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Reliability of Left Ventricular Hypertrophy by ECG criteria in Children with Syncope: Do the criteria need to be revised?

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Abstract

Background—In the out-patient setting, children who present with syncope routinely undergo electrocardiograms (ECG). Because of concerns for hypertrophic cardiomyopathy, children with syncope meeting ECG criteria for left ventricular hypertrophy (LVH), will frequently undergo an echocardiogram.

Objective—Our objectives were to determine if Davignon criteria for ECG waves overestimate LVH in children presenting with syncope, and to study the usefulness of echocardiography in these children. We hypothesize that the Davignon criteria presently used for interpretation of ECGs overestimate LVH, resulting in unnecessary echocardiography in this clinical setting.

Methods—The clinical database of The Children's Hospital of Philadelphia was evaluated from 2002 to 2012 to identify children between 9 and 16 years of age, who presented with non-exercise induced, isolated syncope. From this group of patients, only those with clear-cut evidence of LVH (by Davignon criteria), who also underwent an echocardiogram were selected.

Results—136 children with syncope were identified as having LVH by Davignon ECG criteria. None of these patients manifested any evidence of hypertrophic cardiomyopathy, with normal ventricular septum (average Z-score -0.68 ± 0.84), LV posterior wall (average Z-score -0.66 ± 1.18), and LV mass (average Z-score 0.52 ± 1.29). No significant correlation was found between summed RV6 plus SV1 and LV mass. Correlations between additional ECG parameters and measures of LVH by echocardiography were similarly poor.

Conclusion—In children presenting with syncope and LVH by ECG, there was no evidence of true LVH by echocardiography. We propose that the Davignon ECG criteria for interpreting LVH in children overestimate the degree of hypertrophy in these children and the yield of echocardiography is extremely low.

Keywords

Syncope; Left ventricular hypertrophy (LVH); Electrocardiogram (ECG); Echocardiogram

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Introduction

Syncope in adolescents is a symptom that creates concern in parents and primary care physicians (pediatricians and family practitioners). On many occasions, these children are brought to an Emergency Department for further evaluation [1]. An overwhelming majority of these patients are referred for further evaluation to a pediatric cardiologist. Children with syncope, who present to pediatric cardiologists, routinely undergo ECGs. Prominent voltages in left precordial leads of the ECG is often interpreted by pediatric cardiologists as left ventricular hypertrophy (LVH), using the Davignon criteria [2]. In the setting of syncope plus LVH noted on ECG, an echocardiogram (ECHO) is often performed to rule out serious cardiac conditions that cause LVH, particularly hypertrophic cardiomyopathy. However, the yield of these echocardiograms is extremely low, and may be partly responsible for driving up the cost of medical care [3].

Our objectives were 1) to determine if the Davignon ECG criteria overestimate LVH and lead to unnecessary echocardiograms, and 2) to determine the yield of an echocardiogram in the setting of non-exercise induced, isolated syncope with LVH on ECG. We hypothesize that the echocardiogram will be of limited utility in the group of adolescents with syncope and ECG finding of LVH (by Davignon voltage criteria alone) and may not justify its cost.

Methods

Study population

An Institutional Review Board (IRB) approved retrospective analysis of the cardiology database of Children's Hospital of Philadelphia, was conducted between January 1, 2002 and December 31, 2011, covering a time span of 10 years. Pediatric patients aged 9 to 16 years, who presented with isolated, non-exercise induced syncope, had LVH based on the Davignon ECG criteria and had also undergone an echocardiogram on the same day, were included in this study. These echocardiograms were ordered by pediatric cardiologist due to LVH detected by ECG. All episodes of syncope occurred while standing or change of posture to erect position and clinically were considered to be a form of vasodepressor syncope. Children with exercise-induced syncope, known cardiac diagnoses, known hypertension, prolongation of QTc interval, presence of preexcitation or bundle branch block were excluded. Patients with ECG findings of abnormal ST-T wave changes, LV strain pattern, unusual T wave morphology and wide Q waves (>40 ms) were also excluded, as in the presence of these findings echocardiograms are performed regardless of LVH.

