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ORIGINAL ARTICLE

Implementation of a Pediatric Chest Pain Local Consensus Guideline Decreases the Total Tests Performed Without Negatively Affecting the Yield of Abnormal Cardiac Results

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Abstract

Pediatric chest pain is common and though usually benign often leads to unnecessary diagnostic testing. There is limited evidence as to whether a local consensus guideline can decrease testing frequency without negatively affecting the overall yield. In addition, it is unknown whether the addition of pulmonary function testing to a cardiopulmonary exercise test increases the diagnostic yield in pediatric patients with chest pain. A retrospective chart review was performed on all new pediatric patients who presented with chest pain at our academic center's pediatric cardiology clinic 18 months before and after the implementation of a standard management guideline. Data from the encounter-associated echocardiogram, cardiopulmonary exercise test, and pulmonary function test, when available, were analyzed. There were no significant differences in patient volume or demographic characteristics in the 18 months before ($n=768$) and after ($n=778$) guideline implementation. There were significant reductions in the number of ordered echocardiograms ($n=131$; 17% vs. $n=75$; 9.6%, $p<0.001$) and cardiopulmonary exercise tests ($n=46$; 6% vs. $n=29$; 4%, $p=0.04$) with no concerning pathology discovered in either group. Associated pulmonary function testing performed prior to with exercise testing discovered abnormalities in 19% of the total patients tested. The implementation of a local consensus guideline for pediatric chest pain results in fewer unnecessary tests ordered. There was no concerning pathology before or after guideline implementation, therefore conclusions regarding the diagnostic yield of these guidelines are unfeasible. The addition of pulmonary function testing to cardiopulmonary exercise tests increases the potential diagnostic yield in these patients.

Keywords Chest pain · Echocardiogram · Cardiopulmonary exercise test · Pediatric

Introduction

Chest pain is a common complaint with 20% to 40% of people experiencing it at some point in their lifetime [1]. Despite its prevalence, chest pain in children has a cardiac etiology less than 1% of the time with the most common identifiable causes of pediatric chest pain being musculoskeletal and pulmonary [2, 3]. Despite this low incidence of cardiac etiology, pediatric chest pain remains a significant reason for referral to pediatric cardiology [4]. These referrals often lead to unnecessary testing, including echocardiogram and cardiopulmonary exercise testing (CPET). These tests can be a significant financial burden for both the patient and hospital [5].

As the work-up for pediatric chest pain rarely reveals pathology, institutions are implementing targeted testing or practice-based algorithms to minimize unnecessary testing [5]. There has been minimal research into whether these algorithms increase the diagnostic yield while decreasing the amount of total testing ordered. Additionally, even though pulmonary etiologies are a known major cause of pediatric chest pain, there has been no research into whether adding pulmonary function testing to the standard CPET performed during the work-up for chest pain increases the ability to detect meaningful pathology.

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The aims of this study are (i) to determine the effect of the newly instituted local consensus guideline on testing ordered; (ii) to examine if the overall yield for pathology changed after local consensus guideline implementation; and (iii) to examine if adding pulmonary function testing to CPET can increase the diagnostic yield in these patients. The hypothesis of this study is that the local consensus guideline will reduce the number of unnecessary tests ordered.

Methods

In October 2016, the Heart Institute at Cincinnati Children's Hospital Medical Center implemented a new local consensus guideline to be used by all pediatric cardiologists for the initial evaluation and management of chest pain in pediatric patients referred to the outpatient clinic with this chief complaint (Fig. 1). This local consensus guideline was developed by the authors using a review of the literature and available expert opinion. To achieve consensus approval, all outpatient pediatric cardiologists had the opportunity to provide feedback on multiple iterations of the guideline prior to widespread implementation. The guideline was available at every outpatient clinic visit with a chief complaint of chest pain. When utilized, nearly all providers reported following the guideline. There was widespread adoption as monitored by the electronic medical record.

