Evaluation of a Computer Program for Diagnosis of Congenital Heart Disease

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AT THE TURN of the century Sir William Osler stated, "Medicine is a science of uncertainty and an art of probability."[1] However, no attempts to use an explicit probability theory in diagnosis was made until 1961, when the authors[2] applied an expansion of Bayes' theorem of conditional probability[3] to the diagnosis of congenital heart disease. This paper will be concerned with: (1) a review of the methods used in this approach and (2) an evaluation of the accuracy of diagnosis using the computer program as compared to that of three physicians.

METHOD

Since the method employed is a statistical one, it is first necessary to clearly define the population to which the statistics apply. In the present study the population consists of all patients referred to the Cardiovascular Laboratory of the Latter-day Saints Hospital with the clinical diagnosis of congenital heart disease. The a priori incidence figures used are specific for this population and would not necessarily apply to patients with congenital heart disease referred to another laboratory or clinic.

The other statistics used in the calculation, however, represent the incidence of each symptom in each disease. For our purposes it is convenient to define symptoms as age group, complaints, physical findings, and ECG findings. The list of symptoms is shown in table 1 and the list of diseases is shown in table 2. Table 3 illustrates a corner of the symptom-disease matrix. The x's refer to the symptoms and the y's to the diseases. The number 65 at the intersection of column x_5 with row y_8 indicates that symptom x_5 (severe cyanosis with clubbing of the fingers) occurs in 65 per cent of patients with disease y_8 (tricuspid atresia without transposition). The numbers contained in this matrix were obtained where possible through evaluation of 452 cases which had passed through this laboratory. In certain instances these statistics were not adequate and it was necessary to estimate the frequency with which each symptom occurred in each disease based on: (a) available information from the literature and (b) consideration of the pathologic physiology of the disease. To this extent the equation and the disease matrix represent a mathematical model of the authors' concepts of the logical process used to make a diagnosis.

The equations used to estimate the probability that a given patient pre-

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*Research Career Award, National Institutes of Health.

Table 1.—*List of Symptoms to Be Evaluated by Physician*

Code*		Symptoms
BW	†	x_1 = age 1 mo. to 1 yr.
BW	†	x_2 = age 1 to 20 yr.
BW	†	x_3 = >20 yrs.
BW	†	x_4 = cyanosis, mild
BW	†	x_5 = cyanosis, severe (with clubbing)
BW	†	x_6 = cyanosis, intermittent
BW	†	x_7 = cyanosis, differential
BW		x_8 = squatting
BW		x_9 = dyspnea
BW		x_{10} = easy fatigue
BW		x_{11} = orthopnea
BW		x_{12} = chest pain
BW		x_{13} = repeated respiratory infections
BW		x_{14} = syncope
BW		x_{15} = systolic murmur loudest at apex
B		x_{16} = diastolic murmur loudest at apex
B	†	x_{17} = systolic murmur loudest in left 4th interspace
B	†	x_{18} = diastolic murmur loudest in left 4th interspace
BW	†	x_{19} = continuous murmur loudest in left 4th interspace
B	†	x_{20} = systolic murmur with thrill loudest in left 2nd interspace
B	†	x_{21} = systolic murmur without thrill loudest in left 2nd interspace
BW	†	x_{22} = diastolic murmur loudest in left 2nd interspace
BW	†	x_{23} = continuous murmur loudest in left 2nd interspace
BW		x_{24} = systolic murmur loudest in right 2nd interspace
BW		x_{25} = diastolic murmur loudest in right 2nd interspace
BW	†	x_{26} = systolic murmur heard best over posterior chest
BW	†	x_{27} = continuous murmur heard best over posterior chest
BW	†	x_{28} = accentuated 2nd heart sound in left 2nd interspace
BW	†	x_{29} = diminished 2nd heart sound in left 2nd interspace
BW		x_{30} = right ventricular hyperactivity by palpation
BW		x_{31} = forceful apical thrust
BW		x_{32} = pulsatile liver
BW		x_{33} = absent or diminished femoral pulsation
BW	†	x_{34} = ECG axis more than 110°
BW	†	x_{35} = ECG axis less than 0°
BW	†	x_{36} = R wave greater than 1.2 mv in lead V_1
BW	†	x_{37} = R′ or qR pattern in lead V_1
BW		x_{38} = R wave greater than 2.0 mv in lead V_6
BW		x_{39} = T wave in lead V_6 inverted (no digitalis)
W	†	x_{40} = early diastolic murmur loudest at apex
W	†	x_{41} = late diastolic murmur loudest at apex
W	†	x_{42} = holo-systolic murmur loudest in left 4th interspace
W	†	x_{43} = mid-systolic murmur loudest in left 4th interspace
W	†	x_{44} = holo-diastolic murmur loudest in left 4th interspace
W	†	x_{45} = early diastolic murmur loudest in left 4th interspace
W	†	x_{46} = mid-systolic murmur with thrill loudest in 2nd left interspace
W	†	x_{47} = holo-systolic murmur with thrill loudest in 2nd left interspace
W	†	x_{48} = mid-systolic murmur without thrill loudest in 2nd left interspace
W	†	x_{49} = holo-systolic murmur without thrill loudest in 2nd left interspace
BW		x_{50} = murmur louder than gr 3/6

*B: symptom used on brown check-off sheet; W: symptom used on white check-off sheet. †Indicates presence of mutually exclusive symptoms within brackets which must be handled as special cases (see text). (From Warner et al.[2])

