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ACTA PÆDIATRICA NURTURING THE CHILD WILEY

ORIGINAL ARTICLE

Major congenital heart defects are rarely diagnosed after newborns' hospital discharge with modern screening

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Abstract

Aim: Our aim was to assess undiagnosed congenital heart defects (CHD) after newborns' hospital discharge in patients with a murmur or CHD suspicion, to find out the signs that predict CHDs and to estimate the costs of the examinations.

Methods: We reviewed retrospective medical records of patients (n = 490) referred for the evaluation of CHD suspicion during 2017–2018.

Results: The median age of the patients was 2.5 (IQR 0.5–7.4) years. Sixty-three (13%) patients had an abnormal echocardiography. Neither ductal-dependent nor cyanotic CHDs were found. Cardiac interventions were performed for 14 out of 63 (22%) patients. Clinical signs indicating CHDs were murmur grade ≥3 (10/11 [91%] vs. 53/479 [11%], $p < 0.001$) and harsh murmur (15/44 [34%] vs. 48/446 [11%], $p < 0.001$). Abnormal electrocardiography did not indicate CHD (8/40 [20%] vs. 55/447 [12%], $p = 0.165$). The total cost of the examinations was 259 700€. The share of the cost of studies assessed as benign was 59%.

Conclusion: Only a few CHDs were found after newborn hospital discharge among patients who received foetal and newborn screening and were examined due to CHD suspicion. The high number of benign murmurs in children leads to many referrals, resulting in unnecessary healthcare costs.

KEYWORDS
congenital heart defect, echocardiography, healthcare costs, heart defect screening, murmur

1 | INTRODUCTION

Heart murmurs are common in children and are the most frequent reason for referrals to paediatric cardiologist. A heart murmur can be heard in up to half of school-aged children.[1] This raises a lot of concern, leads to many examinations and referrals to paediatric cardiologists and increases healthcare costs.[2,3] While most murmurs are benign physical findings, a murmur can be a sign of cardiac pathology.[4] The estimated incidence of all congenital heart defects (CHD) is 75 per 1000 live births, if tiny muscular ventricular septal defect (VSD) and other trivial lesions are included. However, the incidence of moderate and severe forms of CHD is only six per 1000 live births, implying that most children with a murmur will not have a significant heart disease.[5] Cardiovascular symptoms and signs are useful in the evaluation of the significance of murmurs and the need for an echocardiography.[6–8]

Abbreviations: AI, aortic insufficiency; AS, aortic stenosis; ASD, atrial septal defect; CHD, congenital heart defect; CoA, coarctation of aorta; ECG, electrocardiography; EPS, electrophysiologic study; FS, fractional shortening; iRBBB, incomplete right bundle branch block; LV, left ventricle; MI, mitral insufficiency; PDA, patent ductus arteriosus; PFO, patent foramen ovale; PS, pulmonary stenosis; RBBB, right bundle branch block; VSD, ventricular septal defect; WPW, Wolff–Parkinson–White.

Severe forms of CHDs, such as duct-dependent or cyanotic CHDs, must be diagnosed in their early phases before the deterioration of the condition. In a Czech study conducted before the era of the routine use of pulse oximetry screening, 12% of all major and 26% of postnatally diagnosed CHDs remained undiagnosed before discharge from the hospital. The majority of delayed diagnoses were VSDs and coarctations of the aorta (CoA). Symptoms leading to diagnoses were most commonly murmur (51%) and cyanosis (26%).[9]

In Finland, CHDs are currently screened effectively with foetal anomaly screening, with pulse oximetry screening directly after birth and with clinical examination before discharge from delivery hospital. The purpose of this study was to assess the amount and severity of undiagnosed CHDs in this highly pre-screened population after discharge from the delivery hospital. Our study material was based on the examinations conducted on the basis of elective referrals to the Paediatric Cardiac Outpatient Clinic due to heart murmur or CHD suspicion. In addition, we aimed to determine the signs and symptoms that most reliably predict CHDs. We also aimed to estimate the costs incurred by visits to the Paediatric Cardiac Outpatient Clinic due to benign murmurs.

