Screening Children for Heart Disease With a Portable Tape Recorder

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SCREENING of children for heart disease is at this time best done by an auscultatory technique. Previous articles have described the process of recording heart sounds on high fidelity equipment and listening to them on playback equipment (*1–3*). The main advantage of this process over direct auscultation is that the physician may listen to the tapes in a quiet place at a time of his choice.

A preliminary study to investigate the feasibility of this method for screening children's heart sounds for heart disease was begun in Chicago in 1954 (*1*). Satisfactory results led to a mass field trial on more than 33,000 school children in that city during 1959–60 (*2,3*). About 1,000 children were screened per week, using fixed equipment set up in a mobile trailer. Sixty-four cases of definite organic heart disease, a rate of 2 cases per 1,000 children screened, were found in the study. Half of these cases were previously unknown.

In late 1961, the Advisory Committee of the Heart Disease Control Program, Chronic Diseases Division, Public Health Service, recommended that comparative and evaluative studies of this method be initiated using portable equipment assembled by the program from adaptable components available on the commercial market (*4*).

Since the Pennsylvania Department of Health was interested in the method for possible use in school health programs, a preliminary field test using the new equipment was conducted in that State during the 1962–63 school year.

Lancaster County was selected as a trial area for several reasons. The Heart Association of Lancaster County, a new organization, was eager to initiate a community service project and the Pennsylvania Department of Health had a well-functioning cardiac clinic which could provide followup for the children found positive in screening. The county, a medium-sized community with 275,000 people, was ideal for a field trial. It had urban, suburban, and rural communities and schools.

The study's main objectives were to: (*a*) test the practicability of using portable equipment by determining its portability and sturdiness and the frequency and cost of repairs and maintenance under field conditions; (*b*) determine how many children could be screened in an hour and in a school day; (*c*) ascertain the number of tapes to which a physician could

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listen per hour and for how many hours; (*d*) determine the yield of unknown heart disease by this method; and (*e*) determine the cost per screenee.

Materials and Methods

From the 2d, 7th, and 12th grades of 20 public and 5 parochial schools in Lancaster, Pa., and from 1 parochial high school in Lancaster County, 4,530 students, all of whom had undergone physical examinations during the previous year, were selected for study. Results of the physical examinations were to serve as checks on the heart disease screening method with tapes. It was believed that this method might uncover additional cases of organic heart disease.

Preparation for the screenings included a letter to each physician in the county outlining the project, talks to the parent-teacher associations, and a visit by the coordinator of the project to each school to orient the school nurses and to leave informational brochures, brief medical questionnaires, and consent slips for the parents.

The screening equipment was loaned by the Heart Disease Control Program, Public Health Service. The recording unit consisted of a modified tape recorder and monitor unit, a contact heart-sound microphone, a separate voice microphone, and a special recording chair and arm. Playback equipment consisted of a tape deck and amplifier with modifying filters, headphones, and an oscilloscope for visual observance of the signal. The screening components have been described elsewhere in more detail (*4*).

With the child sitting forward, the microphone was applied to two chest sites: to the apex, as determined by the point of maximum impulse, and to the base, at the sternal border of the third left interspace. Eleven seconds of heart sounds plus 2 seconds for identification data were recorded at each site. Two cardiologists listened to the tapes and independently classified them as "technically unsatisfactory," "negative," or "suspicious."

A team of eight cardiologists was employed. All of the first readings and about 20 percent of the second were done by a group of seven Lancaster physicians (Dr. John H. Esbenshade, Jr., Dr. Samuel H. Hauck, Dr. Carl H. Hoover, Dr. Richard H. Mann, Dr. Arthur Martin, Dr. Harvey H. Seiple, and Dr. Myron M. Rubin). A Philadelphia cardiologist (Dr. J. W. Fewell) with previous experience in heart-sound taping did most of the second readings. All children whose heart sounds were considered suspicious by either the first or second listeners or both were recalled for direct auscultation and a brief physical examination by two cardiologists. Also recalled were children who had a history of possible or definite heart disease or rheumatic fever and those whose tape recordings were judged technically unsatisfactory by one or both listeners. Children with suspicious findings at the recall examination were referred through their private physicians for complete workups if diagnostic information was not already available.

