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An Analysis of Diagnostic Reasoning
III. The Construction of Clinical Algorithms[1]

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As "input" data are converted to "output" conclusions, diagnostic reasoning traverses a complex series of intermediate decisions, each of which is intended to identify and preferably to explain the entities cited in the preceding stages (1, 2). Because these intermediate decisions are ignored during the formulation of Bayesian and other statistical theories (3–11) about the diagnostic process, a purely statistical approach to diagnosis has two insurmountable handicaps (2). For purposes of identification, calculations of statistical probability cannot provide the precise diagnostic evidence that is desired in modern science and that can often be obtained with suitable technologic tests. For purposes of explanation, current statistical strategies do not delineate the sequence of morbid anatomic and pathophysiologic entities that act as "proximate causes" for the observed clinical manifestations. The statistical conclusions may produce the name of a "disease" as a likely candidate in diagnostic nomenclature, but they do not demonstrate the disease, or explain what has happened.

The statistical strategies, however, have a powerful intellectual attraction. Because the input data are specified, and because their manipulation with Bayesian or other calculations is also specified, statistical strategy offers the scientific advantage of expressing a rational process in mathematical symbols. This advantage would be lost if clinicians, trying to preserve their customary "art" in diagnostic reasoning, were to renounce the new statistical formulations in favor of traditional methods of branching logic. The total rejection of computational tactics in diagnosis would deprive clinicians of a unique scientific opportunity to elevate their mode

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of reasoning from its current state of amorphous "judgment." Without a delineated expression of strategy in clinical reasoning, the clinician would remain scientifically inarticulate, knowing what he thinks, and knowing that his thoughts are important, but having no mathematical equations or other coherent techniques with which to display the logic of his rational pathway.

Until recently, a clinician who wanted to retain the traditional "art" of diagnostic reasoning could not avoid its concomitant scientific aphasia. Having no symbols, no structures, and no tactics with which to demonstrate his patterns of thought, he could not attempt to express his reasoning with any of the traditional oral, written, or graphic patterns of scientific communication. A chemist could use chemical formulas, drawings, and arrows to show the path of an enzymatic transformation; a physicist could use photographs to show the path of an electron's movement; but a clinician had no substance or method that could show the path of a rational sequence.

A sublime paradox of the age of inanimate digital computers is the solution it provides for this long-standing intellectual dilemma. Although computational "hardware" can perform the calculations that might allow statistical conjectures to become substitutes for human thought, computational "software" provides the concepts and diagrams with which thought itself can be maintained, discerned, expressed, and dignified. Not by using the computer itself, but with the graphical notation developed as a prerequisite to computation, a clinician can now, at long last, specify the flow of logic in his reasoning.

In this concluding paper of this series, I should like to outline some of the principles and applications of the algorithms, flow-charts, and decision tables with which diagnostic reasoning can begin to achieve the reproducibility and standardization required for science.

A. BASIC CONCEPTS AND NOMENCLATURE

1. *Algorithm*

The word *algorithm* is commonly used in computer activities to refer to the plan of strategy for solving a problem. People constantly use algorithms in daily life. We all have plans of strategy for deciding what to do about an impending traffic light, a ringing telephone, or a verbose writer. In the case of the traffic light, a traditional algorithm would be: if it is green, go; if it is yellow, slow down; if it is red, stop.

Despite an appealing simplicity and general utility, this algorithm would be inadequate for many situations that confront a driver approaching a traffic light. An ambulance on an emergency mission might not stop for a red light; a driver who sees people or another car occupying the intersection might stop although the light is green. Because so many variations can occur in the associated conditions, a complete algorithm for a particular problem must contain instructions that provide rules of action not only for the ordinary occurrence of the problem, but also for situations that are exceptions to the ordinary.

The recognition of the way that specific circumstances may modify a general principle is one of the hallmarks of good clinical judgment, and is a crucial distinction between the clinician's concern for the nuances of individual patients, and the statistician's concern with the average characteristics of a group. "The object of statistical methods," as R. A. Fisher (12) has said, "is the reduction of data." The statistician wants to reach decisions by compressing or obliterating individual details into the construction of a general case. The individual details, however, are often the essentials of clinical reasoning. A clinician will practice a poor brand of medicine if he makes decisions only on the basis of general formulations that ignore the distinctions of individual patients.

Nevertheless, a clinician must arrive at certain general formulations. He cannot practice medicine at all if he regards each patient as so unique that no general principles of decision can be established. Thus, in devising strategies for the decisions of clinical practice, a clinician must search for an operational balance. At one extreme is the intellectual chaos of excessive details that cannot be rationally formulated; at the other extreme is the futile imprecision of statistical generalizations that cannot be realistically meaningful. Between these two extremes lie the algorithms that describe good clinical reasoning: rules that are specific enough to manage the standard situations, broad enough to encompass the common exceptions, and flexible enough to allow separate decisions for the rare.

2. *Flow Charts*

The sequence of logic in algorithmic strategy is conventionally illustrated with a flow chart, which contains diagrams and graphic symbols for each act of reasoning in the strategy.

The flow chart for a "traffic-light" algorithm is presented in Fig. 1. A description and justification of the contents of this algorithm will be presented later. For the moment, let us consider the different graphic symbols that have been used in this portrait of rational thought.

Every flow chart must have a starting point, which is marked START in Fig. 1, and placed in an oval outline. Ellipses, ovals, or circles can be used for instructions about the beginning or end of an algorithm, and particularly for designating the sites of continuation when a flow chart extends beyond a single page. Even if the chart is confined to a single page, the flow may sometimes be broken and continued at another location on the same page in order to avoid the confusion of visual complexity that would occur if one set of directional lines crossed over a previous set of lines. No such continuations were necessary in the pattern of Fig. 1.

Two main types of "boxes" are used to indicate the logical activities within a flow chart. A *decision box* contains a statement of a question to be answered; an *execution box* contains a statement of a procedure to be performed. In Fig. 1, the decision boxes are shown as flat hexagons; the execution boxes are shown as rectangles. A decision box is followed by a branching in which the rational pathway takes the direction indicated by the answer to the question. Each box must have at least two outlet branchings (commonly YES and NO), but many other branchings (such as MAYBE, UNKNOWN, etc.) can be used according to the type of question and the possible answers. Arrows are used to indicate the exits and pathways leading from one decision or execution box to the next. When several different exits all lead to the same pathway, the arrows join in a common flow, as shown in the far right of Fig. 1.

> The symbols employed in flow-charts are not sacrosanct, and may vary from one user to the next. In fact, as long as arrows were maintained to

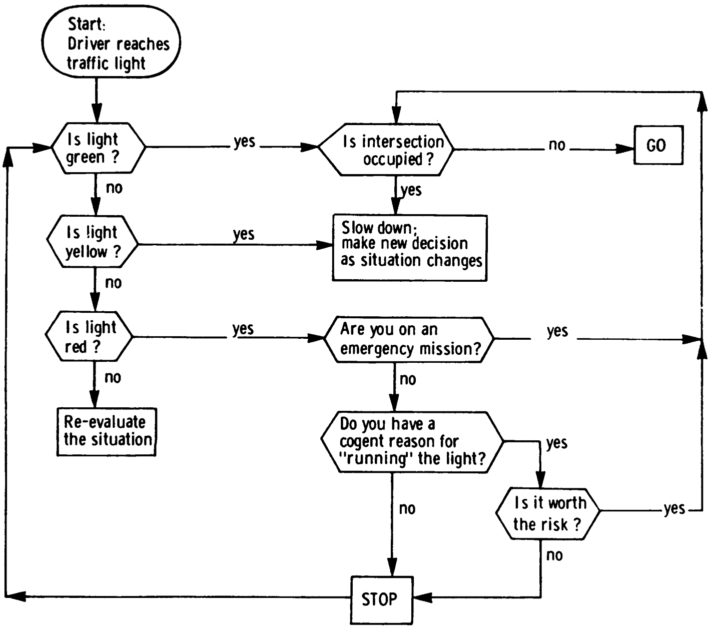

FIG. 1. Flow chart for traffic-light algorithm (for details, see text).

show the directional flow of logic from one question or statement to the next, the entire chart could be constructed without any kind of oval, hexagonal or rectangular boxes. Like digitalis preparations, any collection of these graphic symbols can work effectively provided that they are used in a well-defined, consistent manner. Readers who are familiar with the conventional graphology of flow-charts will note that I have used flat hexagons instead of the customary diamond shape for decision boxes. In constructing such boxes, I prefer the graphic and esthetic convenience of writing out the question and then enclosing it in a flat hexagon, rather than to squeeze the writing into a predrawn diamond, or to waste the unused space occupied at the upper and lower poles of a diamond that is drawn afterward. In some of the illustrations to be shown later, the decision and execution boxes all appear as rectangles, and in other illustrations, no boxes are used.

3. *Decision Tables*

The same strategies outlined in Fig. 1 could have been portrayed alternatively in a *decision table,* which is a tabular array of sets of conditions, and of the decisions selected as a response to each set of conditions. In a conventional form, such a table has four major sections (13, 14). The *condition stub* section shows the conditions under examination, and the *condition entry* section shows the presence or absence of each of the conditions under scrutiny. An *action stub* section shows the possible actions (or decisions) that can be taken for the various conditions that are present, and an *action entry* section shows the responses for each combination of conditions. The illustration in Fig. 2 shows an example of a decision table that contains exactly the same strategies portrayed in Fig. 1.