Subsequently, a retrospective chart review of all pediatric patients who presented as a new patient to the pediatric cardiology clinic with chest pain from April 1, 2015 to April 1, 2018 was performed. Exclusion criteria were patients older than 21 years of age and patients seen in the emergency department or other inpatient areas of the hospital for chest pain prior to the outpatient cardiology visit. As the guideline was released on October 1, 2016, this was used as the delineating point to compare outcomes before and after CPG implementation. A chart review was performed to determine if these patients had an echocardiogram, CPET and/or pulmonary function testing as part of the work-up for chest pain, and the results for those studies were recorded. CPET was included as local practice for chest pain evaluation often included a screening exercise test; this practice was discourage in the local consensus guideline (Fig. 1). In addition, other co-morbidities that could potentially explain abnormal results (i.e., cardiomyopathy, myocarditis, etc.) were noted.

Transthoracic echocardiography was performed with either a Philips iE-33 or EPIQ system (Philips Electronics; Andover, MA). Measurements were analyzed using Syngo Dynamics (Siemens Healthcare, Munich, Germany). All studies were interpreted by a pediatric cardiologist. CPET was performed on the cycle ergometer using the ramp protocol. The ramp cycle ergometry protocol uses an upright cycle ergometer (Corival; Lode; Groningen, The Netherlands) and consists of setting an initial work rate based on patient's body surface area with linear increases every minute for a goal to reach peak exercise after eight to ten minutes. Expired gases were measured continuously using breath-by-breath gas analysis throughout the study utilizing a metabolic cart (Ultima Cardi02; Medgraphics MGC Diagnostics; Saint Paul, Minnesota or TrueMax 2400; Parvo Medics; Salt Lake City, Utah). The predicted peak oxygen consumption (VO_2) was calculated using the prediction equations described by Wasserman et al. 1999 and Cooper et al. 1984 [6, 7]. A percent predicted peak VO_2 greater than 80% was considered normal. Percent predicted peak power (in watts, W) was calculated using the prediction equation described by Wasserman et al. [6].

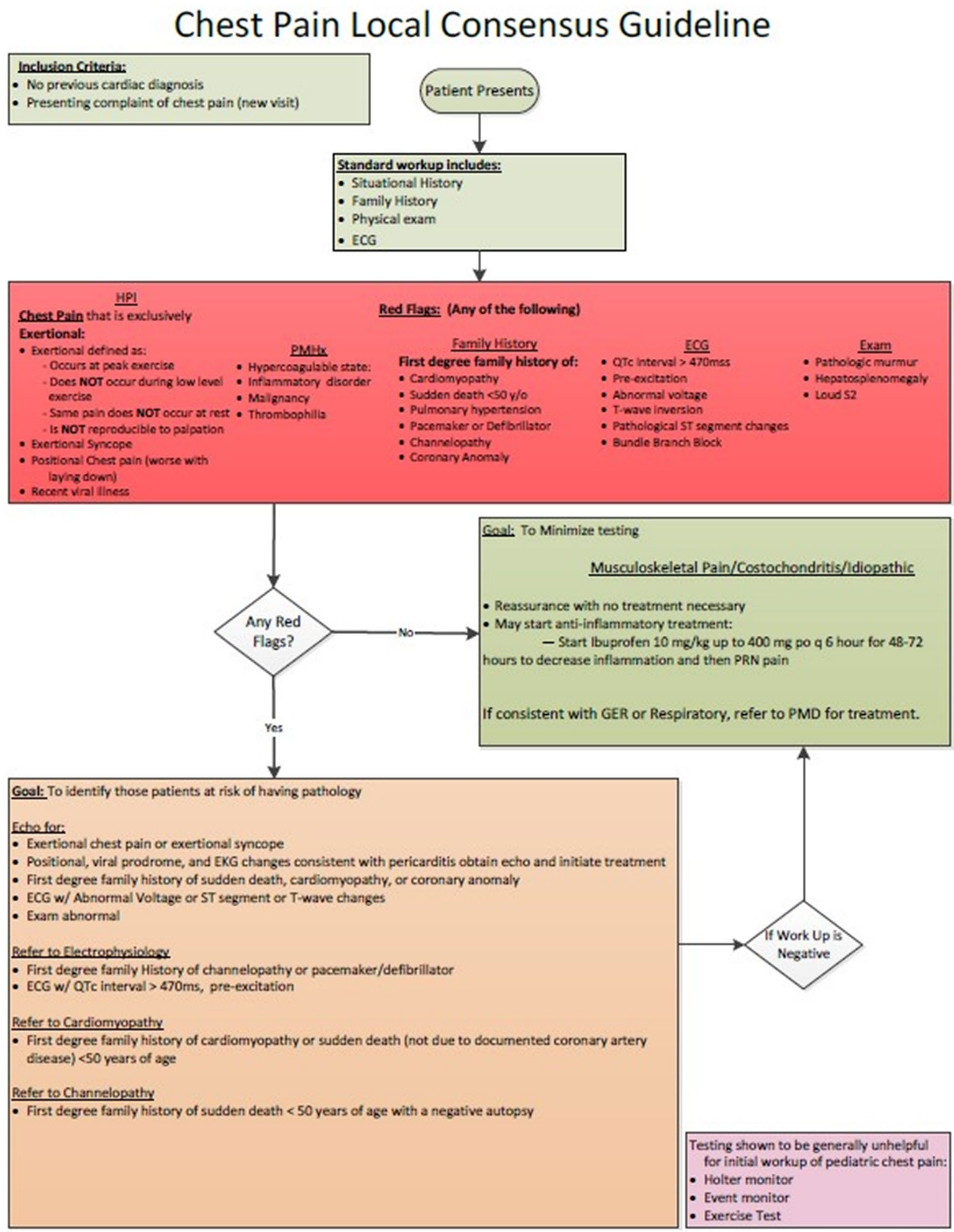
Fig. 1 Local consensus guideline for the initial evaluation and management of chest pain in the pediatric cardiology clinics at Cincinnati Children's Hospital Medical Center. *HPI* history of present illness, *PMHx* past medical history, *ECG* electrocardiogram, *GER* gastroesophageal reflux