Key notes

- Screening for congenital heart defects (CHD) is carried out well in Finland, and therefore, only a small number of significant heart defects are diagnosed after newborn's hospital discharge.
- Murmur grade =/>3 and harsh murmur are clinical findings suggesting CHD.
- The high number of benign murmurs in children, as well as the difficulty in recognising benign murmurs, leads to many referrals resulting in unnecessary healthcare costs.

2 | PATIENTS AND METHODS

We retrospectively reviewed the patient charts of children with elective referrals to paediatric cardiologists at Tampere University Hospital (TAUH) due to CHD suspicion or heart murmur between 1 January 2017 and 31 December 2018. TAUH is a tertiary hospital in Tampere, Finland, that serves as a central hospital of Tampere, which has a population of about 530000 inhabitants and 4500 live births per year. Patients were referred by local general practitioners in primary health care from child health centres, school health care or from other outpatient clinics in health centres; from private health care; or from other departments of TAUH after being discharged from the delivery hospital. All newborns in the study district undergo foetal anomaly screening, pulse oximetry screening and clinical examination before discharge including an echocardiography if a murmur is heard on the routine pre-discharge neonatal physical examination or if other abnormal screening results exist.

Elective referrals leading to echocardiography were included. We included only those patients without a previous echocardiography. In addition, serious CHDs were searched from emergency room and intensive care unit consultations. Referrals due to chest pain, genetic disorders, arrhythmias, previously known CHD and hereditary heart diseases were excluded.

The clinical signs and symptoms that comprised a CHD suspicion included murmur, abnormal femoral pulses, abnormal blood pressure gradient between arms and legs, constant split of S2, tachypnoea and excessive sweating. Murmur was considered pathological if it had a harsh quality, grade ≥3, a certain location or diastolic or continuous timing.[8,10] Electrocardiography (ECG) findings considered to indicate CHDs were signs of atrial or ventricular hypertrophy, pathological Q-waves, ST-abnormalities, right bundle branch block (RBBB), incomplete RBBB (iRBBB) with R' >10 mm, T wave abnormalities, delta waves or superior frontal plane QRS axis.

Data on referrals, symptoms, clinical examination findings, limb blood pressure measurements, ECG- and echocardiography findings were collected retrospectively from medical records. The follow-up visits, heart medications and cardiac surgical and catheter interventions after diagnosis were recorded. Echocardiography findings were classified as normal, abnormal or physiologic (patent foramen ovale [PFO], tiny patent ductus arteriosus [PDA] or tiny mitral insufficiency [MI] with no need for cardiac follow-up).

Hypertension was defined by age-specific reference values.[11] ECGs were analysed according to age-specific reference values.[12] Different evaluation criteria were used for infants up to 1 week of age.[13] iRBBB was defined as terminal R wave in V1, wide terminal S wave in leads I and V6 with normal QRS duration.[14]

Statistical analyses were performed using IBM SPSS Statistics for Macintosh (version 28.0; IBM). Frequencies and percentages were used for categorical variables. The median and interquartile range (IQR) (Q1–Q3) were expressed for the non-normally distributed variables. The normal distribution of the continuous variables was assessed using histogram and normal distribution tests. Categorical variables were compared with chi-squared tests. p-values <0.05 were considered statistically significant. The cost estimate was calculated based on the year 2017 level of the Paediatric Cardiology Unit's visit fees charged by the hospital. The Research Director of the Pirkanmaa Hospital Districts gave permission for the study. According to Finnish legislation, register-based studies do not need Ethics Committee approval.

