Detection of Heart Disease in Children

1919-1967

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SUMMARY
Since 1959, auscultation by physicians in screening 49,496 school children has yielded 4.5 cases of heart disease/1,000 students screened. Sensitivity by analysis of “inserted” cases averages 64%, but varies with capabilities of examining physicians.

X-ray and ECG evaluations on smaller populations have yielded, respectively, 2.7 and 2.5 cases/1,000 children screened, and sensitivity results average 30 to 40%.

The tape-recorded heart sounds technique has yielded 2.9 cases/1,000 in screening 188,925 children. Sensitivity by analysis of “inserted” cases averages 75% and, in the population of “naturally occurring” heart disease, 56%.

In 23,148 school children, an analog-digital device (PhonoCardioScan) has yielded 4.8 cases/1,000 children screened. Of “inserted” cases, 69% have been detected. Sixty-four to 80% of “naturally occurring” cases have been detected.

With each technique, approximately 40% of the heart disease detected had been previously unknown. The specificity of these methods ranges from 95 to 99%.

For primary screening the analog-digital device is the most effective currently available alternative to examination by cardiologists.

Additional Indexing Words:
Screening techniques Congenital heart disease
Rheumatic heart disease Heart sounds
X-ray screening ECG screening
Tape-recorded heart sounds Analog-digital device

SINCE 1915, the need for screening school children to detect heart disease has been recognized. In that year the Association for the Prevention and Relief of Heart Disease was organized. It enlisted the cooperation of the New York City Board of Education for a study of the problem of heart disease in school children. Dr. Robert H. Halsey accepted the task early in 1917, but World War I interrupted his services. On his return in 1919, the Public Education Association had formed a cardiac committee which had undertaken the formation of special classes

“for the segregation of cardiac children.” A screening mechanism was instituted by which these children were to be identified. The primary screening was done by principals and teachers of 17 schools in New York City. They referred to Dr. Halsey “all children in class and school having, or suspected of having, any cardiac defect, for examination and disposition.” Of 44,000 school children, 946 were referred. Two hundred twenty-eight of these were found to have organic heart disease (86% rheumatic and 14% congenital), a yield of 5.2 cases/1,000 children screened.¹

During the discussion of Dr. Halsey’s report,¹ Dr. William St. Lawrence made a prophecy that is only now becoming a reality: “Dr. Halsey has begun an experiment which will undoubtedly have great influence on the ultimate management of cardiac children in

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the public school . . ." It is the continuation of this "experiment" that is the subject of this paper, which reviews all available data (including several unpublished studies) on methods for detecting heart disease in children in order to evaluate the efficacy of various screening techniques.

Review of Methods

Screening by Physicians

The screening method first employed was auscultation by physicians. Between 1926 and 1941 studies from New South Wales,2 Boston,3 Philadelphia,4, 5 Detroit,6 San Francisco,7, 8 Cincinnati,9 and Louisville10 reported a prevalence of heart disease ranging from 1.4 to 9.5 cases /1,000 students screened. Sensitivity* and specificity† data of physician auscultation in these studies are not available, for in order to make such determinations, a reliable standard method for detecting and correctly diagnosing all heart disease in the studied populations must be assumed. The screening method must then be compared to the standard. A good standard for determining heart disease was not available in these populations.

ECG and X-ray Screening

Prior to the 1950's, activities in the area of heart disease detection in children consisted almost exclusively of direct examination by physicians. It soon became apparent that screening examinations by physicians experienced in cardiac diagnosis was not feasible because of the serious shortage of such physicians. During the 1950's, evaluation of the ECG11-14 and the chest x-ray13, 14 as screening methods revealed that these techniques were not sensitive enough to be utilized by themselves in screening programs. This information correlated well with the subjective impression of pediatric cardiologists. It was felt that a more effective screening mechanism for detection of heart disease in children should be evaluation of the cardiac sounds.