Results

Of 4,530 students in the 2d, 7th, and 12th grades, heart sounds of 4,139 (91.4 percent) were taped (table 1). An average of 55 children were processed per hour, including registration, undressing, taping, and redressing.

Sounds of 391 were not taped; parental permission was denied for 41 of these, and 194 students were absent on the day of taping. An additional 156 12th graders in one school refused to participate despite parental consent (table 2). The refusals occurred when a few athletic heroes decided at the last minute not to be taped with a subsequent bandwagon effect.

The physician-listeners' interpretations are shown in table 3. Ninety-nine (2.4 percent)

Table 1. Participation in heart-sounds screening by school grade, Lancaster County, Pa., 1962–63

School grade	Total children	Taped	
		Number	Percent
Total	4,530	4,139	91.4
2d	2,772	2,616	94.4
7th	1,110	1,056	95.1
12th	648	467	72.1

Table 2. Reasons for nonparticipation in heart-sounds taping, Lancaster County, Pa., 1962–63

Children eligible	Number	Percent of eligible (N=4,530)	Percent of children not taped (N=391)
Total	4,530	100.0	
Number taped	4,139	91.4	
Number not taped	391	8.6	100.0
Parents denied permission	41		10.5
Absent on day of taping	194		49.6
Child refused to be taped	156		39.6

Table 3. Tape interpretations by physician-listeners, Lancaster County, Pa., 1962–63

Recordings read	Number	Percent of total (N=4,139)	Percent of technically satisfactory (N=4,040)
Total	4,139	100.0	
Technically unsatisfactory [1]	99	2.4	
Technically satisfactory	4,040	97.6	100.0
No suspicious murmurs or sounds	3,701		91.6
Suspicious murmurs or sounds [2]	339		8.4

[1] So classified by both listeners or classified technically unsatisfactory by one and negative by the other.
[2] So classified by one or both listeners.

of the 4,139 recordings were considered technically unsatisfactory. Of the 4,040 considered technically satisfactory, 339 (8.4 percent) were classified as "suspicious." Although all 339 children with "suspicious" findings were recalled for auscultation, 46 (13.6 percent) did not return, including 4 children with known congenital heart disease (table 4).

Of the 293 who did return, 109 (37.2 percent) were found to have innocent murmurs and 29 (9.9 percent) suspicious murmurs. The 29 were referred for further diagnostic evaluation. Three did not appear for the final workup (table 5). Of the remaining 26 with suspicious murmurs, 13 had innocent murmurs and 13 (50.0 percent) had definite organic heart disease upon further evaluation.

Based upon heart sounds considered suspicious on tape, table 6 shows a yield of 15 known cases of heart disease (14 congenital and 1 rheumatic) and 2 additional cases of previously unknown rheumatic heart disease. No cases of congenital heart disease were newly discovered. The results represent a total prevalence of 4.1 cases per 1,000 among 4,139 children taped, of which 0.5 cases per 1,000 were previously unknown. Not included in this figure are three cases of congenital heart disease not considered suspicious on tape. Addition of these 3 cases would increase the prevalence to 4.8 cases per 1,000. Furthermore, on the basis of the 50 percent yield among children who returned for final workup, 1 or 2 cases might be expected among the 3 who did not return

Table 4. Findings on auscultation of children with suspicious murmurs on tape, Lancaster County, Pa., 1962–63

Children recalled	Number	Percent of total (N=339)	Percent of examined (N=293)
Total	339	100.0	
Did not return	[1] 46	13.6	
Examined	293	86.4	100.0
No murmur	155		52.9
Innocent murmur	109		37.2
Suspicious murmur	29		9.9

[1] Includes 4 children with known congenital heart disease.