3 | RESULTS

A total of 1243 elective referrals after discharge from the delivery hospital were received in the TAUH Paediatric Cardiac Outpatient Clinic during 2017 and 2018. The study inclusion criteria were met by 490 patients who underwent clinical examinations and echocardiography (Figure 1). The median age of the patients was 2.5 (IQR

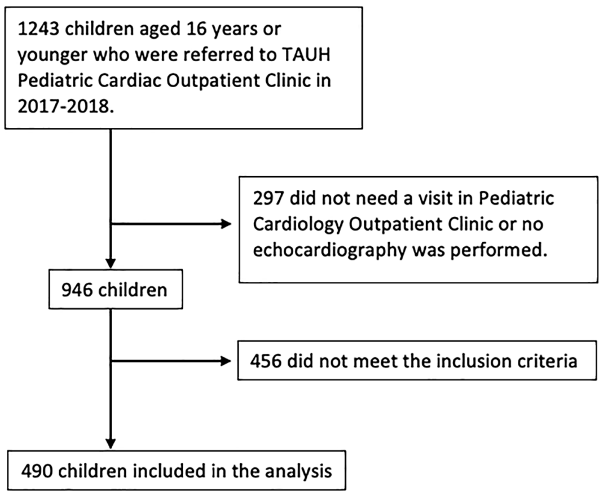

FIGURE 1 Flowchart of patient selection.

0.5–7.4) years and 265 (54%) were males. Forty-seven per cent ($n=230$) of the study patients were under 2 years of age. Of the referrals, 172 (35%) were from other outpatient clinics in health centres, 152 (31%) from child health clinics, 80 (16%) from TAUH Paediatric Department, 36 (7%) from other TAUH departments, 30 (6%) from school health care, 13 (3%) from private health care and 7 (1%) from other institutes. The reason for the referral was murmur in 459 (94%) cases, abnormal ECG in 66 (14%), abnormal femoral pulses in 15 (3%), abnormal blood pressure gradient in 6 (1%) and other reasons in 11 (2%) of the cases.

Altogether, 301 (61%) of the cases had normal and 126 (26%) physiologic findings in echocardiography with no need for cardiac control. An abnormal echocardiography was found in 63 of the 490 (13%) patients, with altogether 71 cardiac lesions (one patient could have more than one cardiac lesion). Thirty-five (49%) were shunt lesions, 29 (41%) valvular lesions and seven (10%) others. Neither ductal-dependent nor cyanotic CHDs were found. The CHD diagnoses in the age groups are shown in Table 1. There was no statistically significant difference in the number of CHDs between sexes (male 31/265 [12%] and female 32/225 [14%]) or age groups, respectively $p=0.406$; $p=0.840$.

During the study period, four children with undiagnosed significant CHDs came to the emergency department due to symptoms. An 8-week-old infant had a critical CHD and an abnormal left coronary artery from the pulmonary artery (ALCAPA) and died. A 2-week-old infant with heart failure symptoms had a large VSD and needed medication but not operation. A 7-month-old infant with weak femoral pulses had CoA and was treated with angioplasty. The fourth symptomatic patient (1-year-old) had myocarditis.

Until spring 2020, after a median (IQR) follow-up time of 2.3 (1.8–2.8) years, 14 surgical or catheter interventions were made for 14 of 63 (22%) patients with a CHD at the median (IQR) age of 6.0 (1.8–15.2) years (Table 2). In addition to these interventions, one transesophageal electrophysiologic study was performed. Five of 63 (8%) patients with a CHD needed heart medication during the follow-up period.

TABLE 1 ECG and echocardiography findings and heart defect diagnosis by age group.