Screening by Use of Tape-Recorded Heart Sounds

In the mid-1950's, the Heart Disease Control Program of the Public Health Service became interested in utilizing tape-recorded heart sounds as a screening tool, a technique which had been initiated in Chicago.15 It was demonstrated that a physician could screen more rapidly by the tape-recorded mechanism than he could by direct examination. In addition, this technique facilitated the use of cardiologists as "screeners" by enabling them to evaluate the tapes at their own convenience. Ambient noise could also be reduced.

Specialized equipment for tape-recording heart sounds was developed by the Heart Disease Control Program,16 and was extensively studied.14, 17, 18 The heart sounds of each child were recorded on magnetic tape from two chest sites, the apex and the base (at the third left intercostal space). Each chest site was recorded for 11 sec. The most common method of evaluating tape-recorded heart sounds was to have separate interpretations by two "physician readers." The agreement between readers was low, in the range of 24 to 25% in cases of heart sound abnormalities.14, 15 For this reason, at least two separate readings of the tapes were required. Any child identified as having what were considered "suspicious" heart sounds on either reading was sent for a recall examination by a cardiologist as a secondary screening mechanism. All subsequent data on tape-recorded heart sounds in this presentation are on the basis of two or more readings.

The necessity of having two physicians listen to each tape recording reduced the efficiency of the technique in terms of conserving physician time. For example, the use of tape recordings should have allowed a single physician in 2 to 3 hours to evaluate the heart sounds recorded by a technician during a full working day. Duplicate evaluations of the tapes doubled the expenditure of physician time, thus minimizing a major advantage of this technique over direct examination of children.18

The tape-recorded heart sounds system had other inherent disadvantages. These included frequent equipment failure, variation in quality of recordings, logistical problems in re-recording the heart sounds of children who had previous unsatisfactory recordings, and the relatively high cost of the program.18-21 Listener fatigue during evaluation of the tapes by the "readers" limited their effective continuous functioning to approximately 1 hour or 120 cases screened.

Screening by an Analog-Digital Device

In the early 1960's, a portable analog-digital device* (ADD) became available for testing.

*PhonoCardioScan, Humetrics Division of Thiokol Chemical Corporation.

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The input to this device is a single electrocardiographic lead (used primarily for timing purposes) and the output of an air-coupled crystal microphone. Four chest sites are customarily evaluated on each child (apex and second, third, and fourth intercostal spaces at the left sternal border). This device is operated by a specially trained technician and gives an immediate visual readout in digital form, identifying as "suspicious" any of the following: (1) a murmur in systole which exceeds the machine's programmed limits for frequency, amplitude, and duration; (2) a diastolic murmur; and (3) splitting of the second heart sound greater than 50 msec.

Ten cardiac cycles are evaluated at each chest site. If, at any chest site, six or more of the cycles examined are outside normal limits in any one of the three aforementioned parameters, the patient is considered to have "suspicious" heart sounds. He is then examined by a pediatric cardiologist as a secondary screening mechanism. The theoretical advantages of this system of screening lie primarily in two areas: (1) An immediate result is obtained. When a technically unsatisfactory screening occurs, the patient is immediatly available for rescreening, thus eliminating many logistical problems inherent in the tape-recorded heart sounds technique. (2) The primary screening procedure can be performed by specially trained nonmedical technicians, thus eliminating physicians' participation in the first stage of screening.

Review of Results

Detection of Organic Heart Disease (Table 1)

The detection rates for organic heart disease reported in subsequent paragraphs should not be misconstrued as being identical with true prevalence of heart disease in children of school age. The reported rates are undoubtedly lower than true prevalence for several reasons. The studies were seldom random samples, and children sick at home, hospitalized, or in special schools were not included in the screened populations. The prevalence of heart disease in these children has been shown to be significantly above the average. The prevalence of heart disease in nonresponders (children included in the study populations who refused to be screened) has also been high. In addition, the fact that the screening methods are less than 100% sensitive compounds the discrepancy between detection rates and true prevalence of organic heart disease in school age children.