Table 2.—*List of Diseases Included in Differential Diagnosis*

	Diseases
y_1	= normal
y_2	= atrial septal defect without pulmonary stenosis or pulmonary hypertension*
y_3	= atrial septal defect with pulmonary stenosis
y_4	= atrial septal defect with pulmonary hypertension*
y_5	= complete endocardial cushion defect (A-V commune)
y_6	= partial anomalous pulmonary venous connections (without atrial septal defect)
y_7	= total anomalous pulmonary venous connections (supradiaphragmatic)
y_8	= tricuspid atresia without transposition
y_9	= Ebstein's anomaly of tricuspid valve
y_{10}	= ventricular septal defect with valvular pulmonary stenosis
y_{11}	= ventricular septal defect with infundibular stenosis
y_{12}	= pulmonary stenosis, valvular (with or without probe-patent foramen ovale)
y_{13}	= pulmonary stenosis, infundibular (with or without probe-patent foramen ovale)
y_{14}	= pulmonary atresia
y_{15}	= pulmonary artery stenosis (peripheral)
y_{16}	= pulmonary hypertension,* isolated
y_{17}	= aortic-pulmonary window
y_{18}	= patent ductus arteriosus without pulmonary hypertension*
y_{19}	= pulmonary arteriovenous fistula
y_{20}	= mitral stenosis
y_{21}	= primary myocardial disease
y_{22}	= anomalous origin of left coronary artery
y_{23}	= aortic valvular stenosis
y_{24}	= subaortic stenosis
y_{25}	= coarctation of aorta
y_{26}	= truncus arteriosus
y_{27}	= transposed great vessels
y_{28}	= corrected transposition
y_{29}	= absent aortic arch
y_{30}	= ventricular septal defect without pulmonary hypertension*
y_{31}	= ventricular septal defect with pulmonary hypertension*
y_{32}	= patent ductus arteriosus with pulmonary hypertension*
y_{33}	= tricuspid atresia with transposition

*Pulmonary hypertension is defined as pulmonary artery pressure $\geqq$ systemic arterial pressure. (From Warner et al.[2])

senting certain symptoms will have any one of the diseases listed in the matrix are as follows:

Equation 9:

$$P_{y_1/(x_1, x_2, \ldots x_j)} = \frac{P_{y_1} P_{x_1/y_1} \ldots P_{x_j/y_1}}{\sum_{\text{all } k} P_{y_k} P_{x_1/y_k} P_{x_2/y_k} \ldots P_{x_j/y_k}}$$

Equation 10:

$$P_{y_1/(x_1, \bar{x}_8, \ldots x_j)} = \frac{P_{y_1} P_{x_1/y_1} (1 - P_{x_8/y_1}) \ldots P_{x_j/y_1}}{\sum_{\text{all } k} P_{y_k} P_{x_1/y_k} (1 - P_{x_8/y_k}) \ldots P_{x_j/y_k}}$$

Table 3.—*Portion of Symptom-Disease Matrix*

	Diseases	Incidence	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
y_1	.....	0.100	01	49	50	01	00	01	00	01
y_2	.....	.081	10	50	50	02	01	02	00	01
y_3	.....	.005	30	60	10	20	10	20	00	01
y_4	.....	.001	10	20	70	30	10	25	00	01
y_5	.....	.027	20	50	30	15	05	10	00	01
y_6	.....	.005	10	40	50	01	01	01	00	01
y_7	.....	.001	20	70	10	65	10	05	00	01
y_8	.....	.018	50	48	02	30	65	01	00	10
y_9	.....	.001	10	45	45	22	44	01	00	22
y_{10}	.....	.054	40	55	05	25	25	10	00	30
y_{11}	.....	.063	40	55	05	30	30	10	00	40
y_{12}	.....	.045	20	70	10	01	01	01	00	01
y_{13}	.....	.013	20	70	10	01	01	01	00	01
y_{14}	.....	.014	90	09	01	10	90	00	00	80
y_{15}	.....	.001	05	45	50	01	01	01	00	01
y_{16}	.....	.013	10	45	45	01	01	01	00	01
y_{17}	.....	.001	30	60	10	05	01	01	00	01
y_{18}	.....	.072	20	40	40	01	01	01	00	01
y_{19}	.....	.002	20	30	50	45	45	01	00	01
y_{20}	.....	.008	20	50	30	01	01	01	00	01
y_{21}	.....	.013	70	29	01	01	01	01	00	01

The equation numbers refer to those in the original article by the authors in which the equations were derived. Equation 9 states that the probability of the patient having disease y_1 if he has symptoms x_1, x_2, through x_j may be calculated by multiplying (P_{y_1}) the incidence of the first disease by the probability (P_{x_1/y_1}) obtained from the data matrix that symptom x_1 will occur in this disease. These terms must also be multiplied by the probability of each of the other symptoms presented by the patient occurring in this disease (P_{x_j/y_1}). Such a calculation must be performed for each disease. The sum of all these numerators is the normalizing term which appears in the denominator.