		Condition Entry										
		1	2	3	4	5	6	7	8	9	10	11
Condition Stub	Is light green ?	Y	Y	N	N	N	N	N	N	N	N	N
	Is light yellow ?	N	N	Y	N	N	N	N	N	N	N	N
	Is light red ?	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
	Emergency mission ?				Y	Y	N	N	N	N	N	N
	Cogent reason to "run light" ?						N	Y	Y	Y	Y	Y
	Good excuse if caught ?							N	Y	Y	N	N
	Is it worth risk ?							N			Y	Y
	Is intersection occupied ?	N	Y		N	Y			N	Y	N	Y
Action Stub	GO	X			X				X		X	
	WAIT		X	X		X				X		X
	STOP						X	X				
		Action Entry										

FIG. 2. Decision table for traffic-light algorithm. (The letters *Y* and *N* represent *yes* and *no*. The letter *X* shows the action to be taken for each set of conditions. For further details, see text.)

Like flow-charts, decision tables can be constructed in various ways, and certain principles of logical design can be used to enhance simplicity and eliminate redundancy (13, 14). Since any well constructed decision-table can be converted into a flow-chart, and vice versa, either procedure can be chosen for portraying a logical pathway. The correspondence between the two procedures is indicated by the occasional use of the name *decision tree* for what has here been called a *flow chart.*

In general, flow charts are preferred by computer programmers, since the chart shows the direct sequence of the path of logic, and can be easily translated into a computer program. The sequential arrangement may often save space because it can allow several decisions to terminate in a common sequence, and because it can eliminate the repetition of components that are necessary for some decisions but unnecessary for others. Thus, in comparison to the decision table of Fig. 2, the flow chart of Fig. 1 contains no blank spaces for situations in which the particular condition was not applicable. On the other hand, a decision table might be more convenient than a flow chart for portraying certain diagnostic decisions that depend on a particular array of information, rather than on the specific sequence in which each component of the array was noted.

Because I am more familiar with flow charts than with decision tables, the illustrations in the rest of this dissertation will be based on flow charts. Regardless of whether the components of clinical strategy are portrayed in flow charts or in decision tables, however, the potential value of these graphic media should now be apparent. They offer a method of depicting rational processes that cannot be expressed in the conventional equations, parameters and calculations of mathematics, and that cannot be demonstrated visually with the photographs or conventional diagrams of science. Furthermore, these new graphic media are both strict enough to provide exactness in expressing the main paths of thought for a decisional process, and flexible enough to allow the construction of branching paths when the main path requires modifications or diversions.

B. PROCEDURES IN JUSTIFICATION

A requirement of scientific or logical reasoning is not merely that decisions be reached, but that each decision be justified. The justification can consist of diverse

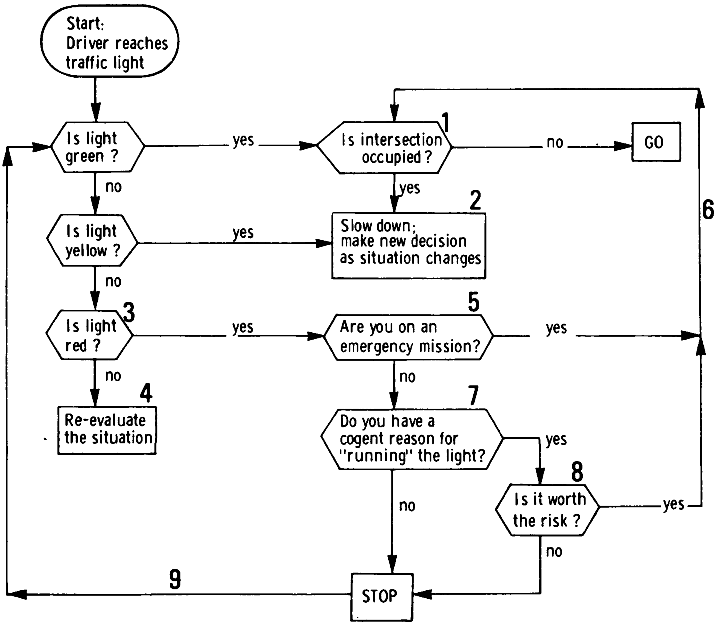

FIG. 3. Points of justification in traffic-light algorithm (for details, see text).

forms of factual evidence and conceptual principles. For example, the justification procedures used as "proofs" for theorems in grade school geometry contain a cohesive pattern of logic, making sequential use of accepted axioms and of previously proved theorems.

The decisions of clinical reasoning, however, can seldom be justified with neat patterns of mathematical logic, and a suitable substantiation will require reference to different types of data and principles, derived from practical observations in the world of clinical reality. The addition of suitable justification, containing citations of data or principles to substantiate each decision, is the activity that converts a flow chart from an arbitrary set of rules into a scientific document.

To illustrate a procedure of justification, the flow-chart of Fig. 1 is repeated in Fig. 3, with appended numbers that will be used as references in the following discussion of the reasons for the decisions made in the "traffic-light" algorithm.

1. With a green light, a driver would ordinarily proceed ahead with unchanged speed unless he sees that he may crash into an object (such as an automobile, person, or construction) that occupies the intersection. The state of the intersection must therefore be assessed before he continues.
2. This execution box could be entered in two different ways, each of which calls for the driver to "slow down" and then make a new decision as the situation changes. If the intersection is occupied by a moving object, the driver can anticipate its time of departure, and can plan to proceed accordingly. If the situation does not change because the object is stationary, separate decisions are needed. The other entrance to this box occurs if the light is yellow. The decision to "slow down"

is based on the awareness that such lights are usually brief, and followed by red lights. The next decision would be based on the driver's plan of response to the red light.

3. Connoisseurs of flow-charting will recognize that this decision box is redundant here. Instead of including the question, "Is light red?", we could have assumed that when a traffic light is neither green nor yellow it must be red. Accordingly, the red light question could have been eliminated, and the "NO" exit from the yellow-light box could have led directly to the box asking about an emergency mission, thus sparing us the need for the diversion that follows in point 4.
4. At this step in the algorithm, the driver has decided that the traffic light is neither green nor yellow nor red. He must therefore reevaluate the situation. Has he suddenly entered a strange new land that uses unconventional colors for traffic lights? Has he mistaken some other type of light for a traffic signal? Has he become color blind?
5. We are now thinking about breaking the law by "running" a red light. Since we shall, as noted later, always assess the risk of injury before crossing the intersection, our main deterrent to law-breaking is the fear of arrest. Although the term "emergency mission" is not defined here, it would refer to a situation (such as an ambulance urgently racing to a hospital, or a fire truck enroute to a fire) where a universally acceptable excuse exists for "running" the light.
6. This line represents a common pathway for the ending of several situations in which a driver, planning to take the legal risk of crossing against a red light, is first led to check that occupancy of the intersection does not create the additional risk of a crash or other injury.
7. In this situation, the driver does not have a mission that would be universally accepted as an "emergency." He now contemplates whether he has some other "cogent" reason (i.e., one that he thinks would be acceptable to a policeman) for crossing against the light.
8. He believes his reason is "cogent," but before the algorithm allows him to proceed, we caution him about the consequences. Suppose the policeman does not accept the excuse? Even if the excuse is accepted, would being stopped by a policeman be worth the time wasted in giving the explantion? (Connoisseurs of red-light running will probably suggest that the driver, before all this soul searching, should have checked to see whether any policeman are present to note the contemplated malefaction. If no policeman is evident, a "cogent" excuse may be unnecessary. Since our goal is to provide justification, however, this example will stay within the bounds of order and law).
9. The arrow here demonstrates the recursive quality of many sequential thought processes. After the driver stops, he constantly rechecks to see whether the light has turned green. If it has not changed, he continues his mental "loop" through the "nongreen" pathway until the light turns green.

After noting the extensive justification procedure needed for so simple a decision as what to do at a traffic light, the reader may now begin to appreciate the enormous complexity involved in trying to create and to justify algorithms for the intricate problems of clinical diagnosis. The activities will require several types of major intellectual effort:

1. To compose flow charts whose contents are adequate for typical clinical situations as well as for exceptions to the typical.
2. To arrange each chart into a diagram that is logically clear, esthetically attractive, and intellectually economical. (An example of such "economy" in the traffic-light flow chart would have been the removal of the extraneous "red light" decision, as noted in the third paragraph of the justification).
3. To provide a clinically convincing account of the reasons for each of the decisions that require justification. The justifying statements for many minor decisions may not be wholly necessary and can be omitted. For many other minor decisions, however, and for all major ones, the justification is the crux of scientific "proof" for the procedure. After a justified algorithm has been established and generally accepted, its flow-chart can be used thereafter without the appended "proof," in a manner similar to the way that a new laboratory test, having had its basic validity demonstrated, can then be employed without constant recourse to the methodologic documentation.

Justifications have been omitted from all of the flow-charts that will be shown later, but can usually be found in the text of the reference where the charts first appeared.

C. THE CAPACITIES OF DIGITAL COMPUTERS

Because the operation of digital computers has been the prime stimulus for attention to the development of algorithmic procedures, and because computers depend on different kinds of algorithms, a knowledge of the functions performed by computers will be useful background in contemplating the diverse algorithms needed for clinical activities.

A computer ordinarily operates with two sets of information: one set contains a program[3] of the algorithmic instructions for "processing" a collection of data; the other set of information provides the data subjected to the processing. For these activities, the computer has four main "intellectual" capacities: it can acquire, store, retrieve, and interpret data. The distinctions of these capacities, which are not well understood by most clinical readers, will be defined and illustrated in the paragraphs that follow.