Specialist Examination

Table 1 indicates the number of cases of organic heart disease detected by various screening mechanisms. The data presented under the heading, "specialist examination," are a composite of data from seven different studies reported between 1959 and 1966. Data collected prior to 1950 have been omitted in an effort to minimize errors in final diagnoses which may have occurred prior to the use of modern diagnostic techniques. In two of the studies the screening examination was performed once. In one of these, the examiner's qualification was that he be "experienced in cardiac diagnosis," and in the other study the examiners were described as pediatricians or internists. In a third study, some children had single examinations by a cardiologist while some had duplicate examinations by different cardiologists. In the four remaining studies duplicate examinations were used in each instance. Qualifications of the examining physicians in these four studies ranged from "qualified physicians" to pediatric cardiologists. The average number of

Table 1

<table>
<thead>
<tr>
<th>Detection of Organic Heart Disease by Various Screening Mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Specialist</td>
</tr>
<tr>
<td>X-rays</td>
</tr>
<tr>
<td>ECG</td>
</tr>
<tr>
<td>Tape recording</td>
</tr>
<tr>
<td>ADD*</td>
</tr>
</tbody>
</table>

*Analog-digital device.
cases of organic heart disease detected by
direct physician examination in all studies
was 4.5/1,000 children screened. The range
was 2.3\textsuperscript{14} to 6.2\textsuperscript{11}

X-rays
The x-ray data presented in table 1 come
from a single study reported in 1959.\textsuperscript{11} Two
and seven-tenths cases of organic heart dis-
ease were detected per thousand children
screened.

ECG
The ECG data are a composite of three
studies,\textsuperscript{11–13} one employing an eight-lead elec-
trocardiogram,\textsuperscript{13} and the other two utilizing
only the V\textsubscript{5R} lead.\textsuperscript{11, 12} The average number
of cases of heart disease detected was 2.8/1,000 children screened. The range was 2.0\textsuperscript{11}
to 5.4.\textsuperscript{12}

Tape Recording
The tape-recording data are from 13
studies\textsuperscript{13–15, 20, 21, 24–31} and in each instance
represent at least duplicate readings of tape
recordings. The average number of cases of
heart disease found was 2.9/1,000 children
screened, with a range of 1.1\textsuperscript{29} to 7.0.\textsuperscript{18}

Analog-Digital Device (ADD)
The ADD data are a composite of five
studies,\textsuperscript{22, 23, 32–34} four of which employed a
single ADD screening\textsuperscript{22, 32–34} and one of which
employed two ADD screenings with a positive
result on either screening being interpreted
as suspicious of heart disease.\textsuperscript{23} The average
number of cases of heart disease detected
was 4.8/1,000 children screened, with a range
of 3.2\textsuperscript{22} to 6.2.\textsuperscript{34}

Yield of Previously Undetected Heart Disease
(Table 2)
Table 2 is a compilation of data on the
yield of previously undetected or previously
undiagnosed heart disease identified by vari-
ous screening mechanisms. Unfortunately, the
data in the literature on heart disease de-
tected by ECG and x-ray do not specify
what percentage of cases were previously
unknown. For this reason these two screening
procedures do not appear in this table.

Specialist Examination
The data on specialist examinations in
table 2 are derived from three studies\textsuperscript{20, 22, 23}
in which cardiologists were the screening
physicians. These are the only studies in
which the cases of detected heart disease
were broken down into previously known
and previously unknown categories. The rate
of detection of "unknown" cases averaged 2.5/
1,000 children screened. The range was from
2.4\textsuperscript{22} to 2.5.\textsuperscript{20, 23}

Tape Recording
Tape-recorded heart sounds data in table
2 are from 11 studies\textsuperscript{15, 20, 21, 24–31} in which
the detection rate of previously unknown
heart disease was mentioned. The average
was 1.1 cases/1,000 children screened, with
a range from 0.0\textsuperscript{25} to 5.0.\textsuperscript{18}

Analog-Digital Device (ADD)
Four recent studies\textsuperscript{22, 23, 33, 34} comprise the
ADD data presented in table 2. An average
of 2.1 cases of previously unknown heart
disease per thousand children screened was
detected by this technique. The range was
1.6\textsuperscript{22} to 2.2\textsuperscript{34} cases.