The statistics that are used in solving equation 9 are determined solely by those symptoms present in the particular patient. It is apparent that the absence of a symptom (i.e., cyanosis) may significantly alter the diagnosis. To account for this fact it is necessary to consider the absence of symptoms as information. An expansion of the equation to take the absence of symptoms into account is shown by equation 10. In the example illustrated in this equation the patient did not have symptom 8; thus, if P_{x_8/y_1} represents the probability of symptom 8 occurring in a patient with disease y_1, then the complement ($1 - P_{x_8/y_1}$) represents the probability of a patient with this disease not having symptom 8. Although this form of the equation does not require any complication of the symptom-disease matrix, it does introduce the need for clear definition of mutually exclusive symptoms. Mutually exclusive symptoms are shown on the symptom list in table 1 by brackets and

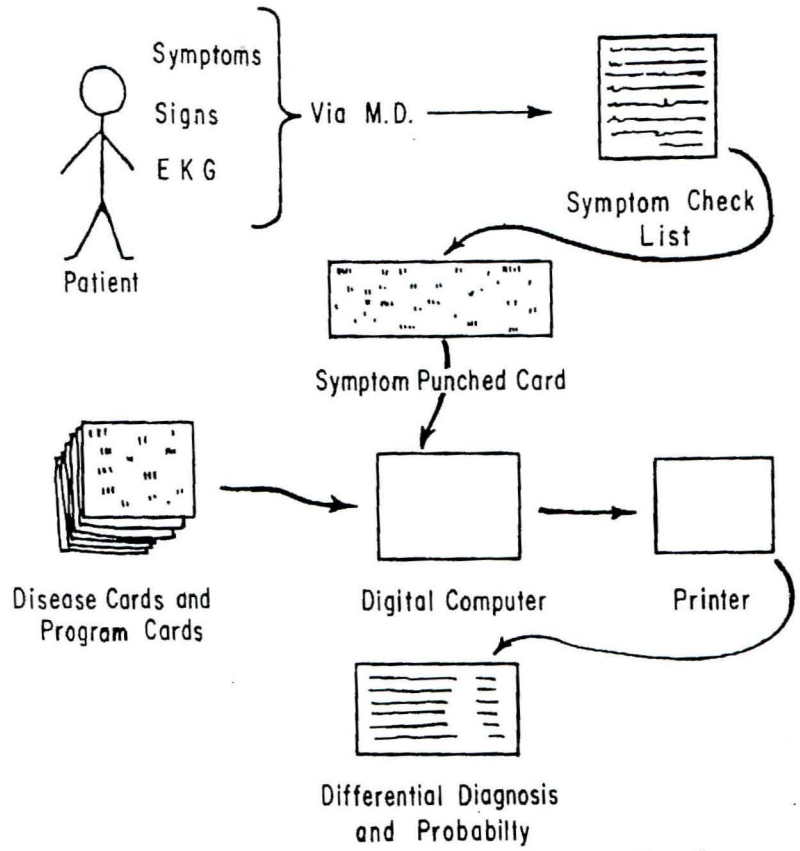

Fig. 1.—A block diagram representing the flow of information into the computer.

must be handled as special cases in the computation. For instance, if symptoms 4, 5, 6, and 7 are not present then equation 10 uses $(1 - P_{x_4/y_k} - P_{x_5/y_k} - P_{x_6/y_k} - P_{x_7/y_k})$ in the calculation, since this is the probability of no cyanosis occurring in each of the diseases. However, if x_4 (mild cyanosis) is present, P_{x_4} is used in the calculation and x_5, x_6, and x_7 are ignored since other forms of cyanosis are automatically excluded. If one of a set of mutually exclusive symptoms is determined to be present, it would be an error to consider the absence of other symptoms in this set as additional information.

A block diagram of the flow of information that occurs in processing a case through the computer diagnosis program is illustrated in figure 1. The physician, after examining the patient and looking at the phonocardiogram and the electrocardiogram, fills out a check-off list noting with a check mark those symptoms present in the patient. The code numbers corresponding to these symptoms are punched on an IBM card and fed to the computer along with the cards containing the symptom-disease matrix and the computer program. At the end of the calculation, the computer prints out a list of diseases with corresponding probabilities, listing only those diseases whose probability exceeds 0.01.

Table 4

% OF CASES IN WHICH CASE WAS DIAGNOSED CORRECTLY WITH AT LEAST 1% PROBABILITY

	# Of Cases		By M.D.	By Computer
LGV	56		95%	89%
AFT	72		96%	93%
JS	74		76%	88%
Total	202	Average	88%	90%

Samples of the physician's *Symptom Check-off List* and the *Computer Printout* are given in the Appendix, on pages 374 and 375.

Method of Evaluation

In this study three physicians made a total of 202 observations on 74 patients. This experiment was designed to provide a comparison of the accuracy of diagnosis using the computer program with the accuracy of each of the three physicians' diagnoses. In each case the computer diagnosis was compared with the diagnosis of the physician who supplied the computer with the clinical data. The physician was required to list his diagnoses in the same form as the computer, assigning a probability to each diagnosis listed.

The correct diagnosis in each case was determined by follow-up studies such as heart catheterization, heart surgery, or autopsy. This provided a reference by which to judge the computer's and physicians' diagnoses based on the following questions:

(1) In what fraction of the cases did the physician or computer list the correct diagnosis and give it a probability of at least 0.01?

(2) How did the probability rating given by the computer to the correct diagnosis compare with the probability rating given this diagnosis by the physician who supplied the computer with the clinical findings?