Age groups	0–3 months ($n=85$)	3–6 months ($n=40$)	6–12 months ($n=57$)	1–7 years ($n=177$)	>7 years ($n=131$)
ECG finding (% of the total age group)	Abnormal 8 (9%)	Abnormal 2 (5%)	Abnormal 1 (2%)	Abnormal 4 (2%)	Abnormal 25 (19%)
Echocardiography finding (% of the total age group)	Normal 25 (30%)	Normal 27 (68%)	Normal 40 (70%)	Normal 116 (66%)	Normal 93 (71%)
	Physiologic 50 (59%)	Physiologic 8 (20%)	Physiologic 7 (12%)	Physiologic 40 (22%)	Physiologic 21 (16%)
	Abnormal 10 (12%)	Abnormal 5 (13%)	Abnormal 10 (18%)	Abnormal 21 (12%)	Abnormal 17 (13%)
Diagnosis n (% of defect in a certain age group)	VSD 5 (46%)	PDA 2 (40%)	Bicuspid aortic valve 3 (28%)	ASD secundum 6 (26%)	AI 7 (33%)
	PDA 3 (27%)	ASD secundum 1 (20%)	ASD secundum 2 (18%)	VSD 5 (22%)	MI 3 (14%)
	PS 1 (9%)	VSD 1 (20%)	PDA 2 (18%)	PDA 5 (22%)	Mitral prolapse 2 (9%)
	AI 1 (9%)	Enlarged left ventricle 1 (20%)	VSD 1 (9%)	AS 3 (13%)	AS 2 (9%)
	Left ventricle trabeculation 1 (9%)		CoA 1 (9%)	AI 2 (9%)	VSD 1 (5%)
			AI 1 (9%)	PS 1 (4%)	PDA 1 (5%)
			MI 1 (9%)	Bicuspid aortic valve 1 (4%)	CoA 1 (5%)
					Restrictive cardiomyopathy 1 (5%)
					Bicuspid aortic valve 1 (5%)
					Pulmonary hypertension 1 (5%)
					Coronary fistula 1 (5%)

Note: A single patient can have multiple diagnoses. Only elective referrals included.

Abbreviations: AI, aortic insufficiency; AS, aortic stenosis; ASD, atrial septal defect; CoA, coarctation of aorta; MI, mitral insufficiency; PDA, patent ductus arteriosus; PS, pulmonary stenosis; VSD, ventricular septal defect.

At the Paediatric Cardiac Outpatient Clinic, 407 (83%) of the 490 patients had a murmur. The description of the murmur was musical/vibratory in 180 (44%), harsh in 44 (11%), other description in 51 (13%), and without any description in 132 (33%) of the cases. Echocardiography was abnormal in 34% of the patients with a harsh murmur. Five per cent of the patients with a musical/vibratory murmur and 26% with a murmur of another description had abnormal echocardiography. The cross table on the concordance of murmur grade between the referring doctor and paediatric cardiologists is displayed in Table 3.

The percentages of CHDs found in patients with a certain symptom or sign are shown in Table 4. Five patients had an audible murmur at the back, but only one had an abnormal echocardiography (CoA).

Eight patients without murmur had a CHD: one VSD, two PDAs, one cardiomyopathy, two bicuspid aortic valves and two aortic insufficiencies (AI). Of all the children included in this study, 83 (17%) had no murmur at the Paediatric Cardiac Outpatient Clinic. Two patients had a limb blood pressure gradient over 10 mmHg, and both had CoA.

Table 5 shows abnormal ECG findings and their relation to echocardiography findings. ECG was obtained from 487 (99%) study patients. Altogether, 49 ECG abnormalities were found in 40 cases. One patient with atrial hypertrophy on ECG had restrictive cardiomyopathy. Abnormal ECG did not statistically significantly indicate CHD in our study group (8/40 [20%] vs. 55/447 [12%], $p = 0.165$).

Clinical signs that indicated CHDs were murmur grade ≥3 (10/11 [91%] vs. 53/479 [11%], $p < 0.001$) and harsh murmur (15/44 [34%] vs. 48/446 [11%], $p < 0.001$). Also, a murmur heard on the aortic area or back did not indicate CHD (8/32 [25%] vs. 55/458 [12%], $p = 0.053$).

The best combination of clinical signs in finding a CHD was a pathological murmur (definition: grade ≥3 or harsh or diastolic or continuous murmur or a murmur heard best in aortic area or back), having a sensitivity of 58% and a specificity of 71%. When adding pulmonary area as the location of the murmur, the sensitivity increased to 59% but specificity decreased to 66%. Abnormal clinical findings (definition: pathological heart murmur added with pulmonary area or abnormal femoral pulses or enlarged liver or abnormal breathing sounds) had a sensitivity of 59% and a specificity of 65% to find a CHD. When abnormal blood pressure and abnormal ECG were added to the abnormal clinical findings, sensitivity was 60% and specificity 63%.