The data on total cases of heart disease
detected in table 2 differ from table 1 because
only those studies reporting a breakdown of
the cases of heart disease into "known" and
"unknown" categories could be used. The only

<table>
<thead>
<tr>
<th>Method</th>
<th>No. screened</th>
<th>Total cases detected per 1,000 screened</th>
<th>&quot;Unknown&quot; cases detected per 1,000 screened</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specialist examination</td>
<td>17,034</td>
<td>5.4</td>
<td>2.5</td>
<td>20, 22, 23</td>
</tr>
<tr>
<td>Tape recording</td>
<td>168,291</td>
<td>2.9</td>
<td>1.1</td>
<td>15, 20, 21, 24-31</td>
</tr>
<tr>
<td>ADD</td>
<td>22,948</td>
<td>4.7</td>
<td>2.1</td>
<td>22, 23, 33, 34</td>
</tr>
</tbody>
</table>

Table 2
Yield of Previously Unknown Heart Disease Detected by Various Screening Mechanisms

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difference of possible significance is an increase from 4.5 to 5.4 cases of heart disease per thousand children screened by the specialist examination method. This difference may be related to the fact that the three studies reported in table 2 had cardiologists as the examining physicians, whereas the other four studies included in the table 1 data were less rigid in qualifications for the examining physicians and yielded a lower rate of detected heart disease.

For the purpose of evaluating any screening program, the yield of previously undiagnosed disease is a more significant parameter than is the total yield of the disease in question. This fact is of considerable importance in screening of heart sounds. Cardiac abnormalities associated with loud murmurs and grossly abnormal heart sounds are as a rule detected by almost any heart sounds screening technique. In most studies the majority of such cases had been previously detected by the family physicians.

**Clinical Trials of the Analog-Digital Device**

(Table 3)

Early in the evaluation of the ADD, trials of the device in "clinical" situations were undertaken. A study of 270 children with heart disease intermingled with 438 normal children was instituted at Los Angeles Children's Hospital. Of the 270 patients with heart disease, 244 had congenital heart disease, 24 had rheumatic heart disease, and two had rhythm and conduction disturbances.

In this study, the ADD identified 264 (98%) of the 270 children with heart disease and 416 (95%) of the 438 normal children correctly. These data are presented in table 3.

The six cases of heart disease missed by the ADD included one case of tetralogy of Fallot with severe right ventricular outflow obstruction and a grade I murmur, one of aorticopulmonary window with pulmonary hypertension and no murmur, one of ventricular septal defect with pulmonary hypertension and no murmur, one of atrial septal defect with pulmonary hypertension and a grade I to II systolic murmur, one of Marfan's syndrome and a grade I murmur of aortic insufficiency, and one of ventricular aortic defect and a grade II murmur.

In evaluating any study in which specific known cases of heart disease are screened by a detection mechanism for the purpose of determining the mechanism's sensitivity, the nature of case material selected for study is of prime importance. Both direct physician screening and tape recording are known to be relatively insensitive in the detection of aortic insufficiency murmurs of high frequency and low intensity, atrial septal defects, and coarctations of the aorta. These same deficiencies pertain to ADD screening, with the exception that in ADD screening the ability to identify atrial septal defects is enhanced by the machine's evaluation of splitting of the second heart sound. It is obvious that if one selected a population of heart disease cases consisting primarily of aortic insufficiency and coarctation of the aorta, a very low sensitivity would be reported for any screening mechanism. Similarly, if the heart disease population consisted exclusively of