Study design

Demographic data, including age, weight, sex, body surface area and race, along with personal and family histories, physical examination findings and the final diagnoses were obtained from clinical records. Only patients who underwent echocardiography were evaluated. ECGs were analyzed for LVH based on voltage criteria. Criteria for LVH included amplitudes of R wave in V6 (RV6), S wave in V1 (SV1), the standard Sokolow-Lyon criterion (SV1+RV6) and Q wave in V6 (QV6). Definite LVH was diagnosed when at least 2 of these criteria exceeded the 98th percentile of Davignon normative values. Due to the

frequent presence of deep Q waves even in normal ECGs, Q wave analysis was performed only when corresponding R wave voltage in V6 also exceeded 98th percentile. This added more stringency to the diagnosis of LVH by ECG. Patients with non-specific ST-T wave changes were not excluded. A de novo analysis of all old ECGs was done and the investigators performing the analysis were blinded to the results of echocardiograms.

M-mode linear, minor-axis measurements in standard short axis views were utilized for measurement of LV internal diameter at end-diastole (LVIDd) and at end-systole (LVIDs), interventricular septal thickness at end-diastole (IVSd) and LV posterior wall thickness in end-diastole (LVPWd). These dimensions were abstracted from official echocardiography reports as video tapes of many old echocardiograms were not available. From these dimensions, LV mass was calculated (Teich formula) and indexed to height by dividing LV mass by height in meters raised to the power of 2.7. This M-mode based technique for measuring indexed LV mass has been used in several clinical trials in children of this age group [4,5].

This study was approved by the Institutional Review Board of the Children's Hospital of Philadelphia.

Statistical analysis

Results were expressed as mean $\pm$ SD and data were compared using the unpaired Student's t-test. A two-tailed p value of <0.05 was considered significant. The Student-Newman-Keul's test was used in the post-hoc analyses of multiple comparisons. Linear regressions and step-wise linear regression analyses were performed between various ECG and ECHO parameters of LVH. Pearson's correlation coefficient was calculated to evaluate correlation between variables. Z-scores of ECHO parameters based on body surface areas were available from large population data. The z-score parameters that are used in our institution were derived from the population database study from Boston Children's Hospital [6].

Results

Of the 136 patients in our study population, 77 were Caucasian, 54 were African-American, and 5 were other races. The median age was 14.1 years (range: 9–16 years). In our cohort 69% were male, and 41% were female. The clinical and echocardiographic characteristics of these patients are outlined in Table I.

The average ECG amplitudes for R in V6 and S in V1 and the sum of RV6 + SV1 are higher than the 98th percentile values of the Davignon criteria (Table 2). In some patients SV1 values were less than the 22 mm cutoff value proposed by Davignon, however, these lower SV1 values were only included when the RV6+SV1 criterion was calculated.

None of the 136 children manifested any evidence of LVH by echocardiography or evidence of hypertrophic cardiomyopathy. The mean thickness of the LV septum in these adolescents was 0.83 ± 0.3 cm (Range 0.55–1.21 cm). No structural or functional heart diseases were detected. By echocardiography the average Z-score of the ventricular septum was -0.68

± 0.84 , of the LV posterior wall was -0.66 ± 1.18 and of LV mass was -0.52 ± 0.11 , (figure I).

In this study the mean LV mass indexed for height was $32.9 \pm 7.3 \text{ g/m}^{2.7}$. This was comparable to the LV mass in the normal pediatric population established by several previous studies [4,5]. There was no correlation between RV6 + SV1 of ECG and LV mass and LV septal Z-score ($R^2=0.004$ and $R^2=0.0001$, respectively) (figure II A and B).

Correlations between additional ECG parameters i.e. RV6, SV1 and measures of LVH by echocardiography were similarly not significant (Table III).

Discussion

In this study we found that the commonly used Davignon standards for reading pediatric ECGs, overestimate LVH in children with non-exercised induced, isolated syncope that appeared to have a vasodepressor in mechanism. Frequently this led to echocardiograms that had no diagnostic yield. The diagnosis of vasodepressor syncope correlated with the low Z scores for LV volumes in our study.

