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Article

Role of Chest Radiographs and Electrocardiograms in Predicting the Hemodynamics of Congenital Heart Disease

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Abstract: This study aimed to evaluate the role of chest radiographs and electrocardiograms in predicting the hemodynamics of congenital heart disease (CHD). This retrospective study included 50 patients with a diagnosis of CHD who had undergone any form of cardiac intervention, either surgical or nonsurgical between September 2019 and September 2020. Chest radiographs and electrocardiograms were evaluated and compared with the diagnostic gold standard echocardiography. Chest radiographs had the highest sensitivity, specificity, and accuracy, with all being 100%, in detecting situs and cardiac position. There was a very good agreement between chest radiographs and echocardiography in the detection of both situs and cardiac position ($\kappa = 1.00$, $p < 0.001$), while moderate agreement was observed for the detection of cardiomegaly, position of aortic knuckle, main pulmonary artery dilation, and right pulmonary artery dilation. Electrocardiograms had a high sensitivity (100.00%), but modest specificity and accuracy for the detection of left ventricle pressure overload. For the detection of left atrial enlargement and left ventricle volume overload, electrocardiograms had high specificity (94.12% and 94.29%, respectively) but low sensitivity and modest accuracy. There was a moderate agreement between electrocardiograms and echocardiography in the detection of right ventricle pressure overload ($\kappa = 0.43$, $p = 0.002$) and left ventricle volume overload ($\kappa = 0.46$, $p < 0.001$). The study findings indicate that chest radiographs and electrocardiograms alone are not adequate for the assessment of hemodynamics of CHD and reinstates the recommendation that in addition to routine chest radiographs and electrocardiograms, echocardiography should be performed.

Keywords: congenital heart disease; chest radiograph; electrocardiogram; echocardiography

1. Introduction

Congenital heart disease (CHD) remains the most common birth defect, affecting approximately 0.8% to 1.2% of live births across the globe [1]. There is an increasing birth prevalence of CHD globally, with a rise from 4.55 per thousand in 1970-74 to 9.41 per thousand in 2010-17 [2]. CHD is characterized by a structural abnormality of the heart and/or great vessels that is present at birth [2]. Almost one-third of all major congenital anomalies consist of heart defects [3], and CHD malformations can occur as single lesions or in combination with other heart defects [4]. Isolated or single lesions include atrial septal defects (ASD), ventricular septal defects (VSD), and pulmonary stenosis (PS); complex

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or combination lesions include atrioventricular septal defects (AVSD), tetralogy of Fallot (TOF), and transposition of the great arteries (TGA) [4,5]. In 2017, ASD and VSD were reported as the most common subtype of CHD, accounting for almost 30% of all cases of CHD [1]. With only about 15% of CHD cases being attributable to a known cause [4], it presents a significant challenge in developing countries, where both the incidence and mortality rates of CHD have been rising [1]. Therefore, early detection and diagnosis as well as timely interventions are critical to reducing morbidity and mortality [5].

Clinical assessment along with chest radiographs and electrocardiograms remain the core of evaluating children with suspected CHD [6]. However, due to the advent of advanced imaging technologies such as echocardiography, computed tomography (CT) and magnetic resonance imaging (MRI), chest radiographs and electrocardiograms have become traditional approaches [7]. Especially with echocardiography being considered as the primary diagnostic tool, the utility of these imaging modalities for the preliminary diagnosis of CHD is in a decreasing trend. Nonetheless, even in this era of high-end imaging modalities, chest radiographs and electrocardiograms remain the most widely available and economically viable imaging techniques for the initial examination of patients with suspected CHD. Especially in developing countries, these imaging modalities can still be valuable tools for the detection of CHD.

The effectiveness of the advanced imaging modalities including echocardiography, CT and MRI in the diagnosis and management of CHD is well-established [7]. Advanced computer and medical imaging technologies are often employed to obtain the local hemodynamics of the investigated site and illustrate the hemodynamic characteristics [8]. However, there is paucity of studies demonstrating the significance of chest radiographs and electrocardiograms in the detection of CHD. A prior study conducted in the United States demonstrated the advantages of chest radiographs and electrocardiograms in diagnosing certain cardiac defects precisely and emphasized that these diagnostic tools should be retained as a part of routine evaluation of CHD [6]. Another study conducted in Egypt examined the value of chest radiographs and electrocardiograms in the evaluation of patients with heart murmurs in the presence of echocardiography [9]. Nonetheless, to the best of our knowledge, there is no single study that demonstrates the role of these diagnostic tools for the assessment of hemodynamics of CHD. The current study aimed to evaluate the role of chest radiographs and electrocardiograms in predicting the hemodynamics of CHD, taking echocardiography as the diagnostic standard.