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**Table 3**

**Specificity and Sensitivity of the ADD in “Clinical” Situations**

<table>
<thead>
<tr>
<th>Cases screened</th>
<th>No. correctly identified</th>
<th>Specificity (%)</th>
<th>Sensitivity (%)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Los Angeles Children's Hospital</td>
<td>Normals</td>
<td>438</td>
<td>416</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>HD (primarily CHD)</td>
<td>270</td>
<td>264</td>
<td>84</td>
</tr>
<tr>
<td>2. Irvington House New York</td>
<td>Normals</td>
<td>177</td>
<td>148</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>RHD</td>
<td>131</td>
<td>116</td>
<td>68</td>
</tr>
<tr>
<td>3. Denver</td>
<td>Highly suspicious &quot;normals&quot;</td>
<td>35</td>
<td>22</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>HD</td>
<td>22</td>
<td>15</td>
<td>68</td>
</tr>
</tbody>
</table>

Abbreviations: HD = heart disease; CHD = congenital heart disease; RHD = rheumatic heart disease.
grade IV or louder murmurs of valvular stenosis or ventricular septal defects, it is probable that sensitivities would approach 100%. In the second study presented in table 3, performed at Irvington House in New York,36 308 patients with a past history of acute rheumatic fever were evaluated. At the time of the study, 131 of these were considered to have residual rheumatic heart disease, and 177 were categorized as normal. The ADD correctly identified 148 (84%) of the 177 normal children and 116 (89%) of the 131 patients with rheumatic heart disease. In a further breakdown of ADD sensitivity by lesion, it was found that the device correctly identified 68 (92%) of 74 patients with mitral insufficiency, 17 (74%) of 23 patients with aortic insufficiency, two (50%) of four patients with mitral stenosis, and 29 (97%) of 30 patients with combined lesions. With respect to intensity of murmurs, the ADD correctly identified three of five (60%) grade I murmurs, 17 of 23 (74%) grade II, 45 of 50 (90%) grade III, 45 of 47 (96%) grade IV, and all six grade V and VI murmurs.

The third study in table 3 was performed on a clinical population of 58 children consisting of 35 normal children, 22 with heart disease, and one patient for whom the diagnosis was questionable.32 For the purpose of tabulation, the questionable case was removed from the population. In this study, 22 (63%) of 35 children without heart disease and 15 (68%) of 22 children with heart disease, were correctly identified. Of the seven cases of heart disease missed by the ADD, three were cases of mitral insufficiency, and there was one case of aortic insufficiency, one of combined aortic and mitral insufficiency, one of aortic stenosis, and one had an atrial septal defect. The population for this study was a high risk one selected from a group of youngsters who had been recalled from a previous heart survey because of a clinical impression of possible heart disease on the basis of auscultatory, electrocardiographic, or x-ray findings. For this reason the specificity figure of 63% has no meaning when extrapolated to a general population of school children.

One must be wary of extrapolating the data given in table 3 to screening mass populations under field conditions. They are valid only for "clinical" settings. One would expect that field conditions would influence both sensitivity and specificity of this or any other screening mechanism. Interpretation of the data must take into account the number of cases and the types of heart disease which comprise the study population. The heart disease cases in the populations in these studies are not necessarily representative of the "natural" distribution of heart disease in the community at large.

A second consideration of importance in evaluation of data from these ADD studies is that in some instances the technician was relatively inexperienced in the use of the apparatus. It has been fairly well documented that until a technician screens approximately 500 cases, proficiency in the use of the apparatus is less than optimal, and a higher than usual rate of positive screenings (or lower specificity) usually results.23

Sensitivity Determinations by "Inserted" Cases in Field Studies (Table 4)

A second means of evaluating the sensitivity of a screening procedure has been to insert into the population to be screened a given number of well-documented cases of the disease to be detected. The ability of the screening procedure to detect these cases would then be expressed as a percentage, and would theoretically be an indication of the procedure's sensitivity in a field situation. The advantage of this approach over the testing of a screening device in a clinical situation is that the screening procedure is evaluated under the conditions of its ultimate use, that is, in the field on a mass basis. The primary disadvantage of this sort of evaluation is that the estimated sensitivity as determined by this method can vary considerably depending upon what types of cases are "inserted." However, this bias can be minimized if the population of "inserted" cases is representative of the distribution of
types and severity of heart disease cases found in the general population. Also, some index of relative sensitivity is obtained if the screening procedure is compared with other screening mechanisms on the same population of “inserted” cases.