1. *Acquiring Data*

Since data are human artefacts, rather than natural phenomena, data must be created as a result of observation, description, and communication. A patient may have an oppressing sensation under his breastbone, but the sensation does not become the data of "substernal chest pain" until he has communicated its description. Another patient may feel warm, but he does not have a rectal temperature of 103°F

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[3] A computer "program" consists of an algorithm that has been "translated" into the symbols of a "language" that the computer can "understand." Many such languages have been constructed (15). Among the most popular ones in use today are FORTRAN, ALGOL, COBOL, and PL/I.

until a thermometer has been shaken down, inserted in his rectum, removed, inspected, and had its results recorded.

The acquisition of data thus refers to the process of converting an observed phenomenon into a reported description. The process is either transferred or direct, according to whether or not the observer's reported description has been transferred through another observer enroute to the formation of data. For example, the data recorded after a clinician takes a history are transferred from the patient's account of his sensations; whereas the data of physical examination are usually a direct account of what the clinician observed himself. Similarly, data are acquired by transferral when a clinician reads a printed value of 130 from a line marked "130" on a graphic scale of serum sodium levels, but the acquisition is direct when the clinician looks at a series of electrocardiographic wiggles and decides that the P–R interval is 0.12 sec. In many medical applications of computers, the machine acquires the data by transferral through an external observer. In certain new medical approaches, however, the clinician or other intermediary observer is eliminated, and the computer acquires data directly by "taking" a history from a patient, or by "determining" the P–R interval and other measurements from a suitably prepared electrocardiogram.

2. *Storing Data*

The storage of data refers to the way a computer maintains the information it has received. For example, the computer may not store temperature data in degrees Fahrenheit. In such circumstances, the user of the computer might be asked to convert Fahrenheit results into Centigrade before entering the data, or the computer might perform the conversion itself, with an "internal" set of programmed calculations that will translate Fahrenheit input into Centigrade storage.

3. *Retrieving Data*

For retrieval of data, the computer is asked to return the information it has stored. In a simple retrieval, the data would be displayed in the exact form of the storage. In the most common situations of retrieval, however, the computer is asked to sort and count the information, and to print out certain enumerated results. For example, a computer that contains data for the histories of a large population of patients might be asked to indicate how many of those patients had substernal chest pain. The computer would then "sort" through the data for each case, looking for patients with substernal chest pain. Whenever it finds a patient with this symptom, it would add one unit to a special "counter." After the sorting of cases has been completed, the sum on this counter would represent the total number of people with substernal chest pain. In an analogous manner, the computer could perform more complex sortings, such as finding the number of children who had substernal chest pain and a temperature of 103°F.

4. *Interpreting Data*

No subtle judgmental decisions were needed for any of the activities just described in acquisition, storage, and retrieval of data. The computer received information that is preserved and then returned after counting specified classes of data. In addition to these elementary capacities, however, a computer can be instructed to perform interpretations of data. Some of the interpretations are trivial, such as the decision that one number is larger than another. Other interpretations require a designated numerical background, such as the decision that a particular number falls within a certain "range of normal." The interpretations that are especially interesting to clinicians, however, involve sophisticated value judgments about such concepts as *improving* or *worse,* and the intricate subtleties of diagnostic, therapeutic and other clinical decisions.

Since a computer does only what it is commanded to do, it must receive a specific program for each of these decisions, and the person who composes the program must establish suitable strategies and criteria for the decisions. Thus, the computer can store and retrieve the fact that a patient's temperature was 103°F, but it cannot tell us that he had "fever" until a value has been established for the temperature to receive this interpretation. The computer can store and retrieve "substernal chest pain," but it cannot make the interpretation that the pain is "angina pectoris" or due to "coronary artery disease," unless appropriate additional data and specific decisional strategies have been provided for the interpretations.

D. ELEMENTARY CLINICAL APPLICATIONS OF ALGORITHMS

Since diagnostic reasoning is composed of numerous interpretive decisions, the conversion of these decisions into diagnostic algorithms is a formidable task. In view of the difficulties, it is not surprising that some of the relatively successful current applications of "computers in medicine" have been based on algorithms that deal with processes much more clinically simple than diagnostic reasoning.

1. *Acquisition of Data in History-Taking*

To acquire data by "taking" a patient's history, a computer program depends on algorithms for the logical branchings that expand to additional questions when certain routine questions are answered "Yes," and that progress to the next routine question when the reply is "No." The contents of some of the associated algorithms and flow charts have been displayed in reports of such programs (16, 17).

Although diagnostic purposes for the acquired data must be considered when such algorithms are constructed, most history-taking algorithms have been devoted almost exclusively to the logical sequence of getting the data. The type of branching clinical logic used for explanatory diagnostic reasoning has not been part of the strategy. For example, a history-taking algorithm might contain the entire sequence of branching inquiries needed to obtain all the descriptive details about the severity, timing, duration, provocative factors, alleviating factors, and other features of a patient's dyspnea. A quite different algorithm with quite different strategies, however, would be needed to decide diagnostically whether the dyspnea is due to lung disease, to cardiac decompensation, or to other causes.

2. *Acquisition of Data for Visual Patterns*

During the history-taking just described, the basic phenomena were perceived and converted into data by the patient. The computer "acquired" these data by using an algorithm that contained suitable expressions for asking questions and anticipating answers, but the fundamental process of observation had not been "automated" into an algorithmic strategy. The phenomena described in the data were observed by the patient, not by the computer.

In computerized electrocardiography, however, an algorithm has been created for a computer to perform the basic process of observation. The actual perception of the voltages on the tracing is done by an electronic instrument, and an algorithm is used for converting these voltages into electrocardiographic data (18–20). For this process, the computer must receive instructions on how to scan the array of repetitive voltages, and identify them as P-waves, QRS complexes, etc. After these constituents of the tracing have been identified, the algorithm instructs the computer to calculate such data as measurements of cardiac rate, amplitude of various PQRSTU constituents, and intervals between constituents. When these activities are completed, the computer displays the data it has acquired as a basic description of the visual forms on the electrocardiogram. The interpretation of the data requires a different set of algorithms, to be discussed later.

The successful achievement of this type of automated observation is facilitated by the concurrence of several visual features that greatly simplify the optical pattern of an electrocardiogram. The first feature is that the image is two-dimensional, so that only an x and y coordinate need to be considered when the visual record is regarded as a voltage that changes with time. A second feature is that an electrocardiographic tracing, unlike the diverse images seen in a blood cell or a roentgenogram, is essentially linear; its observation thus requires a consideration of change in the pattern of voltage for only a single line, whereas a white blood cell or a roentgenogram has enormously greater visual complexity. A third feature is that the electrocardiographic image has a fixed axial orientation. Like a roentgenogram, the ECG tracing can always be arranged with a distinct top and bottom, whereas a white blood cell can emerge on a smear with its nucleus curving upward, downward, or in various lateral directions. Finally, the ECG pattern, unlike the two-dimensional, linear, axially oriented image on an electroencephalogram, usually shows temporal repetition; and the repetition of the pattern serves as a major aid in the automated recognition and labeling of the constituents.

Although this regularity of pattern has been a boon to the rapid development of automated electrocardiography, the problems of irregular patterns have not yet been solved. Certain simple irregularities in cardiac rhythm have been algorithmically mastered (19, 21, 22) but the gross irregularities of complex arrhythmias have not yet received suitable algorithms for automated identification. No computer can currently deal with complicated arrhythmias, and when they occur, the computer must be replaced by the superior pattern-recognition abilities of a human observer. Furthermore, for nonlinear visual patterns, as in white blood cells or roentgenograms, a satisfactory "recognition algorithm" is extremely difficult to create. Despite intensive efforts in the past few years, no thoroughly successful algorithms have yet been developed for these purposes, although considerable progress has recently been reported for direct computer (23) screening of cardiac roentgenograms.

3. *Storage of Data in Clinical Examination*

In the types of algorithm just described, the computer received its "input" of medical data without the intervention of a clinician. For data acquired during a clinician's examination of a patient, an algorithm can be developed to allow the clinician to "record" (or store) his findings in a computer (24–27). Such algorithms contain a series of branchings that continue the "routine" topics when the clinician's findings are "negative," and that provide appropriate expansions for "positive" results. The basic principle of the algorithms is similar to that used in history taking from a patient, except that the computer gets the information from a clinician; and the scope of the information may include results from the physical, roentgenographic, and other examinations, rather than from history taking alone. Such algorithms are used for entering and storing data in the computer system, but not for any type of diagnostic interpretations.

4. *Retrieval of Laboratory Data*

One of the most currently popular and medically effective uses of computers is for storage and retrieval of the vast amounts of data now being assembled in clinical laboratories. The basic data are usually obtained via the customary laboratory equipment and personnel, and entered into the computer by the personnel. The plan of storage allows the computer to maintain and retrieve an inventory of results for each patient, and to perform sortings, enumerations, and calculations with the data stored for a group of patients (28–30).

The composition of algorithms for these activities requires little or no clinicial sophistication, and excellent programs can be (and have been) developed by programmers familiar with the algorithms for "inventory" procedures, regardless of the type of data that constitute the inventory. Because improved methods of management are needed for the plethora of laboratory data now being produced at medical centers, and because the necessary algorithms can be created by a good computer programmer who has no medical background, the storage and retrieval of laboratory data has been a particularly successful application of computers in contemporary hospital practice.

Efforts are now being made to create systems in which the results of laboratory tests are entered directly into the computer, without human intervention (31). Most of these programs are based on automated recording of the voltages generated as "readings" by the laboratory instruments.