2. Materials and Methods

This was a retrospective study carried out in the Department of Pediatric Cardiology at Max Super Speciality Hospital in Delhi, India. Ethics approval was attained from the Institutional Ethics Committee, Devki Devi Foundation (Reference No: RS/MSSH/DDF/SKT-2/IEC/PED-CARDIO/20-44), prior to study commencement. All patients with a diagnosis of CHD who had undergone any form of cardiac intervention, either surgical or nonsurgical between September 2019 and September 2020, were included in this study. However, those patients who had not undergone any cardiac intervention, either invasive or noninvasive, and were managed medically were excluded. Data were collected in a pre-designed and pre-tested proforma. The chest radiographs and electrocardiograms were evaluated by a pediatric cardiologist, and results were compared with the final diagnosis of echocardiography.

Chest radiographs in anterior posterior, posterior anterior and lateral view were evaluated for the following parameters, namely situs, cardiac position, thymic shadow, cardiomegaly, right atrium enlargement, left atrium enlargement, right ventricle enlargement, left ventricle enlargement, position of aortic knuckle, ascending aorta dilatation, descending aorta dilatation, main pulmonary artery dilatation, right pulmonary artery dilatation, and left pulmonary artery dilatation. Similarly, radiographic features for pulmonary plethora, pulmonary oligemia, pulmonary arterial hypertension, and pulmonary venous hypertension were evaluated.

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The 12 lead electrocardiograms were evaluated for sinus rhythm, rate, P axis, QRS axis, PR interval, QTC interval, QRS duration, right atrial enlargement, left atrial enlargement, bundle branch block, and biventricular hypertrophy. Electrocardiogram features for volume overload and pressure overload of the right and left ventricle were evaluated.

The findings of chest radiographs and electrocardiograms were compared with the findings of echocardiography, taking this tool as the diagnostic standard. The findings from echocardiography were validated using standardized recommendations [10].

2.1. Statistical Analyses

The Statistical Package for Social Sciences (SPSS), Version 27 (SPSS Inc., Chicago, IL, USA), was used for the statistical analysis. The sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood ratio, negative likelihood ratio, and accuracy for each chest radiograph and electrocardiogram variables were calculated, in comparison with echocardiography as the gold standard diagnostic procedure. Cohen's kappa was also calculated as a measure of concordance, or agreement, between the diagnostic methods. Generally, the Cohen's kappa (κ) value ranges from 0 to 1, where 1 implies perfect agreement and 0 implies no agreement [11]. The following interpretations were used: poor agreement <0.20; fair agreement 0.20–0.40; moderate agreement 0.40–0.60; good agreement 0.60–0.80; and very good agreement >0.80. *P*-value of <0.05 was considered as statistically significant.

3. Results

A total of 50 patients (36 male, 14 female), aged 2 months to 23 years, who had a diagnosis of CHD, were included in this study. Chest radiographs and electrocardiograms, as well as the diagnostic gold standard echocardiography, had been performed for all patients.

3.1. Evaluation of Chest Radiographs

The findings of the chest radiographs in comparison with the diagnostic gold standard echocardiography are presented in Table 1. Chest radiographs had the highest sensitivity, specificity, and accuracy, with all being 100%, in detecting situs and cardiac position. For the detection of cardiac chamber enlargement, modest results were obtained, the sensitivity ranged from 57.89% to 84.62%, specificity ranged from 54.17% to 74.19%, while the accuracy ranged from 50.00% to 70.00%. For the detection of cardiac chamber dilation, chest radiographs had high specificity ranging from 93.48% to 97.96% and high accuracy ranging from 90.00% to 98.00%, but lower sensitivity ranging from 25.00% to 75.00%. For the detection of the position of aortic knuckle and pulmonary arterial hypertension, chest radiographs had high specificity (97.83% and 95.24%, respectively) and high accuracy (94.00% and 82.00%), but modest sensitivity (50.00% and 12.50%, respectively).

