DR. SHORT: Yes. This is an important cause of cardiac failure. I would also make the point that I find it useful in patients with resistant cardiac failure to prescribe the short-acting diuretics such as frusemide at four o'clock in the afternoon, as the diuresis is then complete in the evening and this reduces the occurrence of paroxysmal nocturnal dyspnoea.

I would also re-emphasize that rest is important. We discussed it when we were talking about mild cardiac failure but there is a small group of patients whose hearts are so severely diseased that it is worthwhile to restrict severely activity for up to six months. In my opinion patients who are to be kept in bed for such periods ought to be given anticoagulants as a prophylaxis against thromboembolism.

PROFESSOR MACGREGOR: I don't want to discuss cardiac surgery today but in younger patients this would have to be seriously considered. The last case is in contrast with the first three.

Case 4—Heart Failure (Cor pulmonale)

HOUSE PHYSICIAN: This 65-year-old man has smoked 40 cigarettes a day for 40 years. He has chronic bronchitis and emphysema, and has been admitted because of severe breathlessness. On examination he is cyanosed and plethoric. The chest is hyperexpanded and he is using the accessory muscles of respiration. There is pitting sacral and ankle oedema. The sputum is purulent.

PROFESSOR MACGREGOR: He is obviously hypoxaemic and hypercapnoeic. You can feel the warm extremities of so-called high-output failure. The investigations must surely confirm that the heart failure is due to his pulmonary disease.

DR. WOOD: Yes. He is having humidified oxygen through a Venturi mask, and the concentration of oxygen is being maintained in the region of 24-28%. He is also having steam inhalations, physiotherapy, and postural drainage. His sputum is being cultured and in the meantime we're giving him ampicillin. Morphine and high flow rates of oxygen are absolutely contraindicated in view of this patient's respiratory insufficiency.

PROFESSOR MACGREGOR: You are treating the pulmonary disease, which is the cause of his heart failure. I take it that he is also on a diuretic, potassium supplements, and digoxin?

DR. WOOD: Yes, but we should point out to the students that there's some debate about using digoxin in patients with cor pulmonale as it may increase pulmonary congestion. However, digoxin acts on both ventricles and in our experience is useful in such patients if there is associated left ventricular disease.

PROFESSOR MACGREGOR: We've seen four interesting patients. The principles of treatment of heart failure are to establish and treat the precipitating cause, whether it be rheumatic valvular disease, thyrotoxicosis in the elderly, anaemia, or cor pulmonale. Oxygen and morphine must be used very carefully. Although there are a variety of diuretics some of which are inappropriate in mild or severe heart failure, it is necessary to become familiar only with a few. The cardiac glycosides, 186 years after their introduction, continue to puzzle us.

Computers in Medicine

Logical Foundations of Medicine

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For more than two thousand years the diagnoses, the predictions, and the decisions of the doctor have all taken place in a private world of his own. His private programmes are based on his medical training and subsequently develop from his clinical experience. He learns how much reliance can be placed on a certain symptom; he has learnt to discard a sign he was once taught; he has found how unwise it is to advise operation in a given clinical situation and so on. All this clinical experience continually modifies his "programmes." As a decision maker he can become extremely shrewd.

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So natural is this traditional clinical method to the doctor that the possibility of any other hardly occurs to him. He is, of course, helped by scientific progress. The inside of the stomach is photographed or a chemical substance in the body fluids is measured in nanogrammes per millilitre. But the doctor usually assumes that the basis for his work is not thereby affected; that only humans can arrive at a disease label or predict the outcome of a disease.

This assumption has now to be questioned. We now have the opportunity of exploring an alternative medical system and developing its logical structure. This opportunity arises because of developments in relevant mathematics and because of the existence of the computer, whose immense information store and calculating ability makes possible mathematical methods that were previously impracticable.

Computers can be used in medicine in various ways. Some of these uses, though perhaps not intellectually exciting, may be very important, such as the calculation of pay slips. Computers have also been used in hospitals for transmitting and storing medical information expressed in traditional terms. But computers could also be used in a different way, by giv-

ing reality to a logic of medicine and thus making explicit the activities of the doctor that were previously largely implicit. Only in so far as any such logic is developed is any automation of clinical medicine possible. Apparently the first publication making a formal rational approach to the problem of medical diagnosis was that of Ledley and Lusted,[1] and a recent, more detailed publication which also contains a useful bibliography is that of Lusted.[2]

This kind of development that a number of us envisage has already occurred in other fields. Previously in the business of weather forecasting the forecaster developed an expertise from a lifetime study of weather situations and was then asked to predict the likely development of a given pressure system and thus the weather that might be expected. This forecasting of the pressure system, based on the private programmes of an individual, is now replaced by a calculation based on differential equations that describe the behaviour of the atmosphere. The computer has made the calculation possible. The advantage of this method is greater accuracy in the forecasts, and since the method no longer depends on an expertise limited by a single lifetime it is capable of progressive refinement.[3] This analogy emphasizes the disadvantages of the traditional system of medical practice; that the individual skill of a doctor is necessarily limited by the sum of his experiences and can reach only a certain level during his lifetime and is then totally lost; and also that the method is so costly that developing countries at their present rates of economic growth cannot achieve for many years a therapeutic system of medicine taken for granted by the West. The development we envisage is the replacement of much of the private programme of the doctor by a public programme; public in the sense that each step could be explicitly described and written on a blackboard.

