increased consult volume. For lower acuity locations like the general inpatient floor, selective restriction for subjective signs, such as murmurs, may be a feasible alternative. Previous data have shown the high accuracy of pediatric cardiologists in distinguishing pathologic from innocent murmurs.[15–17] In addition, our data show a rare rate of severe/urgent pathology for lower acuity locations, making a strategy of a thorough inpatient cardiology consultation for these indications (with a possible delay in diagnosis) likely safe from a patient care standpoint. Lastly, recent publications have also demonstrated low-reliability of EKGs in identifying cardiac pathology as it pertains to left ventricular hypertrophy in vasovagal syncope patients, and left axis deviation in asymptomatic children, further supporting cardiology evaluation rather than direct echocardiogram ordering in those situations.[18,19]

This study was retrospective and is susceptible to limitations inherent to such a study design. The study relied on accurate documentation especially as it pertained to cardiology consultation taking place prior to the echocardiogram being performed. ACH underwent a change to

an electronic medical record during our study period likely accounting for the inability to determine an echocardiogram indication or cardiology consultation in some first-time echocardiograms. As mentioned in our methods, electronic documentation of ED echocardiograms was not available to classify an AUC indication. In addition, our study was unable to account for the total number of cardiology consultations, specifically when a cardiology consultation was obtained and a low-yield echocardiogram indication was avoided. Future studies in that regard would be helpful to assess for possible improvement in resource utilization with cardiology consultation rather than direct echocardiogram ordering. Lastly, this is a single-center experience which may not be representative of other tertiary care children's hospitals.

In conclusion, there is a relatively low diagnostic yield of first-time pediatric inpatient echocardiograms. Most of the discovered pathology, especially moderate to severe pathology, was found in patients located in higher acuity units. Echocardiograms ordered in a general inpatient setting had a low occurrence of rarely appropriate indications. Echocardiograms for murmurs on the general floor had a low diagnostic yield, raising the question of cardiology consultation versus direct echocardiogram ordering for subjective physical exam signs. In addition, specific inpatient pediatric AUC guidelines may be helpful in the future to improve medical resource utilization.

DISCLOSURES

The authors have no financial relationships relevant to this article to disclose.

AUTHOR CONTRIBUTIONS

Study concept and design were done by S.M.L, E.B, J.A.D, and R.T.C.; data analysis and interpretation were done by S.M.L, E.B, J.A.D, X.T., and R.T.C.; drafting of the article was done by S.M.L; critical revision of the article was done by S.M.L, E.B, J.A.D, X.T., and R.T.C. The article was approved by all authors.

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