**Specialist Examination**

In table 4 the sensitivity data on “inserted” cases of known heart disease on examination by specialists are from two studies. In the first study, physician screening was performed once by either a pediatrician or an internist. In this study, of 52 “inserted” cases, 29 (56%) were detected by the screening physician. In the second study, 34 “inserted” cases of heart disease had duplicate screening examinations by board-certified pediatric cardiologists. Of these 34 cases, eight were missed on both examinations, for a sensitivity of 76%.

**Tape Recording**

The sensitivity data on “inserted” cases for the tape-recording technique are a compilation of six studies. The range of sensitivity results in these studies varied from 63% to 91%, with a mean of 75%. The wide range of variation in sensitivity as determined by this method generated considerable interest. In a study reported from Denver in 1965, 87 cases of heart disease were detected by one or more of three different screening mechanisms. Included in these 87 cases were 14 cases of atrial septal defect. Eleven of the 14 cases of atrial septal defect were missed by the tape-recorded heart sounds screening method. In one of the seven studies comprising the data for tape-recording sensitivity in this table, no cases of atrial septal defect were included in the “inserted” population. In the population of “naturally” occurring heart disease, atrial septal defect is one of the more common lesions. This example points out the lack of reliability of the “inserted” case method in determining the sensitivity of a screening technique relative to the general population.

**Analog-Digital Device (ADD)**

The ADD study reported in table 4 is on the same group of “inserted” patients with known heart disease as one of the two studies which comprise the data on specialist examination. Twenty-four (69%) of 35 “inserted” cases were identified by the ADD.

<table>
<thead>
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<th>Method</th>
<th>Identified</th>
<th>Sensitivity</th>
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<tr>
<td></td>
<td>No. (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average (%)</td>
<td>Range (%)</td>
</tr>
<tr>
<td>Specialist examinations</td>
<td>86 55 64</td>
<td>56-76</td>
<td>19, 23</td>
</tr>
<tr>
<td>Tape recording</td>
<td>370 276 75</td>
<td>63-91</td>
<td>19, 24, 25, 28, 30, 31</td>
</tr>
<tr>
<td>ADD</td>
<td>35 24 69</td>
<td>69</td>
<td>23</td>
</tr>
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</table>

<table>
<thead>
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<th>Method</th>
<th>Normal individuals</th>
<th>Identified</th>
<th>Sensitivity</th>
<th>Heart disease cases</th>
<th>Identified</th>
<th>Sensitivity</th>
<th>References</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>No. %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X-rays</td>
<td>5,774</td>
<td>5,730 99</td>
<td></td>
<td>65 21 32</td>
<td></td>
<td></td>
<td>11, 14</td>
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<tr>
<td>ECG</td>
<td>29,741</td>
<td>28,736 96</td>
<td></td>
<td>253 92 36</td>
<td></td>
<td></td>
<td>11-14</td>
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<td>Tape recording</td>
<td>30,784</td>
<td>29,971 97</td>
<td></td>
<td>150 84 56</td>
<td></td>
<td></td>
<td>13, 14, 20, 37</td>
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<tr>
<td>ADD</td>
<td>10,904</td>
<td>10,268 95</td>
<td></td>
<td>61 39 64</td>
<td></td>
<td></td>
<td>23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2 screenings)</td>
<td></td>
<td>61 46 76</td>
<td></td>
<td></td>
<td>23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3 screenings)</td>
<td></td>
<td>61 49 80</td>
<td></td>
<td></td>
<td>23</td>
</tr>
</tbody>
</table>

*Table 4*

**Table 5**

**Table 5**

**Specificity and Sensitivity of Screening Mechanisms in “Natural” Populations**
Duplicate pediatric cardiologist examination detected 76% of these cases.