Rationality

When we seek to develop a logic of medicine we cannot adopt the entire process the doctor uses since we do not know in detail what this is. The doctor in part uses logic, in part makes use of probability judgements, and recognizes patterns, often with astonishing skill. Though his exact method is unknown we can imitate some of it and quantify aspects of his work. We must develop the logic that seems best fitted to our objective.

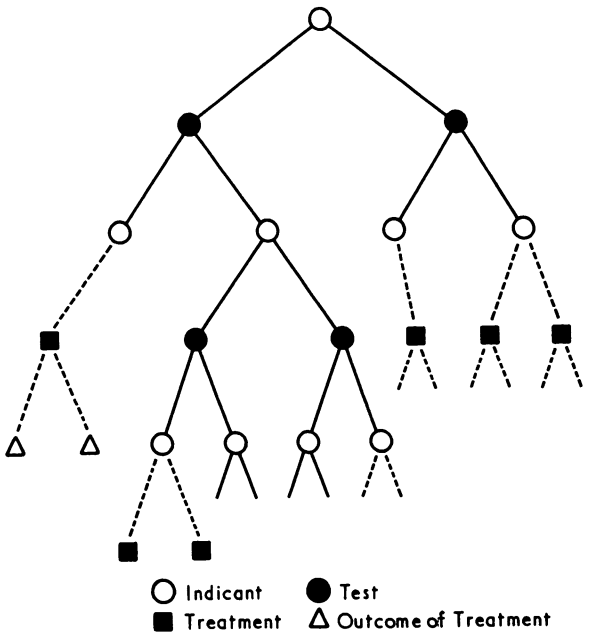
The objective of medicine was first stated by Hippocrates. "First of all," he said, "I would define medicine as the complete removal of the distress of the sick, the alleviation of the more violent diseases and the refusal to undertake to cure cases in which disease has already won mastery."[4] This is an informal definition. To make it formal we have to proceed as follows. We have to attach a certain measure of value to any given state of health, and we think of one state of health as more desirable than another. In a patient with duodenal ulcer, for example, there are certain outcomes which may follow medical treatment and certain outcomes which may follow surgical operation. To each of these outcomes we imagine that a measure of its value is attached—that is, a number. For historical reasons this value is somewhat unfortunately called a "utility." In deciding whether or not to advise surgery the doctor would like to achieve the most desirable outcome—that is, the outcome with the highest utility. But he has only a certain chance or probability of attaining this and can therefore act only to do this—"on the average." The technical term for "on the average" is "expected." Since he tries to make the utility resulting from his decision as great as possible on the average we may say that the objective of medicine is the "maximization of expected utility," an objective known as the principle of rationality. The doctor chooses, in effect, the best bet. The mathematics we shall need are the mathematics of decision making.

We begin with the patient. We regard each symptom he describes, each sign elicited, and the result of each laboratory test as an element of evidence towards the probability that a certain disease is present. For any element of evidence we use the word "indicant," borrowed from the older medical writers but used with a slight change of meaning.[5] A disease then becomes a cluster of indicants, each of which is present with a certain probability. By using statistical methods we can in principle evaluate what a given indicant is worth in the diagnosis of any specific disease. This approach could be better than the doctor's evaluation of the same indicant since it is based on a much wider experience.

But though disease labels may be applied decisions on treatment cannot be made until estimates are made about the utilities of the various states of health that may result from treatment. Some allowance must also be made for the "costs" incurred by a decision on treatment or of some diagnostic procedure. "Cost" is here used in a broad sense to include both financial cost and the anxiety, pain, etc., experienced by the patient as a side effect to the procedure. The estimation of these utilities poses a difficult problem, but we may be able to infer them from an analysis of the decisions that doctors are observed to take.[6] Their use also implies consequences not readily accepted. For decision making in practice means not only the assignment of a number, a utility, to a particular state of health but some financial equivalent for this utility. A regional hospital board with limited resources, and faced with a choice between two projects, should choose, other things being equal, the one that carries the greater expected gain in human happiness. They make this choice from their experience and judgement, but in so doing they are implicitly putting a monetary value on human life (see, for example, Gerald Leach, *The Biocrats*, 1970, chapter 11).