Table 5. Results of diagnostic workups on children with suspicious murmurs at auscultation, Lancaster County, Pa., 1962–63

Children with suspicious murmurs	Number	Percent of total (N=29)
Total	29	100.0
Did not return for workup	3	10.3
Returned for workup [1]	26	89.7
Innocent murmur	13	
Definite heart	13	

[1] Included ECG and chest X-ray.

(table 5). This additional number would increase the estimated prevalence to slightly more than 5.0 cases per 1,000. It should be noted, however, that the prevalence figures are uncorrected for possible unknown cases missed by the screening procedure, for possible cases among children who were absent from school on the day of taping or who refused or were denied parental permission to participate, and for possible cases among hospitalized and homebound children.

Table 7 shows the distribution by school grade of the 17 verified cases of heart disease considered suspicious on tape. Of the three students with cases of congenital heart disease whose heart sounds were not considered suspicious on tape, two were in the second grade and one in the seventh. Although these figures are too small to allow calculation of reliable rates for each grade, they are included for reference. Accumulation of information from this and future studies will perhaps help determine which grade levels would provide the greatest yield from screening.

Distribution of all 20 cases of heart disease by type of lesion, by whether or not the disease had been detected previously, and by tape interpretation is shown in table 8. The three previously known heart disease cases that were missed on tape were congenital: one in a second grader and another in a seventh grader were diagnosed as pulmonary stenosis; the third, in a second grader, represented a surgically corrected patent ductus arteriosus with no abnormal auscultatory findings. Of the three cases of rheumatic heart disease detected on tape, the previously known one was mitral insufficiency in a seventh grader; the two previously unknown ones were mitral insufficiency in a second grader and aortic stenosis with aortic insufficiency in a seventh grader.

Table 6. Prevalence of heart disease cases among 4,139 school children screened, based upon "suspicious" findings on tape, Lancaster County, Pa., 1962–63

Definite heart disease	Number of cases	Rate per 1,000
Total	[1] 17	4.1
Congenital:		
Previously known	[1] 14	3.4
Previously unknown	0	0
Rheumatic:		
Previously known	1	.2
Previously unknown	2	.5

[1] Excludes 3 cases of previously known congenital heart disease which were negative upon tape interpretation and includes 4 cases of previously known congenital heart disease in children who did not return for recall examination.

Table 7. Distribution of heart disease in children by school grade, based upon "suspicious" findings on tape, Lancaster County, Pa., 1962–63

School children	School grade		
	2d	7th	12th
Number taped	2,616	1,056	467
Congenital heart disease:			
Previously known	7	6	1
Previously unknown	0	0	0
Rheumatic heart disease:[1]			
Previously known	0	1	0
Previously unknown	1	1	0

[1] Excludes 3 previously known cases of congenital heart disease which were negative upon tape interpretation.

All 17 students with congenital heart disease and the student with known rheumatic heart disease were under medical supervision; 5 had had surgery. The two with previously undiagnosed rheumatic heart disease are under medical supervision and are receiving secondary rheumatic fever prophylaxis.

The physician-readers' interpretations of the tapes are compared in table 9. Reader 1 interpreted 7.7 percent of the technically satisfactory tapes as suspicious, whereas reader 2 considered only 1.2 percent as suspicious. We used this formula to arrive at these percentages:

$$\frac{\text{Number of suspicious tapes}}{\text{total number taped—technically unsatisfactory}} \times 100.$$

Thus, for reader 1,

$$\frac{313}{4{,}139-71} \times 100 = 7.7.$$

For reader 2,

$$\frac{59}{4{,}139-59} \times 100 = 1.2.$$

It is important to note that all of the first readings and about 20 percent of the second were performed by a group of 7 cardiologists;

about 80 percent of the second were performed by 1 cardiologist with previous experience in heart-sound taping. The first readers, who had considerably less experience, produced a much higher rate of interpretations of "suspicious" than the second reader. This result apparently follows the general rule that new readers are more cautious and have higher rates of children recalled. The first and more cautious readers missed two of the previously known cases of heart disease but detected both of the previously unknown ones. The experienced second reader missed the same two cases, an additional two known cases, and the two previously unknown, or a total of six.