**Sensitivity and Specificity in the Field (Table 5)**

Another method for determination of sensitivity of a screening mechanism is to evaluate the study population by the screening method in question and to compare the results to a "standard" method of determining all cases of the heart disease existing in the population. Since the prevalence of heart disease in the grade school population averages 5 to 7 cases/1,000, approximately 10,000 children have to be screened in a sensitivity study of this type to yield a minimum of 50 cases of heart disease. Even with this number of cases, the confidence band on the reported sensitivity rate is approximately ± 20%. When one is dealing with a population of 10,000 school children, the problem of setting the standard, or defining all the cases in the population by a standard technique, becomes enormous. In one study,²³ duplicate examination by pediatric cardiologists was established as the standard mechanism for determination of heart disease in the population. Sixty-one cases of heart disease were found by that mechanism. However, when the mechanism was tested with "inserted" cases of known heart disease, the duplicate pediatric cardiologist examinations detected 76% of 34 "inserted" cases. Since there is no "standard" mechanism that picks up all heart disease in a population, interpretation of these sensitivity data must be tempered by judgment.

Sensitivity data on physician examination do not appear in table 5 because usually this procedure has been considered the standard technique to which the others were compared. Validation of physician examination other than by use of the inserted case method has not been accomplished.

**X-rays**

The data on x-ray sensitivity and specificity are a compilation of two studies.¹¹,¹⁴ One was a small study employing full size chest x-rays in a high-risk population (children screened as "suspicious" by the tape-recorded heart sounds technique).¹⁴ The second was a large study employing the standard miniature chest x-ray.¹¹ The sensitivities were 36% and 26%, respectively. The average sensitivity was 32%.

**ECG**

The electrocardiographic data are a compilation of four studies¹¹,¹⁴ two evaluating a full electrocardiogram,¹³,¹⁴ and two using only the V₃₆ lead.¹¹,¹² The two studies employing V₂₆ as the only screening lead detected 26% and 37% of the cases of heart disease. The screening studies utilizing a full electrocardiogram detected 35% and 41% of the cases of heart disease. The average for the four studies was 36%.

**Tape Recording**

The data on tape recording in the general population are from four studies,¹³,¹⁴,²⁰,³⁷ with sensitivities of 45%, 70%, 65%, and 86%, respectively. The average sensitivity was 56%. The study yielding the lowest sensitivity was on the largest population and employed physician and electrocardiographic screening as a combined method to serve as a standard for identification of heart disease in the population. The study yielding 86% sensitivity was on a small group (612) of high-risk children in which 14 cases of heart disease were found by the standard mechanism. Twelve of the 14 were identified by the tape-recorded screening mechanism.

**Analog-Digital Device (ADD)**

These data come from a single study recently completed in Chicago. Three sensitivity rates are reported based on the number of ADD screenings per child, 64, 76, and 80% for 1, 2, and 3 screenings, respectively. For their purposes the sensitivity rate of 76% is of greatest practical significance, for as a future service mechanism in Chicago it is planned to begin by employing two screenings.

The specificity of a screening technique is defined as its ability to identify normals as normal. At first glance, the specificities presented in table 5 look quite similar, and the differences appear to be insignificant. However, this is not true, for in a community

*Circulation, Volume XXXVIII, August 1968*
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program one has to look at the numbers of suspects which must be handled by the secondary screening mechanism. It will be noted that for x-ray screening approximately 1% of the children without heart disease will be screened as “suspicious.” In ADD screening an average of 5% of the normal children are screened as “suspicious.” For this reason, it is imperative that a secondary screening mechanism be built into any ADD screening programs. For example, in the recent Chicago study,23 10,965 children were screened. Six hundred fifty-seven of the normal children were screened as positive by the ADD. The secondary screening mechanism was a clinical examination by pediatric cardiologists with ECG and x-rays as required. On the basis of this secondary screening mechanism, all but two of the suspects who did not have heart disease were correctly identified as normal. These two individuals were referred by the secondary screening mechanism for more extensive work-up for possible heart disease and were finally determined to be normal.