Results

The performance of the computer program is evaluated relative to the physician who supplied the clinical information. This provides a test of the logic of the program but not of the accuracy of the observations, since the physician and computer are starting with the same observations. The three physicians are identified by initials. LGV is an experienced pediatric cardiologist, AFT is a clinical physiologist with less experience than LGV in clinical cardiology, and observer JS is a third year resident in internal medicine. As shown in table 4, LGV and AFT rate the correct diagnosis with a probability of at least 0.01 in 95 per cent and 96 per cent of the cases, respectively. The resident is correct in 76 per cent of the cases. The average is 88 per cent for the three physicians while the computer supplies the correct diagnosis in 90 per cent of the cases. The less experienced observer (JS)

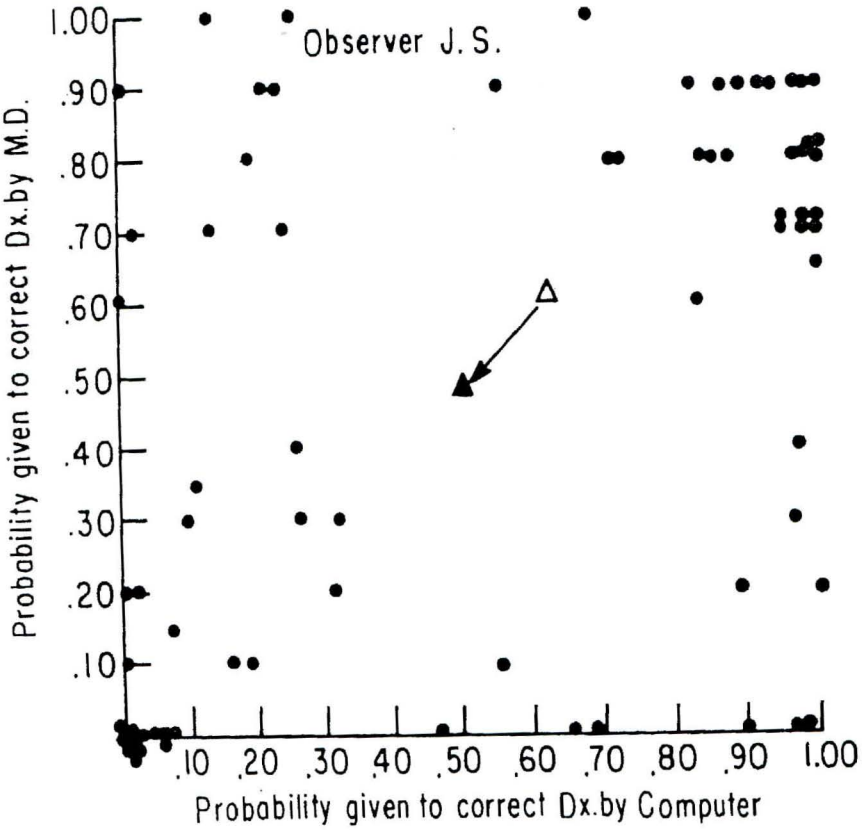

Fig. 2

Figs. 2, 3, 4.—A comparison of the probability assigned to the correct diagnosis to each case by three physicians with the probabilities calculated by the computer.

made errors in symptom recognition as shown by the fact that the computer failed more frequently to make the correct diagnosis from his data than from the data of LGV and AFT. He also made logical errors since the computer made the correct deduction more frequently than he did from his own data.

Figures 2, 3, and 4 are cross plots of the probability rating given in each case to the correct diagnosis by each physician and by the computer using that physician's evaluation of the symptoms present. The points near the origin in each plot are cases in which both the physician and the computer assigned a low probability to the diagnosis which proved correct by follow-up studies. Points in the area of the upper left hand corner of these scattergrams represent cases in which the physician gave a high probability to the correct diagnosis and the computer a low probability. The locus of the solid triangle in these figures represents the co-ordinate of the average rating given to the correct diagnosis by that particular observer and the computer. The open triangle represents the average rating of all three observers.