5. *Interpretation of Clinical Data*

Algorithms were needed for all of the procedures that have just been described, but none of the algorithms dealt with diagnostic *reasoning,* and none required any profound clinical experience or thought. Many of the algorithms could have been constructed by people with no clinical experience, or with no more than one or two student clerkships. That so little clinical knowledge was needed to construct the algorithms does not detract from some of the splendid achievements contained in the cited programs for acquiring, storing, and retrieving medical data. As the new technology of computers was introduced into the ancient traditions of clinical medicine, relatively simple challenges were obviously the first ones that could be approached effectively.

Despite the existing and often laudable progress, however, none of the cited algorithms has entered the higher realm of reasoning that distinguishes clinical activity. Almost all of the results achieved with the computer could have been accomplished without the computer, and are still so accomplished in most medical settings today. The described algorithms and computer programs can enable a clinician to automate his standard methods for maintaining and displaying medical data, but the activities have not affected the standard reasoning with which the data are interpreted and used. Unlike the data, the reasoning remains essentially undefined and unspecified. Its constituents and logical branchings are often relegated to the realm of "art," or consigned to a nondescript rationality called *clinical judgment* (32).

A paramount intellectual challenge for clinicians today is to identify the components and pathways of these judgments, and to express them in suitable algorithms.

If clinicians accept the lure of noninterpretive data processing while preserving the intellectual inertia of their own undelineated reasoning, the result will be merely an automation of the status quo. Because of many existing deficiencies in both the data and the scientific goals of the reasoning (33, 34), the status quo needs to be improved rather than merely automated. For the improvement, clinicians must begin to respect the importance of their own thinking, to explore its constituents and directions, and to convert its logic into algorithmic outlines.

E. ADVANCED CLINICAL APPLICATIONS OF ALGORITHMS

A clinician who begins to think about the way he thinks will soon discover that clinicial reasoning does not follow the simplistic schemes into which it is sometimes cast to illustrate the potential application of computers in medicine. An efficient practicing clinician, for example, does not usually go through a segregated sequence of exclusively history-taking, followed by exclusively physical examination, followed by laboratory tests. He often takes part of the history *while* he does the physical examination; or he may obtain certain laboratory data *before* any of the clinical examinations begin; or he may do parts of the clinical examination, obtain certain laboratory tests, and then complete the clinical examination later.

Another example of the difference between current algorithms and clinical practice is that a clinician interpreting an electrocardiogram seldom confines his attention exclusively to the configuration and measurements of the individual tracing. He compares the findings in the patient's previous tracings, and incorporates data from the concurrent history, physical examination, and laboratory tests. The clinician's final diagnostic decision is based on this mixture of information, not on the single electrocardiogram alone.

A particularly important departure from the contents of current algorithms is created by the diversity of decisions made during clinical reasoning. Although many existing algorithms are concerned with diagnosis alone, an efficient clinician regularly intermingles many other decisions with the diagnostic reasoning. The mixture of decisions includes prognostic estimations, choices of additional paraclinical tests, selection of therapeutic agents, and behavioral planning for the personal interchange with the patient. Algorithms that concentrate on only diagnostic identifications will seldom suffice for the diverse managerial decisions that are an integral, concomitant part of the reasoning used in clinical practice.

For these reasons, when clinicians undertake the rigorous intellectual challenge of describing the pathways of clinical reasoning, the horizon need not be constricted to diagnostic targets alone. The challenge is to contemplate what happens as clinicians think during clinical activities, and to describe the strategy. If the thought processes shift from one type of thinking to another and on to a third before returning to the first, and if this rational pathway can be justified either by valid logic or by documented evidence or by both, then these are the thought processes to be cited in the algorithms. As clinicians enter a new era in patterns of clinical thought, we need not limit the future to preconceptions about the past or to oversimplifications of the present. The object is to preserve the vitality of clinical reasoning while enhancing its scientific effectiveness.

In the remainder of this paper, I shall outline some of the diverse situations that provide challenges in the construction of clinical algorithms. In some of the situations, certain algorithms have already been formed and can be shown as examples. The existing algorithms may appear either primitive or highly developed, but almost all of them are new, unproved, and unaccompanied by the substantiating evidence of their validity. The further scientific development and justification of these algorithms, and the creation of the many required new algorithms will be major challenges for clinical research in the future.

1. *Diagnostic Analysis of Paraclinical Data*

Roentgenograms, electrocardiograms and the data of other paraclinical tests can often receive a preliminary diagnostic analysis without regard to the associated clinical information. After the clinical data are noted, the initial diagnostic decisions may or may not be modified. For example, certain disorders in cardiac conduction or rhythm (such as bundle branch block and supraventricular arrhythmias) are usually diagnosed exclusively from an electrocardiographic tracing, regardless of the patient's clinical signs or symptoms; whereas disorders in cardiac morphology (such as myocardial infarction or myocardial aneurysm) require diagnostic attention to clinical as well as electrocardiographic data.

Algorithms have now been developed for several types of diagnostic analysis that can be performed exclusively with paraclinical data. A series of flow charts for the electrocardiographic diagnosis of cardiac arrhythmias has been presented in recent publications by Lindsay and Budkin (22) and by Wartak *et al.* (35, 36). The latter authors have also demonstrated the use of decision tables for these diagnostic purposes. An example of one of the Lindsay-Budkin flow-charts is shown in Fig. 4, and a Wartak decision table is shown in Fig. 5. In radiology, Tuddenham (37) has begun to develop a series of algorithms for teaching "visual discrimination and search strategy." An example of one of Tuddenham's flow charts for radiographic diagnosis is shown in Fig. 6.

In the situations just described, the clinician had already ordered an electrocardiogram or a roentgenogram, and the purpose of the flow-chart was to help interpret the results. A different aspect of diagnostic strategy involves decisions about which tests to order. In contrast to a "diagnostic interpretation" algorithm, which deals with a fixed array of assembled data, a "diagnostic search" algorithm will branch into different types of tests and data, according to the results found in preceding tests. Since the "search" algorithms require considerations of the interpretation that will be given to each test and its predecessors, such algorithms can often be used both to demonstrate the direction of the search, and to indicate the diagnostic meaning of the results.

An example of a diagnostic-search algorithm for paraclinical chemical data is shown in Fig. 7. This flow chart, which is modified from the one prepared by Rabinowitz, Prout and Walker on page 1097 of the textbook (38) by Harvey *et al.*, indicates the direction and interpretation of the tests that might be ordered after mellituria is discovered as a positive copper-reduction reaction in urine tested with Benedict's solution or Clinitest tablets.

A diagnostic-search algorithm for the laboratory data of acid-base disorders has been prepared by Bleich (39). The algorithm is entered with the results of measurements for a patient's serum sodium, potassium, chloride, and carbon dioxide. Additional measurements of blood pH and pCO_2 may then be requested. If all the solicited data are normal, the algorithm indicates that acid-base equilibrium is undisturbed; otherwise, the algorithm branches into a differential diagnosis of the disturbance.

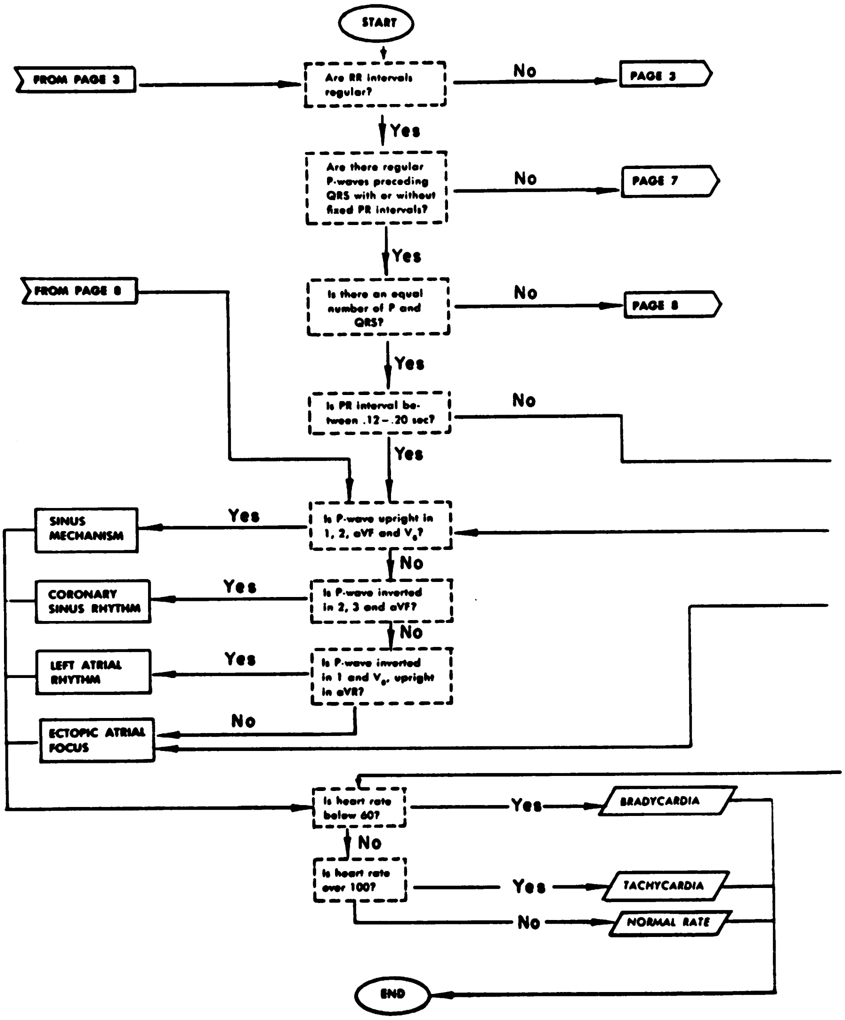
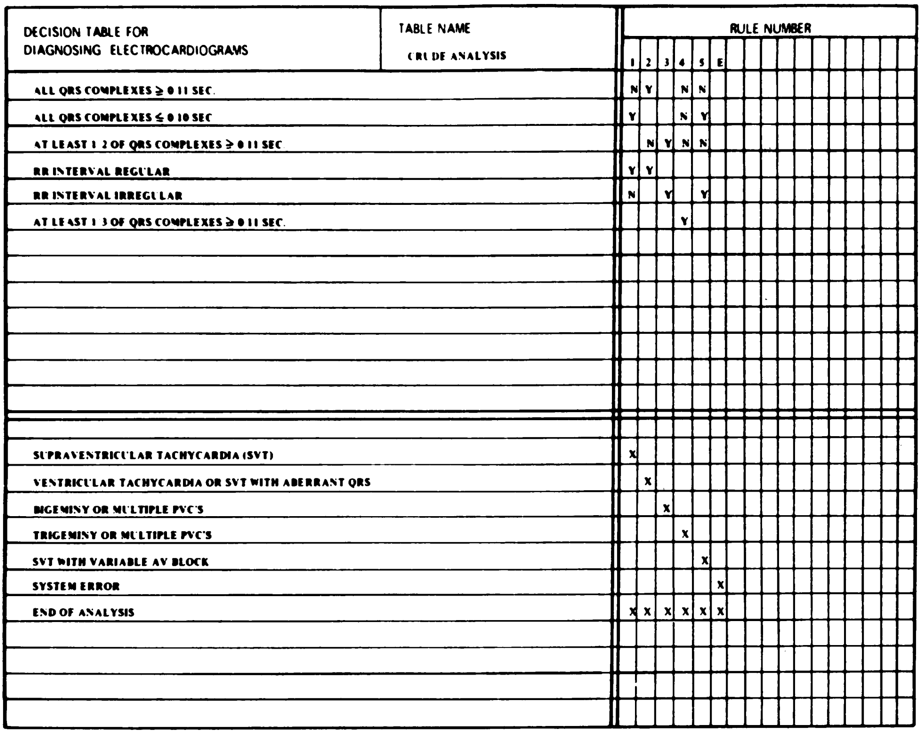