The degree of agreement on "normal" by the first and second readers was 90.8 percent:

$$\frac{3{,}701 \text{ (both readers)}}{4{,}075 \text{ (either or both)}} \times 100 = 90.8.$$

In the Chicago study, this agreement was 97.5 percent (*2*).

Agreement on "technically unsatisfactory" was 9.2 percent:

$$\frac{11 \text{ (both readers)}}{119 \text{ (either or both)}} \times 100 = 9.2.$$

Table 8. Distribution of all heart disease cases in Lancaster County, Pa., study, classified by type of lesion, previous history, and tape results

Type of lesion	Total cases	Known suspicious	Known negative	Unknown[1] suspicious
Total heart disease	20	15	3	2
Congenital heart disease	17	14	3	0
Pulmonic stenosis	5	3	2	0
Ventricular septal defect	4	4	0	0
Tetralogy of Fallot	3	3	0	0
Ventricular septal defect with possible pulmonic stenosis	1	1	0	0
Patent ductus	1	0	[2] 1	0
Aortic stenosis	1	1	0	0
Aortic stenosis and aortic insufficiency	1	1	0	0
Multiple lesions [3]	1	1	0	0
Rheumatic heart disease	3	1	0	2
Mitral insufficiency	2	1	0	1
Aortic stenosis and aortic insufficiency	1	0	0	1

[1] Whether any of the recordings classified negative represented failure to detect previously unknown cases could not be determined by the method used in this study.

[2] Surgically corrected with no residual murmur.

[3] Pulmonic stenosis, ventricular septal defect, atrial septal defect, transposition, and situs inversus. (The student had been operated on in 1950 and was in the 12th grade at time of study.)

Table 9. Comparison of findings of first and second physician-readers, Lancaster County, Pa., study, 1962–63

Reader 1	Findings	Reader 2: Negative	Reader 2: Suspicious	Reader 2: Technically unsatisfactory	Reader 2: Total
	Negative	3,701 [1] *2*	23 *0*	31 *0*	3,755 [1] *2*
	Suspicious	263 *4*	33 *13*	17 *0*	313 *17*
	Technically unsatisfactory	57 *0*	3 *0*	11 *0*	71 *0*
	Total	4,021 *6*	59 *13*	59 *0*	4,139 [1] *19*

[1] Does not include the surgically corrected patent ductus arteriosus with no residual murmur.

NOTE: Italics denote definite heart disease.

The agreement on "suspicious," similar to that on the "technically unsatisfactory," was 9.7 percent:

$$\frac{33 \text{ (both readers)}}{339 \text{ (either or both)}} \times 100 = 9.7.$$

These percentages were lower than the respective 18.9 and 11.1 percent reported in the Chicago results.

Agreement rose to 76.5 percent on the definite cases of heart disease considered suspicious on tape:

$$\frac{13 \text{ (both readers)}}{17 \text{ (either or both)}} \times 100 = 76.5.$$

This proportion compares favorably to Chicago's 50 percent agreement. The yield of definite heart disease from all children recalled by either or both readers was 5 percent. Agreement by both readers that a recording was suspicious increased the chances of there being definite heart disease to 39.3 percent.

Direct expenses for screening the 4,139 children in this study were $4,761.09, or $1.15 per child screened (table 10). The total includes salaries of the project coordinator and clerk-technicians, fees to physicians for tape-listening, mileage charges, and costs of tapes, registration forms, records, and administrative incidentals; it does not include any expenditure for recall examinations since these were done gratis by the project cardiologists.