A progressive improvement in accuracy of diagnosis by both physician and

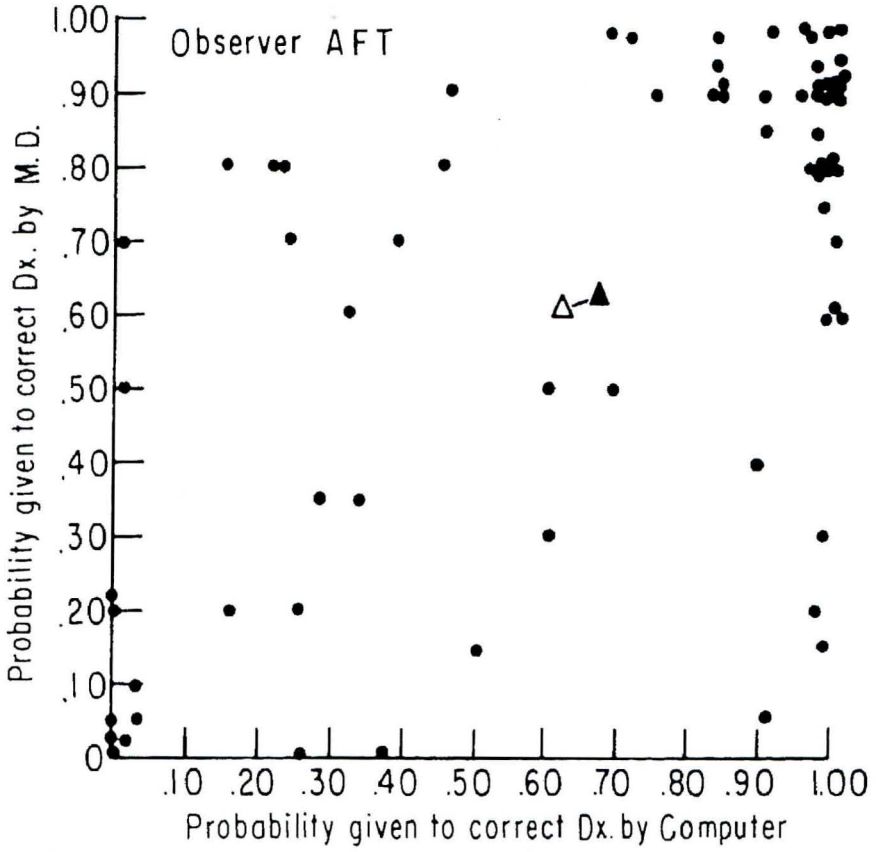

Fig. 3.—See legend, fig. 2

computer is evident from a comparison of these three figures. Figure 2, the plot of the resident physician's (JS) performance, shows a poor correlation (0.19) between the probability rating given the correct diagnosis by the physician and by the computer using his observations. The corresponding coefficient of correlation for AFT was 0.64 and for LGV was 0.73. This indicates that the deductions made by the computer program resemble more closely those of the experienced clinicians than those of the resident.

These scatter-grams are summarized for each of the three observers in table 5. Note that although there is considerable variation among the three observers in their average probability ratings given to the correct diagnosis, the scores listed by the computer for the corresponding physician are almost identical in each instance. This further implies that the accuracy of the initial data supplied to the computer by the observer is an important factor limiting the accuracy of the computer diagnosis.

This data may be compared in yet another way as shown in figure 5. On the ordinate of this figure is the per cent of cases in which the correct diagnosis was given a probability of "x" or greater, where "x" is shown in per cent on the abcissa and ranges from 1 to 100. For example, it can be seen that

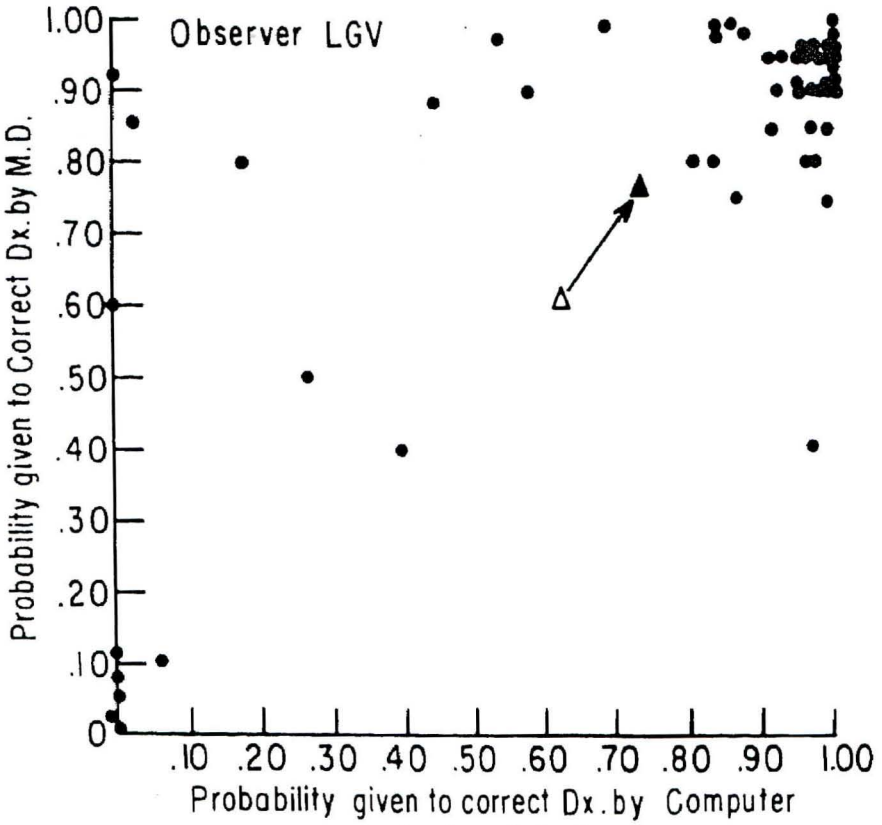

Fig. 4.—See legend, fig. 2

the computer using the data supplied by LGV gave a probability rating of 90 per cent or more to the correct diagnosis in 58 per cent of the cases. It gave a probability rating of 80 per cent or better in 72 per cent of the cases, and a probability rating of 1 per cent or better to the correct diagnosis in 93 per cent of the cases. In the remaining 7 per cent of the cases the correct diagnosis was given a probability less than 0.01 and thus, was not listed by the computer. The computer probability ratings for the other two physicians are illustrated in a similar fashion. The probability ratings for each of the three physicians are also shown in this figure. Note that in each case the plot for the computer data follows the same general course as the plot for the physician who supplied the clinical information on these patients.