FIG. 4. Portion of flow chart for cardiac arrhythmias. Reproduced, with permission, from page 114 of textbook by Lindsay and Budkin (22).

2. *Diagnostic Analysis of Clinical Data*

During the process of obtaining clinical data in a patient's history and physical examination, a clinician constantly contemplates diagnostic possibilities. The directions that he chooses in the sequence of the examination are often intended to exclude or amplify these possibilities. During this process, the clinician works only with the clinical and demographic data obtained during clinical examination, before any paraclinical data have been obtained from ancillary tests.

An example of part of an algorithm for the clinical diagnostic analysis of chest pain is shown in Fig. 8. This segment of the flow chart shows only the paths of reasoning and data that might lead to the indicated diagnoses. The reader is invited to complete the unfinished parts of this algorithm, beginning at each place marked "continue to other topics."



DECISION TABLE FOR DIAGNOSING ELECTROCARDIOGRAMS	TABLE NAME CRUDE ANALYSIS	1	2	3	4	5	E
ALL QRS COMPLEXES ≥ 0 11 SEC.		N	Y		N	N	
ALL QRS COMPLEXES ≤ 0 10 SEC		Y			N	Y	
AT LEAST 1 2 OF QRS COMPLEXES ≥ 0 11 SEC			N	Y	N	N	
RR INTERVAL REGULAR		Y	Y				
RR INTERVAL IRREGULAR		N		Y		Y	
AT LEAST 1 3 OF QRS COMPLEXES ≥ 0 11 SEC.					Y		
SUPRAVENTRICULAR TACHYCARDIA (SVT)		X					
VENTRICULAR TACHYCARDIA OR SVT WITH ABERRANT QRS			X				
BIGEMINY OR MULTIPLE PVC'S				X			
TRIGEMINY OR MULTIPLE PVC'S					X		
SVT WITH VARIABLE AV BLOCK						X	
SYSTEM ERROR							X
END OF ANALYSIS		X	X	X	X	X	X

RULE NUMBER

FIG. 5. Decision table for 'crude analysis' of electrocardiogram. Reproduced, with permission, from page 346 of paper by Wartak, Milliken, and Karchmar (35).

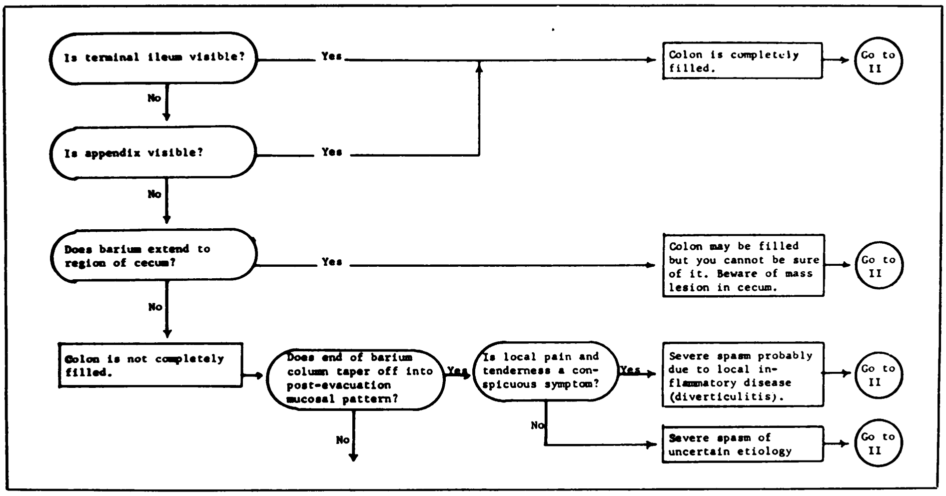


FIG. 6. Flow chart for examining part of a barium enema. Reproduced, with permission, from page 36 of Medical News section of JAMA (37).

D. A. W. Edwards (40) has prepared an extensive flow-chart, shown in Fig. 9, for the diagnostic analysis of dysphagia. The numbers appended to the chart indicate portions of the algorithm for which comments of explanation or justification are provided in Edwards' original paper. Because the logical sequence and

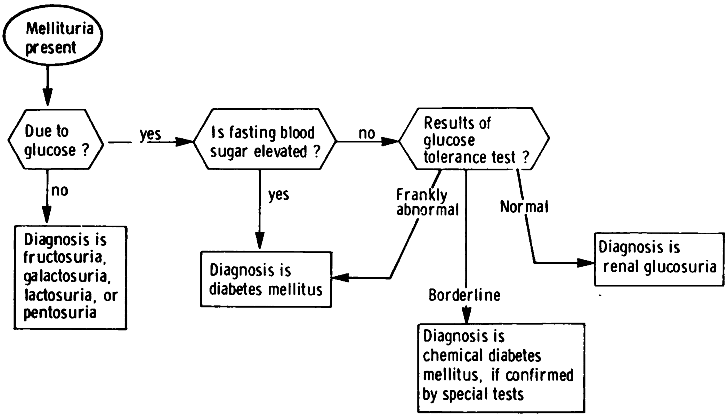


FIG. 7. Diagnostic-search algorithm for mellituria. Modified and redrawn from the original flow chart on page 1097 of Ref. (38).

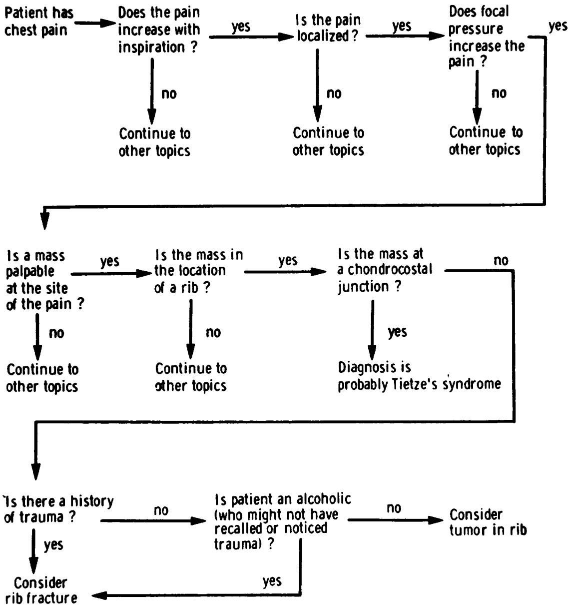


FIG. 8. Algorithm for diagnostic clinical analysis of chest pain (for further details, see text).

its clinical justification are so well organized, Edwards' work is an excellent model of this type of clinical diagnostic algorithm.