There was a very good agreement between chest radiographs and echocardiography in the detection of both situs and cardiac position ($\kappa = 1.00$, $p < 0.001$). Moderate agreement was observed for the detection of cardiomegaly ($\kappa = 0.49$, $p < 0.001$), position of aortic knuckle ($\kappa = 0.54$, $p < 0.001$), main pulmonary artery dilation ($\kappa = 0.46$, $p = 0.001$), and right pulmonary artery dilation ($\kappa = 0.56$, $p < 0.001$). However, there was a fair agreement between chest radiographs and echocardiography in the detection of right atrium enlargement ($\kappa = 0.39$, $p = 0.004$), left atrium enlargement ($\kappa = 0.35$, $p = 0.012$), left ventricle enlargement ($\kappa = 0.32$, $p = 0.023$), and left pulmonary artery dilation ($\kappa = 0.30$, $p = 0.025$).

Table 1. Sensitivity, specificity, predictive values, likelihood ratios, accuracy, and concordance of chest radiograph variables in comparison with echocardiography.

Variables	Sensitivity	Specificity	PPV	NPV	PLR	NLR	Accuracy	κ	p-value
Situs	100.00%	100.00%	100.00%	100.00%	-	0.00	100.00%	1.00	<0.001*
Cardiac position	100.00%	100.00%	100.00%	100.00%	-	0.00	100.00%	1.00	<0.001*
Cardiomegaly	85.00%	66.67%	62.96%	86.96%	2.55	0.23	74.00%	0.49	<0.001*

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RAE	84.62%	54.17%	66.67%	76.47%	1.85	0.28	70.00%	0.39	0.004*
LAE	66.67%	71.43%	50.00%	83.33%	2.33	0.47	70.00%	0.35	0.012*
RVE	81.82%	41.03%	28.13%	88.89%	1.39	0.44	50.00%	0.14	0.163
LVE	57.89%	74.19%	57.89%	74.19%	2.24	0.57	68.00%	0.32	0.023*
Position of AK	50.00%	97.83%	66.67%	95.74%	23.00	0.51	94.00%	0.54	<0.001*
AA dilation	25.00%	95.65%	33.33%	93.62%	5.75	0.78	90.00%	0.23	0.095
DA dilation	-	97.96%	0.00%	100.00%	-	-	98.00%	-	-
MPA dilation	50.00%	95.65%	50.00%	95.65%	11.50	0.52	92.00%	0.46	0.001*
RPA dilation	75.00%	93.48%	50.00%	97.73%	11.50	0.98	92.00%	0.56	<0.001*
LPA dilation	25.00%	97.83%	50.00%	93.75%	11.50	0.77	92.00%	0.30	0.025*
PAH	12.50%	95.24%	33.33%	85.11%	2.63	0.92	82.00%	0.10	0.398

PPV: positive predictive value; NPV: negative predictive value; PLR: positive likelihood ratio; NLR: negative likelihood ratio; κ: Cohen's kappa value; RAE: right atrium enlargement; LAE: left atrium enlargement; RVE: right ventricle enlargement; LVE: left ventricle enlargement; AK: aortic knuckle; AA: ascending aorta; DA: descending aorta; MPA: main pulmonary artery; RPA: right pulmonary artery; LPA: left pulmonary artery; PAH: pulmonary arterial hypertension. * Concordance (agreement) between chest radiograph and echocardiography, as measured by κ, is significant at $p < 0.05$.

3.2. Evaluation of Electrocardiograms

The findings of the comparison of electrocardiograms with the diagnostic gold standard echocardiography are outlined in Table 2. For the detection of left ventricle pressure overload, electrocardiograms had a high sensitivity (100.00%), but modest specificity (54.17%) and accuracy (56.00%). For the detection of left atrial enlargement and left ventricle volume overload, electrocardiograms had high specificity (94.12% and 94.29%, respectively) and modest accuracy (72.00% and 80.00%, respectively), but low sensitivity (25.00% and 46.67%, respectively). The accuracy of detecting other electrocardiogram variables ranged between 60.00% to 70.00%, despite the sensitivity ranging between 50.00% and 86.36%, and specificity ranging between 57.14% and 77.27%.

There was a moderate agreement between electrocardiograms and echocardiography in the detection of right ventricle pressure overload ($\kappa = 0.43$, $p = 0.002$) and left ventricle volume overload ($\kappa = 0.46$, $p < 0.001$). Fair agreement was observed for the detection of right atrial enlargement ($\kappa = 0.30$, $p = 0.027$), and non-significant fair agreement for left atrial enlargement ($\kappa = 0.23$, $p = 0.052$). However, other electrocardiogram variables had poor agreement with echocardiography.

Table 2. Sensitivity, specificity, predictive values, likelihood ratios, accuracy, and concordance of electrocardiogram variables in comparison with echocardiography.