As per local practice, all patients who had a CPET performed also had pulmonary function testing, which can aid in the interpretation of abnormal exercise test results due to potential pulmonary abnormalities. Pulmonary function testing was performed using a metabolic cart. Each patient performed three tests with the best result ultimately used for analysis. Forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) were measured in a standing position prior to exercise. Predicted FVC and FEV_1 were estimated based on gender, age and height [8]. Maximal voluntary ventilation (MVV) was calculated by $FEV_1 \times 40$ [8]. The percentage of exercise breathing reserve was defined as follows: [(MVV—maximum exercise ventilation)/MVV × 100] [6]. Restrictive lung disease was defined as having a FVC and $FEV_1 < 80\%$ of predicted normal [8]. Obstructive lung disease was defined as having an FEV_1 and $FEV_1/FVC < 80\%$ of predicted normal [8].

Data are presented as mean ± standard deviation. Differences between study and control patients were assessed using an unpaired t-test for normally distributed data and the Wilcoxon Signed-Rank Test for non-normally distributed data where appropriate. All tests were performed two sided. A p value < 0.05 was considered significant. Statistical analyses were performed using JMP®, Version 14 from SAS Institute Inc. (Cary, NC).

Results

A total of 1547 patients younger than 22 years old were referred to Cincinnati Children's Hospital Medical Center's outpatient pediatric cardiology clinics from April 1, 2015 to April 1, 2018 with a chief complaint of chest pain. There