Discussion

The need for heart disease screening in school children must be evaluated in relation to the standard of medical care in the community and the ability of medical resources to provide adequate diagnostic and therapeutic services for care of individuals identified by the screening mechanism. Benefits from such programs exist in three areas: (1) Identification of previously undetected cases of heart disease allows these patients to receive medical and surgical care at the most appropriate time. (2) Children with previously recognized heart disease who may have strayed from medical care are identified, and appropriate prophylactic and therapeutic measures may be re instituted. (3) The screening mechanism may be so designed as to identify children who carry a false diagnosis of heart disease. Usually this is accomplished by automatic referral of all children with a history of heart disease to the secondary screening mechanism (pediatric cardiologist). These children may then be “delabeled” or rehabilitated both physically and psychologically. The number of such children “delabeled” by some programs has equalled or surpassed the number of children with previously undetected organic heart disease identified by the same programs.24

A review of available data on screening methods for detecting heart disease in children suggests that for the purpose of obtaining a maximum yield of previously unknown heart disease with a minimum expenditure of physician time and public health dollars, the analog-digital device screening technique is the best technique that is currently available. Adequate data are not yet available to evaluate the use of this device in infants, pre-school children, or in adults.

Inherent in the operation of the analog-digital device in its present state is the necessity for considerable subjective evaluation and judgment on the part of the technician. For this reason results utilizing this instrument may vary considerably with technician ability, judgment, attentiveness, and interest. Plans are being developed for further study of the influence of technician variability upon results.

There is still some question as to what constitutes the optimal design of an ADD screening program. Three alternatives have been proposed: (1) A single ADD screening with all “positives” (children screened as “suspicious” by the ADD) referred for secondary screening by a cardiologist; (2) duplicate ADD screening of each child, with a “positive” result on either screening indicating referral for screening by a cardiologist; and (3) single ADD screening with repeat ADD screening for only those individuals identified as “positive” by the first screening. Individuals remaining “positive” on the second screening would be referred for screening by a cardiologist.33

In the Chicago study,23 the sensitivity of the ADD increased from 64% to 76% when two (instead of one) ADD screenings were em-
ployed. A further increase to 80% occurred with three ADD screenings of each child.

Durnin and associates\textsuperscript{38} screened 3,797 school children, recalling 391 on the basis of the initial ADD screening. On repeat ADD screening of these 391 students, 212 were screened as normal. No heart disease was identified in these 212 students rescreened as normal. Of the 179 students whose second ADD screening result remained abnormal, 13 had congenital or rheumatic heart disease.

From these data one might conclude that rescreening children who had initial "positive" results is desirable in that the number of referrals to the cardiologist for secondary screening is halved without any loss of sensitivity. However, the results of the Chicago study\textsuperscript{23} showed that in their hands some cases of organic heart disease identified as "positive" by the first ADD screening were screened negative by the device the second time. The reason for this discrepancy in results is not readily apparent and deserves further investigation. Variable technician performance is a possible explanation, but this has not been documented.

It should be stressed that any type of screening program for school age children must be a community effort. Mere identification of cases is of no benefit if adequate diagnostic and therapeutic follow-up is not ensured. Development of cardiac or multiphasic screening programs must be accompanied by expansion of community medical resources to provide the necessary follow-up services. It is helpful in planning such programs if private organizations such as heart associations and medical societies are involved from the beginning so that best use can be made of existing resources in private medicine.

Other heart disease detection techniques such as computer analysis of the oscillographic phonocardiogram,\textsuperscript{38} contour plot spectral phonocardiography,\textsuperscript{39} computer analysis of the electrocardiogram,\textsuperscript{40} echocardiography,\textsuperscript{41} and sphygmorecording\textsuperscript{42} are currently being developed and evaluated. Testing of their application to mass screening should be anticipated in the near future as logical extensions of the "experiment" begun by Dr. Halsey in 1919.

\textbf{References}

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Detection of Heart Disease in Children 1919-1967
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Circulation. 1968;38:375-385
doi: 10.1161/01.CIR.38.2.375

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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