Setting normal limits for ECGs by age is important for interpretation of ECGs in children, particularly in diagnosing LVH. Currently, Davignon criteria are commonly used to define normal limits for pediatric ECGs. These criteria are based on a study published in 1979, by Davignon *et al* who analyzed 2,141 pediatric ECGs at a sampling rate of 333 Hz to develop normal limits for children, aged 0 to 16 [2]. These were all Caucasian, Canadian children. Other studies have shown that normal limits even in predominantly Caucasian children could be significantly higher than those suggested in Davignon criteria. For instance, Macfarlane *et al* published a revised set of normal limits in 1989 from Scotland, based on more high-fidelity (500 Hz) ECG recordings that indicate that the upper 98th percentile limit of normal ECG waves could be up to 46% higher than the previously published limits set by Davignon [7]. In 2001, Rijnbeek *et al.* from Netherlands, put forth another set of modified guidelines, recording 1,912 ECGs at a higher sampling rate of 1200 Hz utilizing computerized analysis [8]. This study on Dutch children found that the new normal ECG limits again varied markedly from those of Davignon. Rijnbeek's study found significantly higher R and Q wave amplitudes in the precordial lead V6 than those presented in the Davignon criteria. Overall, these findings suggest that the criteria for amplitudes of ECG waves for LVH diagnosis should be updated.

In a follow-up study by Rijnbeek, the addition of the modified Sokolow-Lyon criterion (SV3R+RV7) increased the sensitivity and specificity of ECGs to detect LVH [8]. Although the standard Sokolow-Lyon criterion (SV1+RV6) is in use during ECG analysis, the modified Sokolow-Lyon criterion (SV3R+RV7) proposed by Rijnbeek, is not in common use in the United States but may have utility in adolescents [9, 10]. It was not possible to utilize the latter criterion (SV3R+RV7) in our study and compare it with LV mass, as V3R and V7 ECG leads are non-standard leads and were not available for analyses in this retrospective study.

Although Rijnbeek *et al* did stratify results by sex, noting that Q, R, and S waves were higher in males than in females during adolescence, they did not take race into account, perhaps due to homogeneity of their population [8]. In the United States, pediatric cardiologists have continued to use Davignon's criteria for the diagnosis of LVH in patients, which is based on a homogeneous Canadian population of 1979 using technology from that era. Given the diversity of the U.S. population, the Davignon criteria may not be applicable to the current US population.

In a more recent study by DiPaulo *et al* on the ECG and ECHO characteristics of asymptomatic adolescent African versus Caucasian athletes, it was found that African athletes more commonly exhibited standard adult R and S wave and Sokolow-Lyon criteria for LVH (89%), as compared to their Caucasian counterparts (42%). The former group also showed a higher incidence of ST segment elevations and T-wave changes. Multivariate analyses found no relation between ECG and echocardiographic parameters in the entire population of athletes, either African or Caucasian [11]. These findings and those reported by other studies [12] indicate that there are basic race-based differences in ECG voltage criteria, which should be included in future revised criteria, to improve the sensitivity of ECG in pediatric patients in a diverse society such as the United States.

The over-diagnosis of LVH by present ECG criteria has several ramifications. Due to parental and physician-anxiety in the group of patients with syncope and LVH on ECG, echocardiograms are ordered in an attempt to rule out hypertrophic cardiomyopathy. This practice stems from physician uncertainty and from the paucity of data regarding the usefulness of echocardiography in pediatric syncope. This paucity of data, prompted us to embark on this study on syncope in this distinct group of adolescents.

A study by Ritter et al, showed that in pediatric patients with syncope, echocardiography did not contribute much if the history, physical examination, and ECGs were normal [13]. In our study we took it a step further and studied a group of patients with LVH on ECG in addition to syncope. This combination has not been evaluated in children. Based on our study, we suggest that a detailed clinical and family history and a thorough physical examination, along with the use of revised and stringent ECG standards for the diagnosis of LVH, may significantly reduce the use of echocardiograms in children with syncope.