Another example of an algorithm for clinical diagnostic analysis is shown in Fig. 10. This flow chart, which deals with the search for causes of edema, represents the consensus of a symposium (41) sponsored by the journal PATIENT CARE, which has pioneered in the pictorial use of flow charts to summarize strategies of clinical diagnosis and therapy. The editors of that journal have created more than 100 flow charts for the analysis and/or management of diverse clinical conditions, and each new issue usually contains one or more additional charts. (A "Pa-

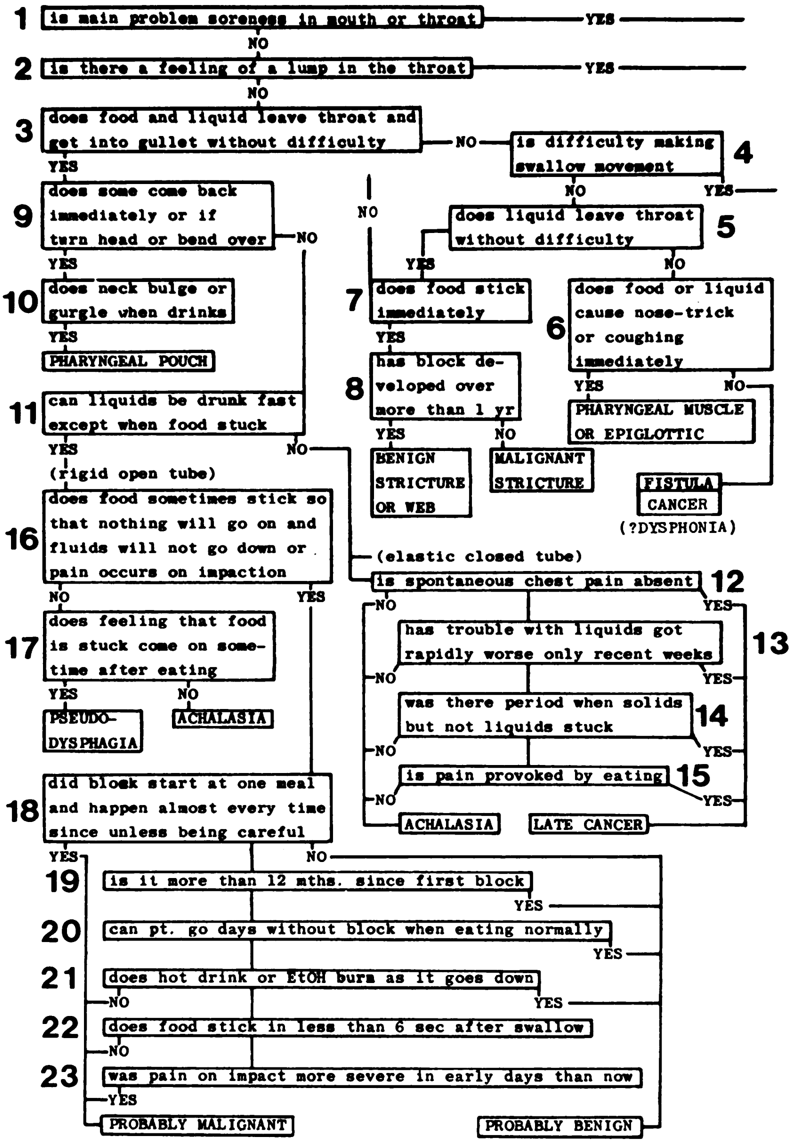


FIG. 9. Algorithm for diagnostic clinical analysis of dysphagia. Reproduced, with permission, from page 381 of Ref. (40).

tient Care Flow Chart Service," available by subscription, is offered by the Miller and Fink Publishing Corporation, 16 Thorndal Circle, P.O. Box 1245, Darien, Connecticut 06820.)

Flow charts of this type can be used to illustrate the difference between the way a novice and an expert approach issues in clinical examination. A flow chart prepared by Johns and Tumulty on page 17 of the medical textbook by Harvey *et al.* (38) shows that an expert who encounters jaundice on examination of the skin will usually not continue immediately with the rest of the cutaneous examination. Instead, the expert will branch into a series of questions that clarify the concomitant features and possible causes of the jaundice. When this branched deline-

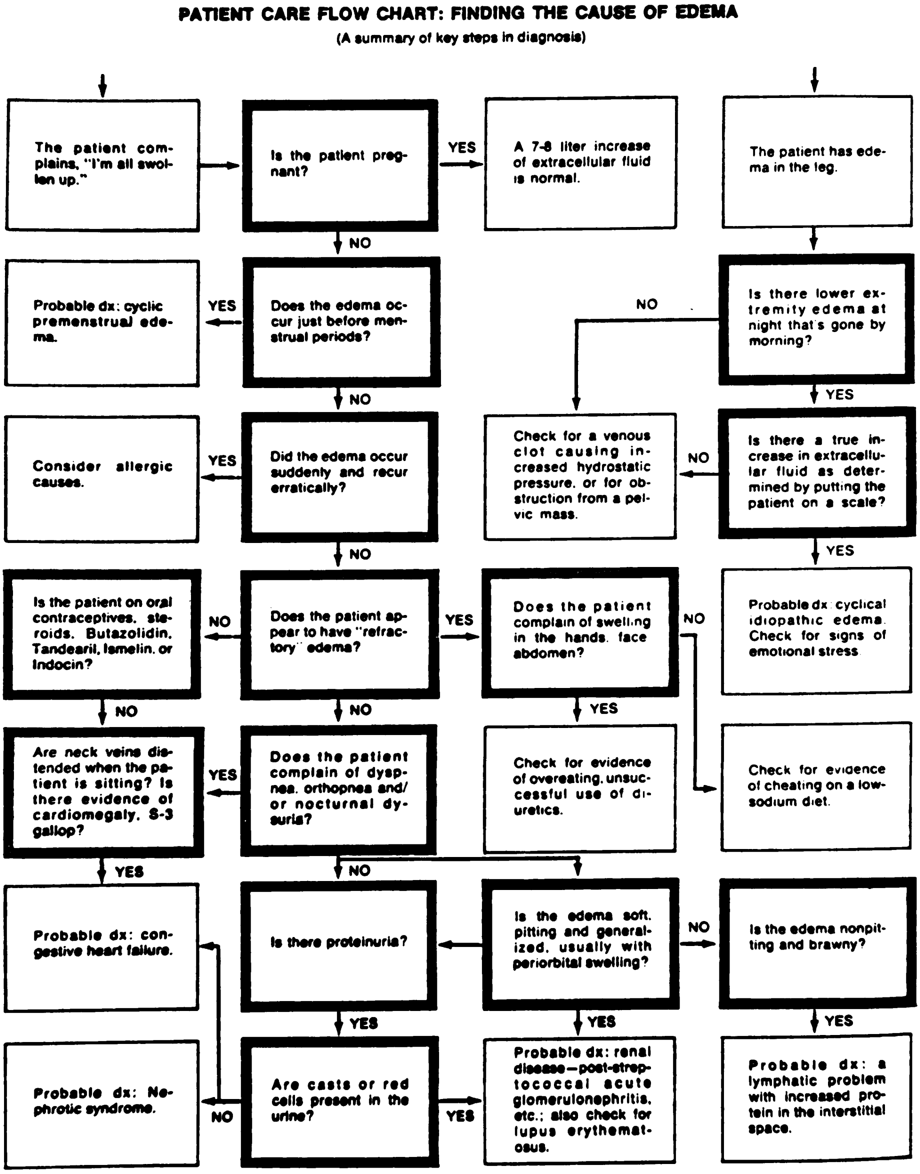


FIG. 10. Algorithm for diagnostic analysis of edema. Reproduced, with permission, from page 50 of panel discussion in PATIENT CARE (41).

ation of the jaundice has been completed, the expert returns to the rest of the cutaneous examination. A neophyte, on the other hand, may not perform this branching, and may simply continue with the rest of the routine examination of the skin.

3. *Planning the Diagnostic Work-Up*

In the two types of analysis that have just been described, the reasoning was restricted to either clinical or paraclinical data. In many modern clinical situations, of course, the two types of data are intermingled during diagnostic activities. Thus, after the routine clinical examination and laboratory tests are performed, the clinician may decide about further clinical examinations and additional paraclinical tests. These results may then lead to further examination procedures, and so on.

The development of suitable algorithms for the strategy of diagnostic work-ups has become a critical challenge in modern medicine. The work-ups, which occupy increasingly large amounts of staff and facilities at any large medical center, are generally uncomfortable and often dangerous for patients, but the strategy of the work-ups has not yet been suitably investigated. Should certain tests be obtained sequentially, or as a simultaneous "battery"? If tests *A* and *B* are both to be done, should *A* always precede *B*, or vice versa?

Since ancillary tests can be ordered at each step in the flow of clinical or paraclinical examination procedures, a thoughtful clinician would like to know not merely the general costs, risks, and advantages of the individual tests, but the specific value of each test at each step in the sequence of examination. For example, the risks of esophagoscopy can be assessed from its consequences in a large series of patients exposed to the procedure, but this information is much too vague for direct clinical utility. What a clinician would really like to know is not the general risk of esophagoscopy, but its risk in individual situations. Such situations include the diverse circumstances of patients who have had an episode of hematemesis, with or without recurrent episodes, with or without persistent bleeding, with or without melena, with or without shock, with or without an antecedent history of gastrointestinal bleeding, with or without an associated history of peptic ulcer, with or without clinical evidence of liver disease, and so on. For patients with hematemesis, the clinician might also like evidence about the value of performing esophagoscopy and upper gastrointestinal roentgenograms immediately as an emergency procedure, as compared to deferring these procedures until a later point at various stages of the patient's management and clinical course. Another example of the need for sequentially specified evaluations occurs in the work-up of a patient with hypertension. In what clinical circumstances and at what stages of the work-up are the greatest diagnostic benefits attained from such hazardous procedures as intravenous pyelography and intra-arterial aortography?