The preceding results were obtained using equation 10. Prior to obtaining these results, however, a short series of cases were run comparing both equations 9 and 10. Equation 9 uses only the symptoms actually present in the patient and does not take into account the absence of symptoms, whereas equation 10 does account for absence of symptoms. Figure 6 indicates the results of this comparison showing that in this series of cases the computer, using equation 10, and the physician gave a probability rating to the correct diagnosis of 70 per cent while the computer, using equation 9, gave a sig-

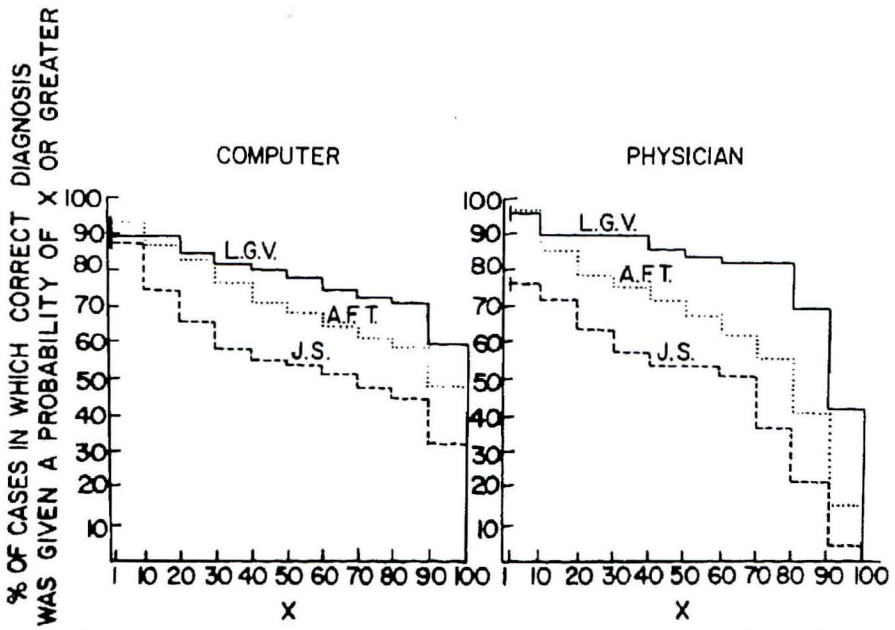

Fig. 5.—On the abscissa is the probability rating (x) and on the ordinate is plotted the per cent of cases in which the correct diagnosis was assigned a probability of x or greater.

AVERAGE PROBABILITY RATING GIVEN TO CORRECT DIAGNOSIS

	# Of Cases		By M.D.	By Computer
L G V	56		76 %	73 %
A F T	72		63 %	67 %
J S	74		48 %	50 %
Total	202	Average	61 %	62 %

Table 5

nificantly lower probability on the average to the correct diagnosis. For this reason equation 9 is no longer used.

An attempt was made to determine whether the computer or the physician were systematically over or under diagnosing any diseases believing that such an analysis might be helpful in looking for flaws in the data matrix. Such an analysis of the performance of the physician and computer with respect to particular diseases is given in table 6. Except for the defect of

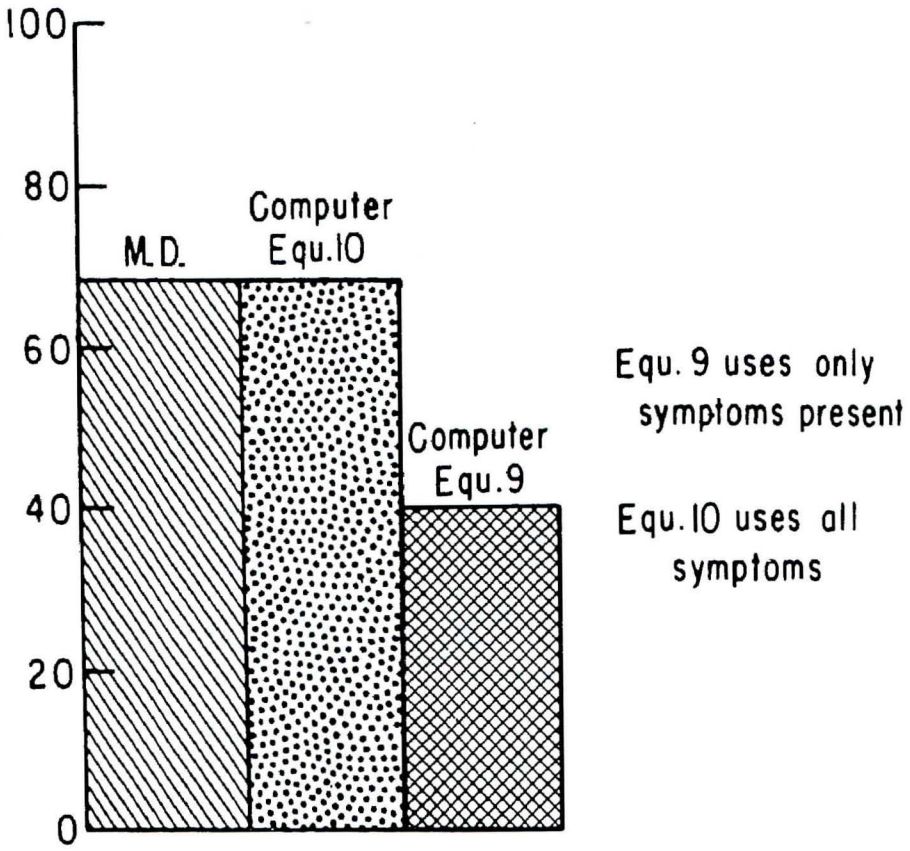

Fig. 6.—A comparison of the probability rating given to the correct diagnosis by the computer using equation 9 and 10 and the physicians' rating.