Chest Pain Local Consensus Guideline
Inclusion Criteria:
• No previous cardiac diagnosis
• Presenting complaint of chest pain (new visit)
Patient Presents
Standard workup includes:
• Situational History
• Family History
• Physical exam
• ECG
HPI
Chest Pain that is exclusively
Exertional:
• Exertional defined as:
- Occurs at peak exercise
- Does NOT occur during low level exercise
- Same pain does NOT occur at rest
- Is NOT reproducible to palpation
• Exertional Syncope
• Positional Chest pain (worse with laying down)
• Recent viral illness
Red Flags: (Any of the following)
PMHx
• Hypercoagulable state:
• Inflammatory disorder
• Malignancy
• Thrombophilia
Family History
First degree family history of:
• Cardiomyopathy
• Sudden death <50 y/o
• Pulmonary hypertension
• Pacemaker or Defibrillator
• Channelopathy
• Coronary Anomaly
ECG
• QTc interval > 470mss
• Pre-excitation
• Abnormal voltage
• T-wave inversion
• Pathological ST segment changes
• Bundle Branch Block
Exam
• Pathologic murmur
• Hepatosplenomegaly
• Loud S2
Any Red Flags?
No
Yes
Goal: To Minimize testing
Musculoskeletal Pain/Costochondritis/Idiopathic
• Reassurance with no treatment necessary
• May start anti-inflammatory treatment:
— Start Ibuprofen 10 mg/kg up to 400 mg po q 6 hour for 48-72 hours to decrease inflammation and then PRN pain
If consistent with GER or Respiratory, refer to PMD for treatment.
Goal: To identify those patients at risk of having pathology
Echo for:
• Exertional chest pain or exertional syncope
• Positional, viral prodrome, and EKG changes consistent with pericarditis obtain echo and initiate treatment
• First degree family history of sudden death, cardiomyopathy, or coronary anomaly
• ECG w/ Abnormal Voltage or ST segment or T-wave changes
• Exam abnormal
Refer to Electrophysiology
• First degree family History of channelopathy or pacemaker/defibrillator
• ECG w/ QTc interval > 470ms, pre-excitation
Refer to Cardiomyopathy
• First degree family history of cardiomyopathy or sudden death (not due to documented coronary artery disease) <50 years of age
Refer to Channelopathy
• First degree family history of sudden death < 50 years of age with a negative autopsy
If Work Up is Negative
Testing shown to be generally unhelpful for initial workup of pediatric chest pain:
• Holter monitor
• Event monitor
• Exercise Test

were 768 patients referred prior to October 1, 2016 before the implementation of the local consensus guideline and 778 patients referred after. A total of 206 echocardiograms were performed in these patients throughout the study period and the results are summarized in Table 1. In the 18 months prior to the implantation of the chest pain guideline, 17% of patients (131/768) had an echocardiogram, which decreased to 9.6% of patients (75/778) following guideline implementation ($p < 0.001$; Fig. 2). Multiple patients in both groups had incidental findings that were not likely related to their chest pain (Table 1). There was no significant cardiac pathology identified in the pre-guideline cohort. Following guideline implementation, there was one abnormal echocardiogram finding of mild left ventricular systolic dysfunction that improved without pharmacotherapy on repeat imaging 3 months later.

A total of 75 CPETs were performed from April 1, 2015 to April 1, 2018 for cardiac work-up of chest pain. There was no difference in the number of tests performed or demographic characteristics between groups. CPET results are noted in Table 2. Of note, 6% of patients (46/768) had a CPET ordered as part of their work-up for chest pain prior to CPG implementation compared to 4% of patients (29/778) following guideline implementation ($p = 0.04$; Fig. 2). There were no abnormal electrocardiographic findings during rest or exercise, and there were no worrisome symptoms during

Table 1 Results of testing performed in the 18 months prior to and after local consensus guideline implementation

	Pre-algorithm	Post-algorithm	Normal values	*p* value
Total Chest Pain Clinic Visits	768	778		
Age (years)	13.4 ± 4.3 (range 8–21)	13.5 ± 4.6 (range 9–21)	NA	0.7
Gender	M395, F373	M403, F375	NA	0.9
Echocardiogram	$N = 131$	$N = 75$		< 0.001
Age (years)	13.9 ± 6.4	13.6 ± 3.2	NA	0.7
Gender	M72, F59	M46, F29	NA	0.4
EKG findings	121 normal 5 ectopic atrial rhythm 2 possible ventricular enlargement 1 possible right atrial enlargement1 left axis deviation1 low voltage EKG	69 normal 3 non-specific interventricular conduction delay 2 possible ventricular enlargement	NA	NA
Abnormal results	5 patent foramen ovale 1 mild mitral valve prolapse 1 bicuspid aortic valve 1 small coronary artery fistula 1 mildly dilated aortic root	2 small atrial septal defect 1 mildly depressed left ventricular systolic function 1 mildly dilated aortic root		