Table 10. Screening costs, Lancaster County, Pa., study, 1962–63

Item	Cost per item	Cost per child
Tape-reading (15 cents per tape-listener × 2 readers × 4,139 children)	$1,241.70	$0.30
Equipment (amortized on the basis of 150,000 tapings)	124.17	.03
Tapes	59.60	.01
Project coordinator and recording technicians	3,058.50	.74
Local travel for project coordinator and technicians (1,971.2 miles @ 10 cents per mile)	197.12	.05
Administrative incidentals	80.00	.02
Total[1]	4,761.09	1.15

[1] Does not include any expenditure for recall examinations since the project cardiologists performed these gratis. Depending on local pay scales and the recall rate, this will vary from 5 to 20 cents per screenee.

Discussion

The Public Health Service and the Pennsylvania State Department of Health, the local heart association, medical society, and parent-teacher associations, the local school administrators, teachers, and nurses, and many volunteers cooperated in the Lancaster County screening project. School nurses were particularly helpful because of their knowledge of the children in their schools. The screening procedure was fast; an average of 55 children were taped per hour. This rate compares favorably with the 250 a day reported by Smith and others (*1*).

The recording equipment performed adequately during each session. Minor adjustments that had to be made on several occasions did not interfere with screening. Duplicate equipment could have been obtained within one-half hour if the need had arisen. In no instance did screening have to be called off or be rescheduled. Necessary repairs were made locally between sessions. Although the recording equipment was considered portable by the women technicians, they usually obtained assistance in moving the bulky chair.

Occasionally the technician delayed screening because she heard music or news from a local radio station over the tape monitor. Apparently the heart-sound microphone acted as a crystal radio receiver. Some of the tapes were recorded, however, with the radio program in the background. Readers were still able to interpret these and listed very few of them as technically unsatisfactory.

The project coordinator devoted considerable time and effort to inducing physicians to listen to the tapes soon after the recording session. The time between the school taping session and receipt of a screening report ranged from 5 to 8 weeks for the Philadelphia physician and from 2 to 3 weeks for the local physicians. The Lancaster physicians were unable to listen in their own offices because not enough listening sets were available, but they were able to do so conveniently at the local heart association office. They were able to screen an average of 120 recordings an hour but could not listen for

more than an hour at a time because of aural fatigue and boredom.

In the Chicago study, the two reader groups complemented each other; each found some cases missed by the other. This was not so in Lancaster where the second readers failed to detect any definite cases missed by the first, presumably because the first readers were the more cautious.

The rate of students recalled in Lancaster, 8.4 percent, was markedly higher than the 1.5 percent reported by Chicago. The higher rate probably was due in part to the initial overcautiousness of those who did the first readings and to their inability, at first, to distinguish between suspicious murmurs, cardiorespiratory murmurs, and adventitious sounds. The observed prevalence of 4.1 cases per 1,000 and the estimated prevalence of slightly more than 5.0 cases per 1,000 fall in the general range indicated in Morton's comprehensive review of heart disease prevalence in school children (*5*).

The prevalence ratio of congenital to rheumatic heart disease was found to be approximately 5:1 in Lancaster County. Morton notes that congenital heart disease is likely to exceed rheumatic, but the rates he lists from more recent studies indicate a ratio considerably less than 5:1. One possible explanation for the discrepancy may be that while the Lancaster group covered a wide age range, only 11 percent were older than 13 years; rheumatic heart disease would be more prevalent in the older age group. Or it may be that the unknown cases missed by screening procedures based on tape recordings are more likely to be cases of rheumatic heart disease than congenital, since aortic and mitral insufficiency appear to be more difficult to detect (*2,3*).

One of the two aortic lesions detected in the Lancaster study represented a known congenital defect; the other, an unknown case of rheumatic heart disease. Possibly these would have been missed had the Lancaster group used the same recording site as the Chicago investigators, the second left interspace instead of the third left.