partial anomalous pulmonary venous connection, only those diseases which occurred more than 10 times in the present series of cases were used in this comparison. In the first column labeled data matrix is the incidence of each disease estimated for our original data matrix from 452 cases seen in our laboratory prior to the beginning of the present series. In the next column under follow-up diagnosis we see the actual incidence of these diseases in the cases that have been analysed in the present study. Notice that several of the diseases occurred more frequently in this short series than was predicted by the data matrix, particularly normal and atrial septal defect. The incidence of each disease predicted by the physician and the computer in this series was calculated by summing the probability given by the computer or M.D. in each case to the diagnosis in question (y_k) and dividing by the total number of observations as shown in the equation at the bottom of the figure. It appears that the computer is tending to under diagnose atrial septal defect while, on the other hand, the physicians tend to under diagnose ventricular septal defect in relation to their incidence in this series. Updating

Table 6

INCIDENCE OF DISEASE PREDICTED BY

	Data Matrix	Follow-up Dx	M.D.	Computer
NORMAL	.100	.317	.242	.241
A.S.D.	.081	.182	.180	.136
P.S.	.058	.087	.116	.086
A.S.	.045	.095	.109	.109
V.S.D.	.252	190	.141	.203
P.A.P.V.C.	.005	.007	.004	.028

(from analysis of 128 cases by 2 observers)

For Computer & M.D., incidence calculated as $\frac{1}{128}\sum_{1}^{128} P_{y_k}$

of the data matrix can be done based on this type of analysis if the new statistics are appropriately weighted with respect to the original figures.

Summary

Our experience with this series of cases in computer diagnosis indicates that the computer's performance at this time is limited by two factors: (1) the accuracy of the input data from the patient as supplied by the examining physician and (2) the accuracy of the data matrix containing the coincidence of symptoms and diseases. In spite of these limitations it is of interest that the computer lists the correct diagnosis with a probability of at least 1 per cent in 90 per cent of the cases and gives an average probability rating of 62 per cent to the correct diagnosis. The computer's performance in this series of 74 patients was essentially identical to the performance of the physicians who made the observations on the patients. The correlation between the probability rating given to the correct diagnosis by the physician and by the computer serves as a measure of the extent to which both are utilizing similar logic to make a diagnosis.

Appendix

Revision of the Present Data Matrix

It was stated in the summary that the computer's performance is limited by the accuracy of the input data and the accuracy of the data matrix. During

SYMPTOM CHECK OFF LIST

(CHECK IF PRESENT)

Age:
- ___ 1. 1 month to 1 year
- ___ 2. 1 year to 20 years
- ___ 3. 20 or more years

Symptoms:
- ___ 4. Cyanosis, mild
- ___ 5. Cyanosis, severe (with clubbing)
- ___ 6. Cyanosis, intermittent
- ___ 7. Cyanosis, differential
- ___ 8. Squatting
- ___ 9. Dyspnea
- ___ 10. Easy fatigue
- ___ 11. Orthopnea
- ___ 12. Chest pain
- ___ 13. Repeated respiratory infections
- ___ 14. Syncope

Murmurs:
- ___ 15. Systolic murmur loudest at apex
- ___ 19. Continuous murmur loudest in left 4th interspace
- ___ 22. Diastolic murmur loudest in left 2nd interspace
- ___ 23. Continuous murmur loudest in left 2nd interspace
- ___ 24. Systolic murmur loudest in right 2nd interspace
- ___ 25. Diastolic murmur loudest in right 2nd interspace
- ___ 26. Systolic murmur heard best over posterior chest
- ___ 27. Continuous murmur heard best over posterior chest
- ___ 40. Early diastolic murmur loudest at apex
- ___ 41. Late diastolic murmur loudest at apex
- ___ 42. Holo-systolic murmur loudest in left 4th interspace
- ___ 43. Mid-systolic murmur loudest in left 4th interspace
- ___ 44. Holo-diastolic murmur loudest in left 4th interspace
- ___ 45. Early diastolic murmur loudest in left 4th interspace
- ___ 46. Mid-systolic murmur with thrill loudest in 2nd left interspace
- ___ 47. Holo-systolic murmur with thrill loudest in 2nd left interspace
- ___ 48. Mid-systolic murmur without thrill loudest in 2nd left interspace
- ___ 49. Holo-systolic murmur without thrill loudest in 2nd left interspace
- ___ 50. Murmur louder than gr 3/6

Patient's Name _____

Case No. _____ Age _____

Observer _____ Date _____

Observer's Diagnosis: Probability

_____ _____

_____ _____

_____ _____

_____ _____

Computer Diagnosis: Probability

_____ _____

_____ _____

_____ _____

_____ _____

Catheterization Diagnosis:

_____

_____

_____

Other Physical Signs:
- ___ 28. Accentuate 2nd heart sound in left 2nd interspace
- ___ 29. Diminished 2nd heart sound in left 2nd interspace
- ___ 30. Right ventricular hyperactivity by palpation
- ___ 31. Forceful apical thrust
- ___ 32. Pulsatile liver
- ___ 33. Absent or diminished femoral pulsation

ECG Findings:
- ___ 34. ECG axis more than 110°
- ___ 35. ECG axis less than 0°
- ___ 36. R wave greater than 1.2 mv in lead v_1
- ___ 37. R' or qR pattern in lead V_1
- ___ 38. R wave greater than 2.0 mv in lead V_6
- ___ 39. T wave in lead V_6 inverted (no digitalis)

SAMPLE OF SYMPTOM CHECK-OFF LIST (see page 366)

the past few months the data matrix has been revised in an attempt to improve the accuracy and performance of the computer.