Pre-algorithm (18 months prior to clinical practice guideline implementation), Post-algorithm (18 months after local consensus guideline implementation)

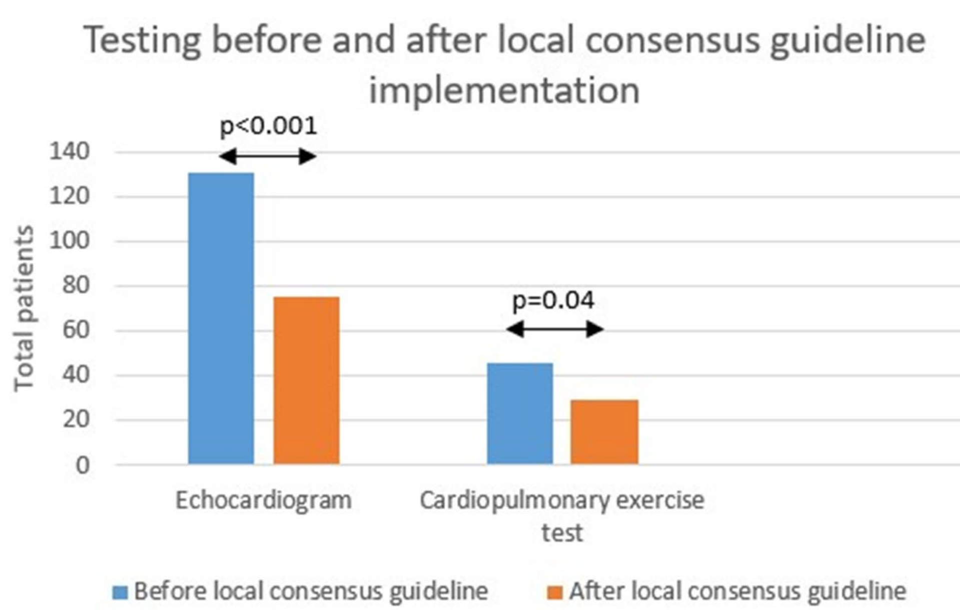


Fig. 2 Bar graph showing the difference between total tests ordered before and after local consensus guideline implementation. *CPG* clinical practice guideline

Table 2 Results of cardiopulmonary exercise and pulmonary function testing performed in the 18 months prior to and after local consensus guideline implementation

	Pre-algorithm	Post-algorithm	Normal values	p value
CPET results	$N=46$	$N=29$		0.04
Referral diagnosis	CP alone = 30 CP + palpitations = 5 CP + dizziness = 9 CP + dyspnea = 2	CP alone = 20 CP + palpitations = 6 CP + dizziness = 3	NA	NA
EKG findings	41 Normal 2 Non-specific T wave changes1 Non-specific interventricular conduction delay1 Left axis deviation 1 Frequent premature atrial contractions	25 Normal 3 Possible left ventricular hypertrophy1 Borderline long QT syndrome	NA	NA
Gender	M25, F21	M17, F12	NA	0.3
Age (years)	15.2 ± 2.7	14.1 ± 3.1	NA	0.1
Height (meters)	1.6 ± 0.1	1.7 ± 0.1	NA	0.2
Weight (kg)	63.4 ± 18	62.9 ± 19.9	NA	0.9
BSA	1.7 ± 0.3	1.7 ± 0.3	NA	0.6
RER	1.1 ± 0.1	1.2 ± 0.1	> 1.1	0.9
Exercise time (minutes)	8.8 ± 1.6	9.2 ± 1.9	Varies	0.5
% Predicted maximum load	85.1 ± 19.5	76.9 ± 22.8	> 80%	0.1
% Predicted maximum VO_2	84.4 ± 18.1	85.5 ± 22.4	> 80%	0.8
Maximum SBP (mmHg)	173 ± 21	170.4 ± 22.9	Varies	0.6
% Predicted Maximum HR	92.9 ± 6.5	94.5 ± 5.2	> 85%	0.3
% Predicted O_2 Pulse	91 ± 19.6	90.6 ± 22.8	> 80%	0.9
VE/VCO_2 slope	26.6 ± 5.1	29.7 ± 4.1	< 30	0.01
Breathing reserve percentage	52.1 ± 13.5	44.7 ± 20.4	> 20%	0.07
Pulmonary function test	$N=46$	$N=29$		0.04
% Predicted FVC	93.5 ± 18	104.5 ± 14.2	> 80%	0.008
% Predicted FEV_1	91 ± 22.5	98.1 ± 10.6	> 80%	0.1
% Predicted FEV_1/FVC	94.8 ± 9.3	93.7 ± 12.6	> 80%	0.7