On the other hand, the Lancaster readers missed two known cases of pulmonic stenosis with murmurs of grade 3 intensity (on a scale of 6) at the second left interspace, as determined by auscultation. In one of these cases, audio and oscilloscopic rescreening of the tape showed that the murmur had not been picked up at the third left interspace. Of course, one must assume that the microphone had been placed exactly at the sternal border or at the third left interspace and that the equipment recorded properly. The other missed murmur was definitely audible on tape although both readers failed to call it suspicious. Had the recording been made at the second left interspace, the murmur might have been more prominent and other auscultatory phenomena such as an abnormality of the second heart sound or the presence of a pulmonary ejection sound might have been noted. Any of these circumstances would have increased the chances of detecting these cases.

In short, while the third left interspace appeared to be a better site for detection of aortic lesions, its use instead of the second left interspace may have been responsible for the readers' failure to detect two pulmonic lesions. The questions arise, therefore, whether selection of this site lessened the chances of detecting unknown congenital heart disease, and whether, three or more sites may not be needed to give the best screening yield.

In evaluating the Chicago experience, Abrams emphasizes the extra costs in money and in time of school personnel and of others that cardiac screening entails. He points out its low yield, the organizational planning required, and other negative aspects. Abrams believes that cardiac screening should be done only as part of a multiphasic screening program, perhaps including measurements of height and weight, tests of vision and hearing, tuberculin test, urinalysis, hemoglobin determination, physical examination, and immunization (*3*). We also agree that it would be best to conduct cardiac screening as an integral part of a coordinated school health program.

Recognizing that the method used in this study would not indicate the number of unknown cases missed, we have not attempted to discuss sensitivity or specificity. To meet this deficiency, however, in the fall of 1963 we began a sensitivity and specificity study. The heart

sounds of approximately 5,000 children have been taped and auscultated at the same session by two cardiologists, who later read the tapes. We are preparing the results for publication.

Summary

A field test of a heart-sounds screening method of detecting heart disease in school children was undertaken in Lancaster, Pa., with newly developed portable tape-recording equipment.

Of 4,530 students in the 2d, 7th, and 12th grades, 4,139 (91.4 percent) were screened; 339 were recalled for an auscultatory examination because of findings on tape interpreted as suspicious. Forty-six of those recalled failed to return.

Examination of the 293 who returned yielded 29 students with findings suspicious enough to require further evaluation. Three did not appear for final workup. Confirmatory data on the remaining 26 revealed 13 with innocent murmurs and 13 with definite organic heart disease.

Four of the 46 who failed to return for auscultatory examination had known congenital heart disease, bringing the total cases of heart disease found on tape by the project readers to 17. Of these, 15 were previously known (14 congenital and 1 rheumatic heart disease); the 2 previously unknown cases both consisted of rheumatic heart disease. Three additional congenital heart disease cases were not detected on tape; one consisted of a corrected patent ductus with no residual murmur.

The 20 cases of heart disease found among the study population gives a prevalence of 4.8 cases per 1,000. The addition of 1 or 2 cases that might have been expected among the children who did not return for further workup would increase the estimated prevalence to slightly more than 5.0 per 1,000.

In the two cases of pulmonic stenosis missed on tape by both readers in the study, grade 3 murmurs at the second left interspace were observed upon auscultation. The major reason for failure to detect these cases was possibly use of the third rather than the second left interspace as the site for the second recording.

The direct screening cost in this study was $1.15 per child.

Because this field trial clearly indicated the need for determining the screening method's sensitivity and specificity, an appropriate followup study was undertaken in the fall of 1963.

REFERENCES

(1) Smith, J. M., et al.: Use of tape-recorded heart sounds in screening of children with heart disease. Circulation 20: 887–896 (1959).

(2) Miller, R. A., et al.: The detection of heart disease in children: results of a mass field trial with use of tape-recorded heart sounds. Circulation 25: 85–95 (1962).

(3) Abrams, I.: Evaluation of tape-recording of heart sounds on a mass scale in school children. School Health 33: 62–69 (1963).

(4) Coleman, D. J., et al.: A new portable heart sound recording system, Amer J Med Electronics 3: 192 (1964).

(5) Morton, W.: Heart disease prevalence in school children in two Colorado communities. Amer J Public Health 52: 991–1001 (1962).