Evidence and Generalized Diagnosis

All doctors are familiar with a symptom or sign or test result on which, in their experience, great reliance can be based in discriminating between two or more diseases. To this intuitive feeling of evidential value a measure can now be applied. Evidence can be measured by the way it changes the



Generalized diagnostic search tree. The doctor chooses tests and treatments and the patient provides indicants and outcomes. The doctor alternates his "moves" with those of the patient as in a game. The diagnostic search tree as such contains only continuous lines, but the generalized diagnostic search tree contains the dotted lines also. The incomplete lines indicate that there is more of the tree that has not been illustrated here.

probabilities or odds. With a new piece of evidence the odds in favour of a disease change and the value of the evidence might be measured by the change in odds. Such a measure is clearly necessary in any formal description of the process of diagnosis, but it can also be incorporated into the fundamental concept of a doctor as a rational decision maker.

The activities of diagnosis, prognosis, and treatment can be seen as an integrated activity that can be represented in the form of a "decision tree." In the course of a diagnostic process the doctor must at each stage select some *test*, such as a question, physical examination, or laboratory test. The response to each test is one of a number of possible indicants, so there is an analogy with a game in which the doctor and the patient make moves in turn. When selecting a test the doctor should take into account the cost of the test and also its potential utility in the sense of cutting down on the search. Expected weight of evidence in a precise technical sense can be used as one such "utility." The possible courses of the diagnostic process can thus be pictured as in the Figure.

When an end-point of the diagnostic search tree is reached the doctor must make decisions regarding treatment and prognosis. At this stage he must take into account the possible outcomes of the available treatments and their costs, and again his decision should be made in accordance with the principle of rationality.

Implications

If we use some estimate of the evidential value of an indicant we may well find that some of the symptoms, signs, and test results used at present carry so little evidence that they could be discarded. We may also find the reverse; that a symptom carries an unexpectedly large weight of evidence. Our colleague, Dr. Knill-Jones, has recently found that the duration of itching in jaundice at least equals the discriminatory value of the plasma gammaglobulin level. Measurement of this power in a wider context could revitalize the art and science of history taking. We may also find that the evidence contained in one indicant is already largely contained in another and that little is gained by eliciting both. Further, when we balance the evidence obtained against the cost of a test, we may find that many of the investigations so often requested—for example, barium meals—can no longer be justified. We must expect surprises when we start buying our evidence in the least expensive market. If these principles were applied they would mean a considerable reduction in the number of tests used in clinical medicine. This reduction, coupled with generally accepted definitions of all indicants, would mean an appreciable simplification in both teaching and practice. This logical approach would lead not to the decline of clinical medicine but to its renewed vigour.

Other consequences could ensue. One of the applications of the computer that seems attractive is its use in handling hospital clinical records. All attempts, including the latest one, seem to have failed.[7] We believe that these attempts must fail until a logic of records is developed, which in its turn must rest on a logic of medicine. We have first to know what we should record before attacking the much simpler technological problem of how to record data in a computer file. The logic of medicine we have outlined allows us for the first time to develop a rational theory for deciding which parts of a clinical record should be retained. Each part can be used as evidence in future decisions and therefore carries an expected value. It should be discarded if its value is less than the cost of transcription and retention.[8]

Realization

The practical realization of the ideas outlined in this paper is at such an early stage that it is impossible to state categorically that a system of clinical medicine based on the principle of rationality would be superior on balance to the working of the traditional system. But it would be surprising if it found no place. Its realization basically rests on the development and application of mathematical theory and the computer. Many of the aspects of the theory of rationality date only from the second world war, and accelerating application of this theory must be expected in many fields. The application in medicine can take place only by the collaboration of doctors with mathematicians. It is idle to expect a mathematician to walk into a hospital outpatient department, to identify a problem, and to formulate it. It is the doctor who must acquire enough insight to be able to collaborate with the mathematician in abstracting from the confusing multifarious data the essence of the problem. Only then can the mathematician say whether the problem is soluble or whether more research is required.

To solve mathematically any clinical problem in this early stage it is essential to select a simple one, and only the very experienced doctor can be relied on to see where the problem really lies. The study, which will have to be prospective, will require explicit definitions of all the indicants, the disease classes, and the treatments and their outcomes. With the use of the statistics which result from the study, programmes will be written and their effectiveness in solving the problem could be compared with traditional methods. This approach is not costly and could be tried in a number of centres in Britain. The complete development of any logic for the whole of medicine is likely to be a long and tedious process.

Though there is little doubt that in the development of mathematical methods much computing power will be necessary, the ultimate place of the computer in the day-to-day practice of such a logic of medicine is as yet undetermined and may be much less than is sometimes supposed.

When we refer to the use of a computer we do not mean its use for the mere speeding up of those information-handling operations that are already explicit in traditional medicine. Instead, we mean its use for carrying out processes that are only implicit in present practice. This idea evokes resistance. Doctors fear that medical practice might be dehumanized. It is, however, trite but true to say that the introduction of a computer means the development of a new partnership in which the machine and the doctor would do the work for which each is best fitted. This should be our goal.

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