The fee for the Paediatric Cardiac Outpatient Clinic visit, including echocardiography, was 530€ in 2017. The cost of the first visits of this research population was a total of 259 700€. In our study group, 290 (59%) patients had normal clinical findings at this visit (including normal blood pressure and ECG, benign murmur or no murmur). The cost of the assessment of children with normal clinical findings was 59% (153700€) of the entire expense. A total of 426 (87%) patients had normal or physiologic findings on echocardiography. The cost of the visits of the patients without CHD was 225 780€ in total.

TABLE 2 Cardiac interventions (surgical or catheter).

	Age groups and number of patients at intervention		
Type of intervention	**0–12 months**	**1–7 years**	**>7 years**
Surgical interventions			
ASD secundum closure	–	3	–
Repair of CoA	–	–	1
Catheter interventions			
PDA occlusion	1	2	–
Balloon dilation of CoA	1	–	–
Balloon pulmonary valvuloplasty	-	1	–
Haemodynamic catheterisation			
Pulmonary hypertension	–	–	1
Restrictive cardiomyopathy	–	–	1
Electrophysiogical study ± catheter ablation	–	–	3

Note: Only elective referrals included.

Abbreviations: ASD, atrial septal defect; CoA, coarctation of aorta; PDA, patent ductus arteriosus.

4 | DISCUSSION

In our data, only a few CHDs were found after newborn hospital discharge among the patients who had undergone foetal and

TABLE 3 Agreement of heart murmur grading among patients with information of the grade from both referrals and paediatric cardiologists ($N = 413$): comparison between referral and assessment by a paediatric cardiologist.

		Paediatric cardiologist				
	Heart murmur grade	**I ($n = 162$)**	**II ($n = 171$)**	**III ($n = 7$)**	**IV ($n = 0$)**	**No murmur ($n = 73$)**
Referral	I ($n = 121$)	66 (41%)	27	0	0	28
	II ($n = 215$)	86	108 (63%)	2	0	19
	III ($n = 40$)	7	28	5 (71%)	0	0
	IV ($n = 5$)	0	5	0	0	0
	No murmur ($n = 32$)	3	3	0	0	26 (36%)

Note: The grey boxes indicate the agreement on the grade, presented as the number and percentage of assessments by the paediatric cardiologists.

TABLE 4 Symptoms and signs in relation to echocardiography findings (percentages by symptoms/signs).

Symptoms	Echocardiography finding	
	Abnormal	Normal or physiologic
Palpitations	1 (8.3%)	11 (91.7%)
Chest pain	1 (10%)	9 (90%)
Syncope	0 (0%)	8 (100%)
Diminished exercise tolerance	4 (20%)	16 (80%)
Tachypnoea	2 (20%)	8 (80%)
Signs		
Murmur		
Grade		
Murmur Gr I	13 (6.8%)	179 (93.2%)
Murmur Gr II	30 (15.2%)	167 (84.8%)
Murmur Gr III	10 (90.9%)	1 (9.1%)
Murmur Gr IV-VI	0 (0%)	0 (0%)
Description		
Musical/vibratory murmur	9 (5%)	171 (95%)
Harsh murmur	15 (34.1%)	29 (65.9%)
Other description	13 (25.5%)	38 (74.5%)
Timing		
Systolic murmur	47 (12.7%)	323 (87.3%)
Diastolic murmur	0 (0%)	0 (0%)
Continuous murmur	4 (80%)	1 (20%)
Constant split of S2	3 (60%)	2 (40%)
Enlarged liver	3 (100%)	0 (0%)
Abnormal femoral pulses	2 (66.7%)	1 (33.3%)
Abnormal breathing sounds	3 (100%)	0 (0%)
Measurements/examinations		
Hypertension	19 (15.6%)	103 (84.4%)
Blood pressure gradient 5–10 mmHg	1 (10%)	9 (90%)
Blood pressure gradient >10 mmHg	2 (100%)	0 (0%)
Abnormal ECG	8 (20%)	32 (80%)

Note: Only elective referrals included. Blood pressure gradient = the gradient difference between upper and lower limbs.

newborn screening and were now examined due to a murmur or a CHD suspicion. During a 2-year period, 63 (13% of elective referrals) CHDs were diagnosed and 22% of these CHDs required surgical or catheter intervention, while only 8% of them needed heart medication. There were no serious CHDs in our data of elective referrals, but in addition to them, four symptomatic infants came to the emergency department (three CHDs and one myocarditis). The majority of the children who are referred to the Paediatric Cardiac Outpatient Clinic due to a murmur do not require echocardiography.