testing that warranted further cardiology follow-up in either group. The results of the metabolic testing were similar between groups (Table 2). Of note, 43% of patients had a percent predicted $VO_2 < 80\%$ of predicted demonstrating an overall poor level of fitness in this cohort. Additionally, 29 of the 75 total patients had symptoms during exercise testing (39%), with 16 patients complaining of chest pain, 10 patients complaining of shortness of breath, 2 patients complaining of palpitations and 1 patient complaining of dizziness. Symptoms did not correlate to EKG abnormalities in any patient.

A total of 75 pulmonary function tests were performed during the study period with 46 pulmonary function tests prior to guideline implementation and 29 following guideline implementation ($p = 0.04$, Table 2). Pulmonary function test results are summarized in Table 2. Pulmonary function testing was abnormal on 19% (14/75) of patients. On further breakdown of pulmonary function testing results, 7% of patients (5/75) demonstrated an obstructive pattern (8% pre-guideline, 3% post-guideline; $p = 0.4$), 11% of patients (8/75) demonstrated a restrictive pattern (16% pre-guideline; 3% post-guideline; $p = 0.1$), and 1% of patients (1/75) demonstrated a mixed pattern with characteristics of both obstructive and restrictive respiratory physiology, and was in the pre-guideline group. 2% (1/46) of the pre-guideline group and 7% (2/29) of the post-guideline group had pulmonary limitations to exercise as evidenced by a breathing reserve < 20% ($p = 0.3$).

Discussion

While chest pain in children can be a frightening and uncomfortable problem for both children and their families, it is rarely due to a cardiac abnormality [2]. Local consensus guidelines have been proposed as a safe and effective tool to minimize unnecessary testing for pediatric chest pain [5, 9]. This study demonstrated a 36% decrease in echocardiograms and 39% decrease in CPETs ordered after guideline implementation. This decrease in practice variation and standardization of care represents a major advantage of a local consensus guideline. Practice variation has been shown to result in increased healthcare costs, worse patient outcomes and greater inefficiency [5]. Standardization is particularly important in a large hospital with multiple providers evaluating new patients in multiple locations. As healthcare costs continue to increase, reducing unnecessary resource utilization and thus decreasing unnecessary spending is essential.

This study demonstrates that the use of a local consensus guideline can reduce resource utilization, as there was a significant decrease in the total echocardiograms and CPETs performed following implementation. It is worth noting that the guideline does recommend an echocardiogram for the evaluation of chest pain that is deemed not to be low risk for an underlying cardiac pathology, such as exertional chest pain or those with physical exam or ECG abnormalities. Thus, some echocardiograms are expected in the post-implementation period. Without a full knowledge of each clinical scenario as this was a retrospective study relying on the electronic medical record, the truly minimized amount of echocardiograms is unknown. Interestingly, the guideline recommends against CPET in the initial evaluation of pediatric patients with chest pain, as prior studies suggest that CPET does not show cardiac abnormality in these patients [10–12]. Despite this recommendation, there were still 4% of patients that underwent this test. Although this was a statistically significant reduction from the pre-guideline period, it suggests that the guideline had a more meaningful impact on echocardiogram than CPET ordering practice patterns. There have been multiple studies demonstrating that local consensus guidelines could theoretically decrease unnecessary testing, but the minimal studies evaluating these guidelines in practice have demonstrated conflicting results [5, 9, 13, 14]. One notable study from Verghese GR et al. demonstrated a decrease in the total number of echocardiograms ordered before and after algorithm implementation over a total 2 year period [14]. A conflicting study from Nguyen T et al. found that appropriate use guidelines for pediatric chest pain did not significantly decrease the number of echocardiograms ordered [13]. Our results support the finding that a local consensus guideline can change echocardiogram ordering practice but also acknowledges that individual behavior may influence the guideline's overall impact.