Variables	Sensitivity	Specificity	PPV	NPV	PLR	NLR	Accuracy	κ	p-value
RAE	53.57%	77.27%	75.00%	56.67%	2.35	0.60	64.00%	0.30	0.027*
LAE	25.00%	94.12%	66.67%	72.73%	4.25	0.80	72.00%	0.23	0.052
RV-PO	86.36%	57.14%	61.29%	84.21%	2.02	0.24	70.00%	0.43	0.002*
RV-VO	63.64%	58.97%	30.47%	85.19%	1.55	0.62	60.00%	0.16	0.184
LV-PO	100.00%	54.17%	8.33%	100.00%	2.18	0.00	56.00%	0.09	0.133
LV-VO	46.67%	94.29%	77.78%	80.49%	8.17	0.57	80.00%	0.46	<0.001*
BVH	50.00%	62.50%	5.26%	96.77%	1.33	0.80	62.00%	0.03	0.709

PPV: positive predictive value; NPV: negative predictive value; PLR: positive likelihood ratio; NLR: negative likelihood ratio; κ: Cohen's kappa value; RAE: right atrial enlargement; LAE: left atrial enlargement; RV: right ventricle; LV: left ventricle; PO: pressure overload; VO: volume overload; BVH: biventricular hypertrophy. * Concordance (agreement) between electrocardiogram and echocardiography, as measured by κ, is significant at $p < 0.05$.

4. Discussion

Given that undiagnosed CHD can lead to life-threatening cardiovascular collapse and cardiac arrest, which are leading causes of death in children, screening and early

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detection of CHD are vital measures [12,13]. However, the diagnosis of CHD is challenging especially among children due to the numerous clinical signs including, dyspnea, cough, and failure to thrive, which can be misinterpreted as symptoms of other illnesses until the diagnosis of CHD is confirmed [14]. Taking a thorough medical history and performing a physical examination remain the integral aspects of diagnosing CHD. Despite asymptomatic and normal physical examination, many children are diagnosed with CHD necessitating the use of other diagnostic modalities for early detection and intervention in these subsets [12]. Traditional teaching methods always highlight chest radiographs and electrocardiograms as essential tools that add a substantial value in the diagnosis of cardiac diseases in children [9]. However, the role of chest radiographs and electrocardiograms in the detection of CHD is still questionable due to previous studies showing low sensitivity and specificity of these diagnostic tools [6,15,16]. Nonetheless, prior studies do recommend routine use of chest radiographs and electrocardiograms for the preliminary detection of CHD [6,9].

The current study demonstrated the role of chest radiographs and electrocardiograms in predicting the hemodynamics of CHD, taking echocardiography as the diagnostic standard. Chest radiographs had the highest sensitivity, specificity, and accuracy, with all being 100%, in detecting situs and cardiac position. There was a very good agreement between chest radiographs and echocardiography in the detection of both situs and cardiac position, while moderate agreement was observed for the detection of cardiomegaly, position of aortic knuckle, main pulmonary artery dilation, and right pulmonary artery dilation. Electrocardiograms had a high sensitivity of 100%, but modest specificity and accuracy for the detection of left ventricle pressure overload. For the detection of left atrial enlargement and left ventricle volume overload, electrocardiograms had high specificity but low sensitivity and modest accuracy. There was a moderate agreement between electrocardiograms and echocardiography in the detection of right ventricle pressure overload and left ventricle volume overload. Varied results were obtained for other chest radiograph and electrocardiogram variables in terms of sensitivity, specificity, accuracy, and concordance with echocardiography. Nonetheless, the study findings indicate that chest radiographs and electrocardiograms alone are not adequate for the assessment of hemodynamics of CHD and reinstates the recommendation that in addition to routine chest radiographs and electrocardiograms, echocardiography should be performed.

In this study, the sensitivity and specificity of chest radiographs for the detection of cardiomegaly were 85% and 66.67%, respectively with a positive predictive value of 62.96% and negative predictive value of 86.96%. In a study conducted by Satou et al., chest radiographs had a high specificity (92.3%) and negative predictive value (91.1%), a low sensitivity (58.8%) and positive predictive value (62.5%) in predicting cardiac enlargement in children [17]. Nonetheless, presence of cardiomegaly can be suspected if the cardiothoracic ratio is >60% in neonates, >55% in infants and >50% in children. In this study, the accuracy of chest radiograph in detecting cardiac chamber enlargement was 70% for right and left atrium, 50% for right ventricle, and 68% for left ventricle, which were lower than that reported in a prior study [9]. Tumkosit et al. reported moderate to high accuracy (73–92%) and specificity (61–96%) of chest radiographs to characterize pulmonary vascularity patterns, with moderate to good agreement (κ = 0.53–0.67) [18]. In our study, although high accuracy (82%) and specificity (95.24%) were obtained for the detection of pulmonary arterial hypertension, there was poor agreement between chest radiographs and echocardiography (κ = 0.1).