As a prerequisite to such information, appropriate algorithms must be constructed to demonstrate the clinical and paraclinical sequence of a work-up for each of the cited conditions. After the algorithm has been prepared as an architectural outline for classifying and storing the subsequent information, the data obtained during the course of work-ups for many patients can then be suitably classified and analyzed for the desired appraisals. This type of evaluation is not available today for *any* of the many clinical conditions that are constantly worked up at modern medical centers. Despite the increasing costs and other problems of contemporary diagnostic work-ups (42), the sequential path of the work-ups has not been adequately outlined or documented. The few existing algorithms do not contain enough detail for satisfactory classifications of data; and the algorithms have not been suitably justified either with physiologic rationales or with empirical data derived from direct observation of patients.

Although many new formats and computer techniques have been proposed for storing the "data base" produced by the diagnostic technology of modern medicine, the technology itself has not been critically evaluated. The new formats and media for the medical record create a rearrangement and recataloging of the data that emerge from a medical work-up, but the sequence of the work-up is not denoted, the data are not "edited," and the results are not assessed. Since the unique pathway of decisions and judgments that characterize the work of a clinician has been omitted from the formats of data stored in both the old and the new media of medical records, the existing media cannot provide satisfactory information for appraising the diagnostic work-up.

The task will require attention, intellect, and effort not from computer experts, but from knowledgeable clinicians. A clinician's irreplaceable role in diagnostic activities is to make choices in clinical management, not just to prepare charts of information. His main job is to arrive at validated decisions, not just to arrange volumes of a "data base." To achieve validation for those decisions, clinicians must create the appropriate algorithms and collect the appropriate information for demonstrating which data are needed in a diagnostic work-up, in what sequence, and why.

4. *Strategies of Clinical Management*

In all of the foregoing clinical algorithms, the decisions were aimed at either attaining a diagnostic name or ordering a diagnostic test. In many common clinical situations, however, an act of therapy may interrupt the diagnostic reasoning before it is completed. The treatment may sometimes act as a diagnostic test or it may provide the ultimate clinical management before a precise diagnosis is achieved.

Consider a patient with a clinical condition manifested by a one-day history of malaise, low grade fever, an aching throat, and a stuffy nose. After finding nothing strikingly abnormal on physical examination, the clinician may regard the condition as a nonspecific viral illness, and may prescribe only minor supportive agents. If the illness promptly subsides, the patient will receive no further tests or treatment, and his "final" diagnosis may be nothing more specific than "flu" or "common cold." If the illness persists or worsens, however, the clinician will then reappraise the situation with additional examinations, tests, or treatment.

A different type of example is provided by an elderly patient with fever, inspiratory chest pain, hemoptysis, negative tests of sputum cytology, and a roentgenographic pulmonary shadow that could be due to pneumonia, to cancer, or to both. Reluctant to expose the patient to the discomforts of bronchoscopy, the clinician may use antipneumonia treatment as both a therapeutic procedure and a diagnostic test. If the roentgenographic shadow disappears completely after the treatment, the clinician may conclude that the diagnosis was pneumonia alone.

In both of the examples just cited, the diverse branchings of a diagnostic work-up were delayed to await results of a treatment that could provide both diagnostic assistance and therapeutic management. This type of delay for "exploratory therapy," or a more simple delay to await the action of time and nature alone, is a common managerial strategy in regular clinical practice, but the strategy is seldom considered in diagnostic activities at academic medical centers. Because of various peculiarities of clinical practice at such centers—the expensiveness and shortage of beds, the need to educate students and house officers, the unrepresentative character of the referred population, the focus on in-patient work-ups rather than out-patient treatment, and an "explanatory" rather than "managerial" scientific orientation (43)—the academic clinician seldom engages in the "watchful expectancy" and diagnostic-therapeutic mixtures of strategy that are used so often and so successfully by the family practitioner. These strategies are nevertheless an important part of the general tactics of clinical management for patients, and will require appropriate algorithms to indicate the roles of both time and treatment as diagnostic agents in clinical management.

Another important distinction between scholastic activities and clinical practice is the role of clinical data in strategies of therapy. For almost a century, medical students have been taught to believe that clinical data were used mainly for deducing a diagnosis, and that therapy then depended on the inferred diagnosis. This hoary custom of academic pedagogy is honored much more by its breach than by its observance in the realities of medical practice. As noted elsewhere (32), clinical data are often used as inferential guides to a diagnostic name, and the diagnosis may often determine at least one aspect of treatment, but many other acts of ordinary treatment depend directly on the clinical phenomena, not on a diagnostic name. Thus, if a patient has chest pain, shock, and a cardiac arrhythmia, we might diagnostically infer that he has acute myocardial infarction, but our only therapeutic act for the myocardial infarction itself is to put the patient to bed. All the other treatment depends on the associated clinical findings. Morphine is given for the pain, not the infarction; vasopressors are given for the shock, not the infarction; and digitalis is given for the arrhythmia, not the infarction.

Although this essay is generally concerned with diagnostic rather than therapeutic reasoning, the diverse algorithms of clinical medicine would be incompletely described without mention of their role in strategies of therapy. Clinicians who create such therapeutic algorithms will find that many critical decisions in treatment depend much more on clinical phenomena than on diagnostic names. An example of a therapeutic algorithm, again borrowed from the collection developed by the editors of PATIENT CARE (44), is shown in Fig. 11. There are 10 major decisions (bordered with thick-lined rectangles) that precede the therapeutic actions noted in the flow chart of Fig. 11. Each of those decisions depends mainly on clinical phenomena, rather than on diagnostic titles.

Not all clinicians will agree with the recommendations made by the panel of experts (44) whose consensus is reflected in the flow chart of Fig. 11. What the chart does provide, however, is a method of outlining a course of therapeutic strategy clearly enough and specifically enough for a reader to decide whether he agrees or disagrees. In contrast to the vagueness and ambiguity with which many therapeutic recommendations appear in free text, the flow-chart format provides a direct, precise demonstration of the observations, decisions, and actions entailed in therapeutic management.

Managerial clinical algorithms (45), sometimes called *protocols* (46), have also become a valuable tool in providing instructions for the patient care activities performed by physician assistants and other "medical extenders." With suitable arrangements of data, the flow chart format can be used both for indicating what to do and for auditing the performance.

5. *Intellectual and Clinical Economy*

The last type of algorithm to be discussed here deals with the problem of "economy" in the sequence of thoughts, tests, and decisions that occur in clinical reasoning. Every observant clinician has discovered that certain "short-cuts" or other maneuvers, either of intellect or of action, can increase the efficiency of his work

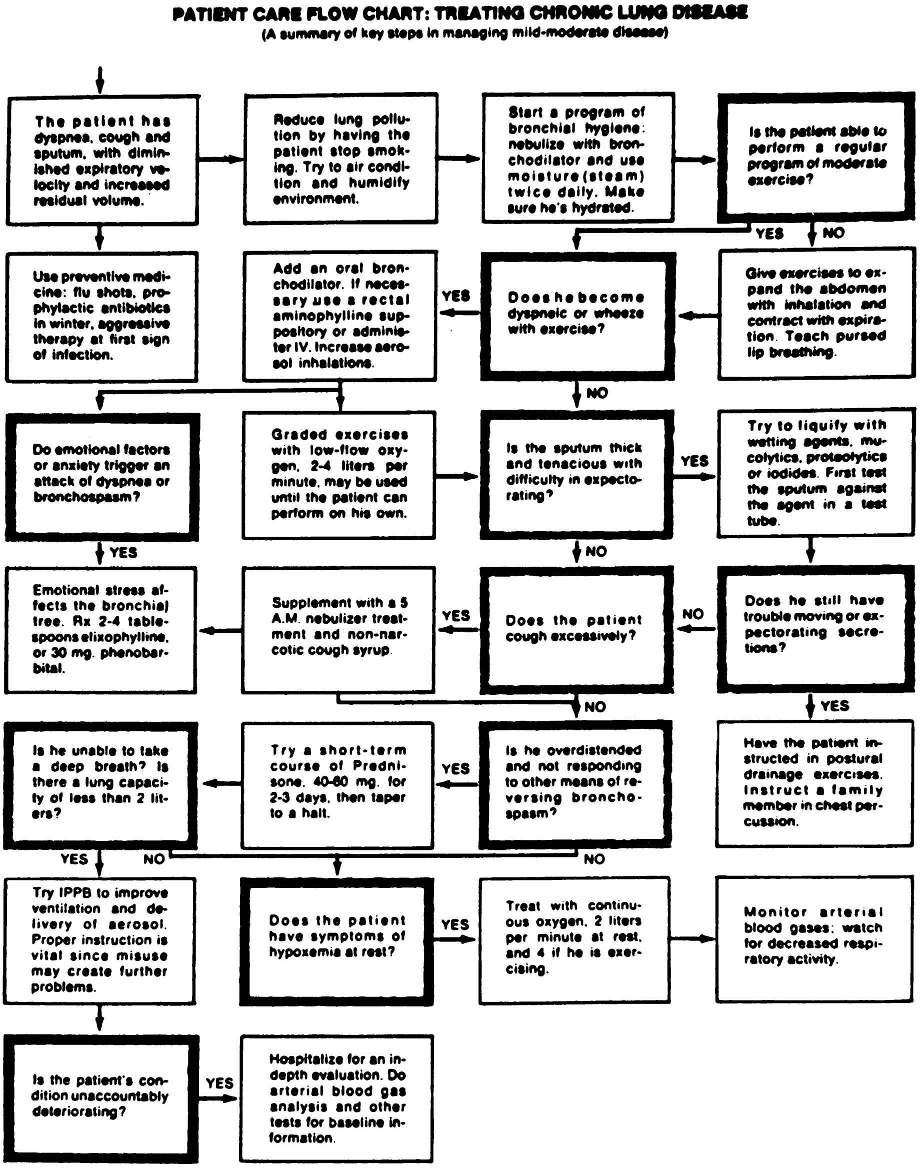


FIG. 11. Algorithm for therapeutic management of chronic lung disease. Reproduced, with permission, from page 62 of panel discussion in PATIENT CARE (44).

in clinical practice. A clearly outlined flow chart offers a method of discerning the relative efficiency or inefficiency of different sequences in the path of clinical decisions.