The number of CHDs detected in previous studies should be related to the patient population studied and the diagnostic methods used. In a murmur study of children aged 2–18 years, 7% of 473 had a CHD. They performed echocardiography on less than half of the patients, so minor defects may have gone undetected.[15] The CHD yield in our study was slightly higher due to the larger age distribution and because echocardiography was performed on all study patients. An English study revealed a CHD in 19% of 150 outpatient children evaluated by echocardiography due to asymptomatic murmur, with CHDs being more common among the youngest infants.[16] In another study of 903 outpatients with a murmur under 21 years of age, a CHD was detected in 27% of infants under 6 weeks of age compared with 6% in older children.[17]

Neither ductal-dependent nor cyanotic CHD was found in our study, which was based on elective referrals after discharge from the delivery hospital. The most probable contributor to the absence of delayed diagnoses of serious CHDs is the foetal and newborn screening system in Finland. If any suspicion of CHD arises in the screening, an echocardiography is routinely performed before the discharge of the newborn. Since our data were collected over only 2 years, the annual variation may affect the incidence of CHD in our study. Due to foetal and newborn screening, our study did not reveal a higher proportion of CHDs in infants than in other age groups, contrary to other studies.[16,17] However, the screening system does not detect all heart defects.[18,19] The physiologic changes in neonates' circulatory systems, such as the closure of PDA and the decline of pulmonary vascular resistance, cause some CHDs (e.g. CoA and VSD) to be diagnosed later, as was seen in our study in patients who came to the emergency room due to symptoms. ALCAPA is not detectable in newborn screening because the symptoms develop later as pulmonary resistance decreases.

Most of the study patients were under 2 years of age and most of the referrals were from primary health care and child health clinics. In child health clinics, clinical examinations, which also serve as a part of screening for CHDs, are made by a doctor for every child at the age points of 4–6 weeks, 4, 8 and 18 months, and 4 years. A murmur heard during examinations often seems to lead to a referral to a paediatric cardiologist even though most murmurs are benign. Shunt lesions comprised the largest group of CHDs in our cohort, which is consistent with previous studies.[5,20] A quarter of patients had physiologic findings such as PFO, PDA and MI in echocardiography. Physiologic findings were most common in the youngest subjects and were detected in 60% of infants under 3 months of age. Knowledge of haemodynamics is crucial in the evaluation of the significance of physiologic findings. Guidelines concerning benign and physiologic findings are needed to avoid unnecessary follow-up visits, leading to waste of resources.[21]

Murmur is the most common reason for referrals to the Paediatric Cardiac Outpatient Clinic, as was also noticeable in our research.[22,23] Even though the characteristics of a benign murmur are well defined, recognition seems to be difficult, and one does not dare to assess the murmur as benign based solely on a clinical examination. However, the murmur was no longer audible at the paediatric cardiologist's office in 11% of our 459 murmur referrals. This suggests that a murmur could have been diagnosed as benign

TABLE 5 ECG abnormalities.

ECG abnormality	The whole ECG abnormality group ($n=49$)	Heart defect on echocardiography[a]	Normal/physiologic finding on echocardiography[a]
Abnormal axis	17 (35%)	3/17 (18%)	14/17 (82%)
Atrial hypertrophy	1 (2%)	1/1 (100%)	0/1 (0%)
Ventricular hypertrophy	6 (12%)	2/6 (33%)	4/6 (67%)
Pathological Q wave	7 (14%)	3/7 (43%)	4/7 (57%)
ST-elevation/depression	1 (2%)	0/1 (0%)	1/1 (100%)
T wave abnormality	6 (12%)	2/6 (33%)	4/6 (67%)
Delta wave	6 (12%)	0/6 (0%)	6/6 (100%)
RBBB	1 (2%)	0/1 (0%)	1/1 (100%)
iRBBB with R' >10 mm	4 (8%)	1/4 (25%)	3/4 (75%)

Note: Only elective referrals included.