In the current study, the sensitivity, specificity and accuracy of electrocardiogram in detecting right atrial enlargement were 53.57%, 77.27% and 64%, respectively, which were lower than the 100%, 97.7% and 98.5% reported in a prior study [9]. The differences in the results could be attributed to the differences in sample size as well as the age group of patients included in the study. Electrocardiogram had a high sensitivity (100.00%), modest specificity (54.17%) and accuracy (56.00%) for the detection of left ventricle pressure overload, but modest sensitivity (50%), specificity (62.5%) and accuracy (62%) for detecting biventricular hypertrophy. Murphy et al. suggests that the use of a single criterion to

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detect left ventricular hypertrophy is often ineffective when the patients under study have diverse cardiac diseases and recommends using methods that integrate multiple electrocardiographic criteria [19].

While this study was focused on the role of chest radiographs and electrocardiograms in predicting the hemodynamics of CHD taking echocardiography as the diagnostic standard, several prior studies have investigated the accuracy of these tools in detecting several cardiac defects. Danford et al. demonstrated that chest radiograph and electrocardiogram had no independent advantage for defect-specific diagnosis of cardiac murmurs in children [6]. The findings of many prior studies indicate that chest radiograph and electrocardiogram have low sensitivity and specificity that can result in the misinterpretation of diagnosis for CHD [12,15,16,18,20,21]. In a retrospective study by Laya et al., the authors concluded that chest radiograph alone is not diagnostic of specific congenital cardiac lesions [15]. Similarly, Fonseca et al. reported that chest radiography had a low sensitivity for structural heart disease, and concluded that the chest radiography does not function as a screening test for neonates with suspected heart disease, particularly in small or premature neonates [22]. Birkebaek et al. evaluated the diagnostic value of chest radiography and electrocardiography while evaluating if asymptomatic children with a cardiac murmur had a heart disease as defined by echocardiography. However, their study demonstrated no role of these diagnostic tools in the detection of heart disease [21]. Corroborating the findings of the aforementioned studies, this study identified the need of other diagnostic tools in addition to chest radiograph and electrocardiogram for the preliminary diagnosis of CHD.

To the best of our knowledge, this study is one of the first to evaluate the role of chest radiographs and electrocardiograms in predicting the hemodynamics of CHD, taking echocardiography as the diagnostic standard. Set in a real-world clinical setting, this study illustrates the importance of these readily available and economically viable imaging tools for predicting the hemodynamics of CHD, especially in resource constraint settings. Nonetheless, this study has a few limitations. As the data were collected retrospectively from the hospital records, the skills of the individuals performing and reporting the chest radiographs, electrocardiograms and echocardiography were not assessed, which could have increased the technical variability. However, the chest radiographs and electrocardiograms were evaluated and compared with the final diagnosis of echocardiography by a pediatric cardiologist in this study. Many patients were lost to follow-up as this was a retrospective study, resulting in the small but adequate sample size (n = 50). Prospective clinical studies which include large sample sizes are needed to support or refute the findings from this study regarding the hemodynamic evaluation of CHD using chest radiographs and electrocardiograms, as compared to echocardiography.

5. Conclusions

This study is one of the first to evaluate the role of chest radiographs and electrocardiograms in predicting the hemodynamics of CHD, taking echocardiography as the diagnostic standard. In detecting situs and cardiac position, chest radiographs had the highest sensitivity, specificity, and accuracy, along with a very good agreement with echocardiography. While modest to high sensitivity, specificity and accuracy, along with moderate agreement with echocardiography, were obtained for some chest radiograph and electrocardiogram variables, varied results were obtained for other variables. Overall, the study findings indicate that chest radiographs and electrocardiograms alone are not adequate for the assessment of hemodynamics of CHD and reinstates the recommendation that in addition to routine chest radiographs and electrocardiograms, the diagnostic gold standard echocardiography should be performed.

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All authors critically reviewed the original draft. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Patient consent was waived as the data was collected retrospectively from the hospital records.

Data Availability Statement: The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest: The authors declare no conflict of interest.

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