It had been found that vague symptoms such as easy fatigue more often detracted from the diagnosis than added to it.[4] For this reason most of the subjective symptoms have been omitted in the new matrix and its corresponding symptom check-off list. In some instances the murmurs observed were not defined clearly enough to fit into the existing categories for the murmurs listed in the check-off list. Thus, is seemed advisable to include in the revision a place for murmurs which could not be accurately classified as to time course of intensity. This gives the clinician a less detailed category

SAMPLE OF COMPUTER PRINT-OUT (see page 366)

CASE NUMBER 1158 PATIENT JB DATE 2 27 62

SYMPTOMS PRESENT 2 28 37 48

SYMPTOMS OMITTED 0

SYMPTOMS USED W

EQUATION USED 10

	DISEASE	PROBABILITY
Y01	N	.2591
Y02	A S D	.5291
Y06	P A P V C	.1870
Y32	P D A @ P H	.0117

in which to place such murmurs. For instance, systolic murmurs are now classified as either holo, mid, or just plain systolic. These, of course, are mutually exclusive. Furthermore, x-ray findings, which were completely omitted from the original matrix, have been added to the present one.

A few of the disease categories of the original matrix have been altered. For example, ventricular septal defect has been divided into three entities: (1) ventricular septal defect with pulmonary flow equal to or less than 1.4 times systemic flow, (2) those with flows greater than this, and (3) ventricular septal defect with pulmonary hypertension. The new list of disease categories is based on an attempt to separate operable and nonoperable diagnoses in certain disease areas.

The incidence figures have been further revised according to a re-tabulation of approximately 637 cases seen in this laboratory. All of the probability numbers representing the coincidence of symptoms and diseases in the old matrix were critically reviewed and changed where indicated by more recent data, either from this laboratory or from the recent literature. Experience with the new matrix has not been sufficient to include results in this paper.

Diagnostic Exercise for Readers

The following five cases have been selected from the patients observed in the present study to give the reader an opportunity to test his skill against the computer diagnosis program. The symptoms that were observed by the physician and used by the computer in making its diagnosis are presented. The reader is invited to use this data in making his own differential diagnosis assigning probabilities to each diagnosis in the differential which will total 100 per cent. Only those symptoms listed in table 1 and the diseases listed in table 2 are included in this study and the observer's diagnosis should be confined to this disease list.

The differential diagnosis that the computer made in each of these cases and the follow-up diagnosis are listed at the end of the article, page 377. The five cases with their observed symptoms are listed:

Case I

Symptoms present:

x_2 = age 1 to 20 years
x_5 = cyanosis, severe (with clubbing)
x_8 = squatting
x_9 = dyspnea
x_{10} = easy fatigue
x_{14} = syncope
x_{34} = ECG axis more than 110°
x_{36} = R wave greater than 1.2 mv in lead V_1
x_{43} = mid-systolic murmur loudest in left 4th interspace

Case II

Symptoms present:

x_2 = age 1 to 20 years
x_6 = cyanosis, intermittent
x_{10} = easy fatigue
x_{12} = chest pain
x_{28} = accentuated 2nd heart sound in left 2nd interspace
x_{30} = right ventricular hyperactivity by palpation
x_{31} = forceful apical thrust
x_{35} = ECG axis less than 0°
x_{37} = R′ or qR pattern in lead V_1
x_{48} = mid-systolic murmur without thrill loudest in 2nd left interspace

Case III

Symptoms present:

x_1 = age 1 month to 1 year
x_4 = cyanosis, mild
x_{28} = accentuated 2nd heart sound in left 2nd interspace
x_{34} = ECG axis more than 110°
x_{48} = mid-systolic murmur without thrill loudest in 2nd left interspace

Case IV

Symptoms present:

x_2 = age 1 to 20 years
x_{43} = mid-systolic murmur loudest in left 4th interspace

Case V

Symptoms present:

x_2 = age 1 to 20 years
x_5 = cyanosis, severe (with clubbing)
x_8 = squatting

x_{10} = easy fatigue
x_{28} = accentuated 2nd heart sound in left 2nd interspace
x_{30} = right ventricular hyperactivity by palpation
x_{34} = ECG axis more than 110°
x_{36} = R wave greater than 1.2 mv in lead V_1
x_{46} = mid-systolic murmur with thrill loudest in 2nd left interspace
x_{50} = murmur louder than gr 3/6

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Computer Diagnoses and Follow-Up Diagnoses for Sample Cases I–V

	COMPUTER DIAGNOSIS:		PROBABILITY:	FOLLOW-UP DIAGNOSIS	
Case I	y_{14}	Pulmonary Atresia	.96	y_{14}	Pulmonary Atresia
	y_{31}	VSD with PH	.02		
Case II	y_5	CECD	.57	y_5	Complete Endocardial Cushion Defect
	y_2	ASD	.34		
	y_3	ASD with PS	.03		
	y_4	ASD with PH	.02		
	y_{31}	VSD with PH	.02		
Case III	y_{27}	Transp.	.56	y_{26}	Truncus Arteriosus
	y_{26}	Truncus	.11		
	y_{28}	Corrected Transp.	.08		
	y_2	ASD	.07		
	y_3	ASD with PS	.06		
	y_6	PAPVC	.04		
	y_{32}	PDA with PH	.03		
	y_{31}	VSD with PH	.03		
Case IV	y_1	Normal	.96	y_1	Normal
	y_{30}	VSD	.03		
Case V	y_{10}	VSD with VPS	.36	y_{10}	Ventricular Septal Defect with Valvular Pulmonary Stenosis
	y_{11}	VSD with IPS	.63		

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