[a]Percentage of a particular abnormality.

with control auscultation and further examinations could have been avoided. Our results are in line with the finding of previous studies that CHD is more likely in children with harsh or loud murmurs.[8,16] In addition, diastolic or continuous murmurs were associated with CHD. A few CHDs were found in children without a murmur, some of them being incidental findings, such as mild AI. In these cases, the family history, or symptoms such as tachypnoea raise concern about a possible underlying CHD. Limb blood pressure measurement is part of the murmur assessment, and a gradient over 10 mmHg was highly suggestive of CoA in our study.

ECG is not routinely used in diagnosing CHDs, unless arrhythmia disease is suspected. It rarely adds diagnostic value to the clinical examination but increases costs.[24,25] Our results support previous findings of the low importance of ECG in the diagnosis of CHDs. However, an ECG can be helpful in assessing the urgency of cardiac examinations[26] or may be useful in older children in whom cardiomyopathy may cause abnormal ECG with zero or minimal murmurs,[27] as was found in our study.

According to the criteria for transthoracic echocardiography in outpatient paediatric cardiology, a presumptively innocent murmur without signs or findings of CHD rarely requires an echocardiography. Instead, if the murmur sounds pathological or a symptomatic patient has a murmur, an echocardiography is needed.[28] However, it is challenging to manage this common clinical problem in the most effective and cost-effective way so that all significant CHDs are diagnosed early.[3] Local practices vary depending on the resources available. During the study period, our practice was to perform echocardiography in all children with a murmur, regardless of whether the clinical findings indicated a benign murmur. However, this strategy increases costs and referrals, because it misguides local practitioners into believing that all children with murmurs need echocardiography. If all benign murmurs in our cohort had been diagnosed in primary health care without echocardiography, it would have saved an estimated 153 700 euros. Healthcare resources are not sufficient to perform echocardiography on all children with a murmur. Primary care would need more training and better diagnostic tools to identify benign murmurs so that echocardiography can be targeted to the children more likely to have a CHD. A diagnosis of a benign murmur by a paediatric cardiologist based on clinical findings can enhance the confidence of local physicians avoiding unnecessary referrals for echocardiography.

Recognising a benign murmur requires both experience and feedback. Auscultation skills can be taught with the help of artificial intelligence (AI). AI could also be used to identify benign murmurs from pathological murmurs. In a virtual validation study assessing an AI algorithm in the identification of pathological murmurs, AI identified pathological murmurs with a sensitivity of 93% and a specificity of 81%.[29] Another small ($n=34$) clinical validation study using AI to assess pathological murmurs had a sensitivity of 87% and a specificity of 100%.[30] In the future, an AI algorithm could be used in primary care to confirm the diagnosis of a benign murmur so that echocardiography would not be needed. An AI algorithm could identify the pathological murmur and help to refer these patients for further investigation. The AI algorithm could be cost-effective in identifying pathological murmurs from a large number of children's murmurs, which would reduce the number of referrals and echocardiography, as well as the healthcare costs.

The limitation of this retrospective study was that we could not estimate the total number of CHDs in our region during the study period. In addition to elective referrals, only major CHDs from the emergency room were included. No CHDs detected before the newborns' discharge were included.

In conclusion, CHD screening in Finland is carried out well; therefore, the number of significant CHDs diagnosed after discharge from delivery hospitals is low. However, the high number of benign murmurs in children leads to many referrals that incur unnecessary healthcare costs. Although the auscultatory finding of the murmur makes it possible to distinguish a benign murmur from a pathological one, additional tools are still needed in primary care to reduce unnecessary examinations. Additional training is needed to improve auscultation skills. Using AI as an additional diagnostic tool could help save healthcare costs.

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CONFLICT OF INTEREST STATEMENT

Tuija Poutanen and Kaisa Ylänen do not have conflicts of interest.

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