Overall, as there was no concerning pathology noted before or after guideline implementation, no conclusion can be made about the effect of guideline implementation on the diagnostic yield of testing. There were a few incidental findings on echocardiography, but worrisome, symptom-causing pathology was not found on either echocardiography or CPET. This is likely due to the fact that cardiac causes for pediatric chest pain are rare. This is supported by data from Harahsheh AS et al. in which they discovered heart disease in 8/1656 (0.48%) of patients presenting with chest pain despite all these patients being high-risk based on medical and/or family history [9]. Given the rare nature of cardiac etiologies, our study may have been insufficiently powered to detect underlying pathology. Incidental findings are expected in a local consensus guideline that is appropriately sensitive, in order to ensure patients with important cardiac pathology are not improperly missed.

Unlike other algorithm-based chest pain management studies, all patients in this cohort who underwent a CPET also had pulmonary function testing performed. While there was an exceptionally low-yield for identifying cardiac pathology with echocardiography and cardiopulmonary exercise testing, one in five patients had abnormal pulmonary function testing when evaluated. While it is unclear if the abnormal pulmonary function testing reflects the cause of their chest pain or rather is an incidental findings, this may offer additional support to the non-cardiac nature of the majority of cases of pediatric chest pain. While musculoskeletal causes are felt to be the major identifiable etiology of pediatric chest pain (28–36% of cases), pulmonary limitations are often felt to be the second most common identifiable cause (7–19%) and are potential targets for treatment [3, 11, 12, 15]. However, a significant proportion of chest pain remains unknown in origin (12–52%; 3, 15). Our results suggest a higher rate of pulmonary causes of chest pain than previously reported, although some of these causes may have been incorrectly characterized as "idiopathic." Based on these findings, pulmonary function testing may be a higher-yield initial test for the evaluation of pediatric chest pain than either standard echocardiogram or exercise stress tests in an otherwise low cardiac risk patient.

There are many potential limitations to this study. First, this study occurred in a single large tertiary care medical center with multiple pediatric cardiologists and there was no way to monitor or enforce that physicians followed the guideline. The electronic medical record reminded the physician to follow the local consensus guideline prior to their closing of the medical encounter of the patient with chest pain, but there was no consequence if they chose not to adhere. Secondly, while there was not any significant cardiac pathology identified during the study period, it is possible that there was missed pathology. While the overall numbers of this study are on par or larger than comparable studies, there remains a potential for Type II error due to low sample size. Third, as this was a retrospective chart review accurate information on what aspects of the patient's chest pain necessitated acquiring additional testing is not readily available. Finally, these data only include patients seen in the outpatient setting and does not reflect patients seen in other settings such as the emergency department.

Conclusion

Local consensus guidelines are a feasible and reasonable tool to implement in a large tertiary care children's hospital for the initial evaluation and management of pediatric chest pain in an outpatient cardiology clinic. The use of a local consensus guideline can decrease practice variation and limit unnecessary tests such as echocardiograms and CPETs without negatively affecting the diagnostic yield. A number of patients undergoing evaluation for chest pain have abnormal pulmonary function testing, suggesting that the addition of pulmonary function testing in the work-up of pediatric chest pain may lead to increased diagnostic accuracy.

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Compliance with Ethical Standards

Conflicts of interest None.

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