For example, on learning that the patient has a sore throat, an experienced clinician seldom goes through the traditional ritual of getting a complete account of the present illness, review of systems, past history, social history and other aspects of history-taking before he begins the physical examination. He usually looks at the throat immediately. Having noted the physical findings, or while noting them, he may ask about the symptomatic details of the sore throat and present illness.

At the same time, or slightly later, he may examine the gums and palpate the lymph nodes of the neck. While engaged in these physical procedures, or shortly thereafter, the clinician may ask about other details of the history that seem cogent for the array of clinical decisions that must be made.

These decisions may often be managerial before they are diagnostic. For example, if the patient with a sore throat also has a large pharyngeal mass and complains of rapidly progressive respiratory distress, the clinician may decide to do a tracheostomy before proceeding with any other examination procedures or diagnostic decisions. Similarly, if a patient with active gastrointestinal bleeding is hypotensive and in a cold sweat, the clinician may start an intravenous infusion, make preparations to administer blood, and alert the operating room staff, before he begins any of his exercises in history taking. (An algorithm for the above sequence would have included obtaining a statement about the bleeding, and then a physical examination of the skin and blood pressure before onset of the managerial procedures).

Even in nonemergency situations, many parts of the physical examination and laboratory tests are regularly performed before the total history is consummated. A gastroenterologist, for example, may regularly want to know the results of the array of paraclinical data that can be used to rule out "organic disease" before he concludes that the patient has "functional bowel distress" and begins a probing history about psychosocial-environmental features that may be causing or aggravating the distress.

The clinicians who practice in this sequentially mingled manner generally do so because they have found it more efficient than the tandem conjunction of isolated sequences that they were taught in medical school. The need for such mingling of sequences has been unofficially recognized by leading accreditation agencies such as the American Board of Internal Medicine, which allowed only 45 min for the performance of a complete history and physical examination when a candidate physician sought certification in the Board's oral examination. A candidate who had not learned to mingle sequences could seldom take a complete history and then do a complete physical examination and still be finished within 45 min.

Despite the constant admixture of history taking and physical examination in clinical practice, medical students are traditionally taught to perform the two procedures in an isolated manner, one following the other. This traditional sequence in techniques is probably pedagogically useful for instructing a beginning clinical student, who later learns to perform the mingling as he advances from neophyte to expert. Unfortunately, however, each physician does the mingling differently, ascribing his techniques to "judgment" and "experience," and almost no one can demonstrate exactly how the procedure is done when we want to study its efficiency, teach it to a student, or describe it to a machine.

Regardless of any instruction the delineations might provide for a computer, they are worth creating if only for their value in improving the efficiency of clinical examination, both in performance and in pedagogy. The creation of the appropriate algorithms cannot be done as an act of theoretical strategy. Knowledgeable clinicians will have to study their own activities, and then delineate the algorithmic flow and the rational justifications. In Figs. 12 and 13, I have indicated brief segments of intellectual sequences that can illustrate the managerial inefficiency of delaying certain critical examination procedures while pursuing the conventional sequence of history taking, followed by physical examination, followed by paraclinical tests.

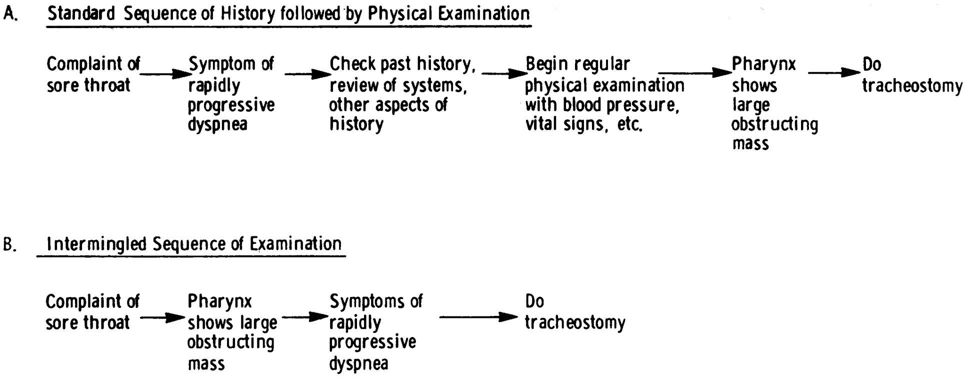


FIG. 12. Economy of intermingled vs standard sequence of examination in patient with sore throat and rapidly progressive dyspnea (for further details, see text).

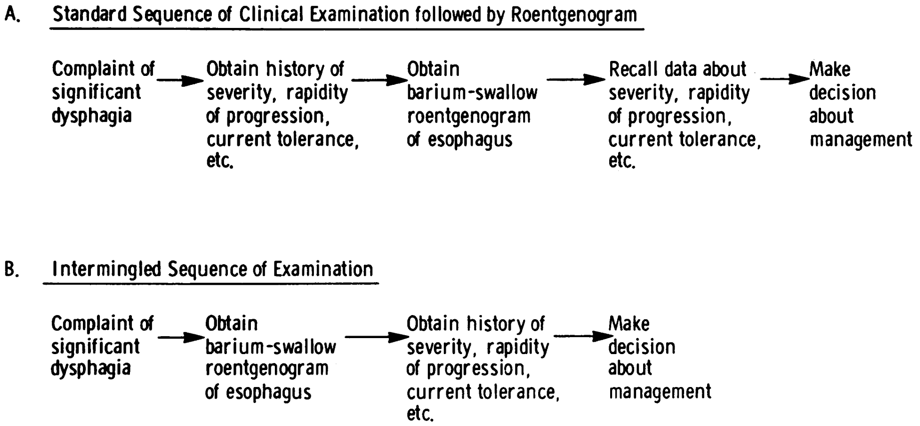


FIG. 13. Economy of intermingled vs standard sequence of examination in patient with significant dysphagia (for further details, see text).

The illustration in Fig. 12 shows the pathway between onset of clinical examination (with the patient's complaint of sore throat) and the clinician's therapeutic conclusion to perform tracheostomy. The pathway required six steps with the conventional sequence in Part A, but only four steps with the mixed sequence of Part B.

In Fig. 13, the clinician must make a decision about therapeutic management for a patient with the complaint of significant dysphagia. With the standard sequence of examination, in Part A, the clinician learns about severity and other descriptive details of the dysphagia before the esophagus is examined roentgenographically. After the roentgenogram is seen, all these symptomatic details must then be recalled for the managerial decision. With the mixed sequence, in Part B, the roentgenogram is obtained immediately after the main complaint is noted. Knowing the roentgenographic findings, the clinical then learns the other symptomatic details as a direct prelude to deciding about management. An extra step, the intermediate recall of symptoms, has been saved. Analogous "economies" are practiced by gynecologists who perform the pelvic examination before obtaining all the historical details in a patient with amenorrhea.

* * *

To avoid an overly prolonged discussion, I shall omit some of the many other important topics for which clinical algorithms are needed. Most prominent among these topics are the role of social, personal, psychic, and financial features in affecting clinical strategies. The relatively simple diagnostic and therapeutic problems illustrated here could be solved with algorithmic plans based mainly on clinical and paraclinical data. In the realistic practice of medicine, however, the algorithmic strategies will be inadequate unless they provide suitable, and often paramount, attention to a patient's demographic and behavioral data. After appropriate algorithms are established for strictly managerial decisions about the pathology of the disease, the algorithms can be modified to include the totality of decisions in the care of the patient.

SUMMARY

The plan of strategy used for solving a problem is called an *algorithm* and can be portrayed either in the sequential treelike structure of a *flow chart* or in the tabular array of conditions and actions that is called a *decision table*. An algorithm prepared for scientific purposes should be accompanied by statements of factual evidence or conceptual principles that provide its *justification*.

An enormous variety of algorithms is needed to describe the many decisions that occur in clinical activities. Some of these algorithms will depict processes that are clinically more simple than diagnostic reasoning. Such algorithms include the instructions for automated acquisition of data in history taking and for automated observation of paraclinical visual patterns. The "elementary" algorithms also include procedures for storage and enumerative retrieval of the data obtained during clinical and laboratory examinations.

The "advanced" clinical algorithms deal with the complex interpretations that occur during diagnostic, prognostic, and therapeutic reasoning. Diagnostic algorithms include the analysis of paraclinical data, the analysis of clinical data, and the plans for a diagnostic workup. Although purely diagnostic algorithms may be followed by separate algorithms for prognostic and therapeutic reasoning, these procedures may often occur in an intermingled sequence in clinical practice. The diagnostic process may be interrupted by treatment that acts as a diagnostic test or that eliminates the need for further diagnosis. The traditional diagnostic succession of history, physical examination, and paraclinical tests may also be performed in a sequence different from conventional pedagogic instructions.

The algorithmic portrayal of these processes is crucial for determining the intellectual "economy" with which they are performed, for improving the way in which they are taught, and for assembling satisfactory data to evaluate their costs, risks, and benefits to patients. The construction of justified clinical algorithms requires intimate familiarity with clinical activities and offers a major new scientific challenge in basic clinical research.

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