The economic burden of overdiagnosing LVH results from the direct costs of a pediatric cardiology referral and unnecessary echocardiograms and total more than \$500 per patient using a conservative estimate [14]. With more than 150,000 estimated yearly pediatric ED visits for uncomplicated syncope [15], and using a conservative estimate of 10% over-diagnosis rate of LVH, there is a potential cost-savings of millions of dollars. The "hidden" costs (known as opportunity costs) of time off from work for family members, the anxiety of an uncertain diagnosis even if the echocardiogram is normal, and the burden on the health care system with increased wait times for cardiology and echocardiography referrals, are much more difficult to quantify but are certainly not trivial.

The revision of the ECG standards may benefit not only this group of patients but many other pediatric conditions when the ECG is used as part of the initial screening test, for example, during the use of certain psychotropic medication or during athletic screenings.

Study Limitations

The retrospective nature of data collection limits the generalizability of this study. The study population is relatively small due to stringent inclusion criteria utilized in this study. M-mode linear, minor-axis measurements were utilized to calculate LV mass rather than 2D area-length method, as this was the technique utilized during our study interval. Even presently, LV mass is calculated by the M-mode technique in our institution.

Conclusions

We conclude that in children presenting with non-exercise induced isolated syncope, the Davignon criteria overdiagnose LVH and lead to unnecessary echocardiography and cost. ECG criteria should be revised to better represent the heterogeneity of the US population and improve specificity.

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Figure I.

Z scores of LV internal diastolic dimension (LVIDd), LV posterior wall thickness in diastole (LVPWd), Interventricular septal thickness in diastole (IVSd) and LV mass are depicted here. The Z scores are all negative, but within normal range. The error bars represent standard error of mean.

Figure II.

A. Scattergram between the sum of R wave in V6 and S wave in V1 (mm) and LV mass (gm) and B. between the sum of R wave in V6 and S wave in V1 (mm) and LV septal Z score. Both showed poor correlations.

Table I

Demographic, clinical and echocardiographic characteristics of patients.

Characteristics	Mean $\pm$ SD
Age (yrs)	13.43 $\pm$ 1.7
Male (%)	97 (71.3)
Height (cm)	162.0 $\pm$ 16.6
Weight (kg)	57.2 $\pm$ 17.5
BSA (m ²)	1.57 $\pm$ 0.33
BMI (kg/ m ²)	21.8 $\pm$ 6.4
SBP (mmHg)	112 $\pm$ 24.5
DPB (mmHg)	64 $\pm$ 14.7
MAP (mmHg)	80.9 $\pm$ 9.1
LVIDD (cm)	4.7 $\pm$ 0.51
LVIDS (cm)	2.9 $\pm$ 0.42
LV septum (cm)	0.83 $\pm$ 0.3
LV posterior wall (cm)	0.80 $\pm$ 0.2
SF (%)	36.7 $\pm$ 11.4

BSA=body surface area; BMI=body mass index; HR=heart rate; SBP=systolic blood pressure; DBP=diastolic blood pressure; MAP=mean arterial pressure; LVIDD=left ventricular Internal dimension in diastole; LVIDS=left ventricular internal dimension in systole; SF=shortening fraction

Table II

In 12–16 year old age group average amplitudes of ECG waves measured in this study were compared with the 98th percentile values of the Davignon criteria.

	Range in This Study (mm)	Mean in This Study (mm)	Davignon Criteria (98 th percentile) (mm)
R in V6	25–40	28.4 ± 3.4	24
S in V1	20–36	23.9 ± 4.5	22
R in V6 + S in V1	44–65	50.7 ± 6.1	42

Table III

Correlation coefficients between ECG parameters of LVH and echocardiographic parameters of LVH. The correlations were uniformly poor. IVS=interventricular septum.

	Correlation Coefficient	R ²	P value
RV6 vs LV mass	0.13	0.01	0.12
RV6 vs IVS	0.04	0.001	0.67
SV1 vs LV mass	0.11	0.01	0.22
SV1 vs IVS	0.005	0.0001	0.95