Review Article

Computers in anaesthesia

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The application of computers to anaesthesia has increased steadily in recent years. This trend will likely accelerate as advances in computer technology produce increasingly powerful computer systems that continue to decline in cost. The growing role of the computer makes it reasonable to expect some knowledge of its capability as part of the training of any anaesthetist.¹

Few professional areas can match the potential for computer applications that exist in anaesthesia and medicine generally. The need for fast, accurate information and reliable, precise electronic instruments is striking. Moreover, the relatively late development of medical applications means that much of the required technology has already been developed by faster-moving disciplines.

The basic principles of computer systems, hardware, and software will be reviewed in order to facilitate a discussion of specific application areas of interest to the anaesthetist. We will identify six main areas: (a) record management, (b) departmental organization, (c) patient monitoring, (d) automation of anaesthesia, (e) computer-assisted learning, and (f) consultation systems. Other areas include many conventional functions which are not specifically aimed at anaesthetists, such as word processing, financial management, and statistics; these will not be dealt with here.

Basic principles

The basic operation of a computer involves three

stages. The first stage (input) is the acceptance of data from a source external to the computer. This normally is a person typing in information at a computer terminal, but can also involve data transmitted by other electronic devices which are connected to the computer system. The input data may be permanently stored in a memory device if it is likely to be needed again.

The second stage (data processing) involves the computer working with the input data to produce computed results, which again may be stored in memory. The manner in which the data is processed depends upon the instructions that the computer has been given in its program. The data processing stage is the time during which the computer is popularly considered to be "thinking."

The final stage (output) is the presentation of the results of the data processing stage. The output may be information intended for humans, in which case it is usually printed on paper or displayed on a screen, or it may be control information transmitted to another electronic device.

Of course, this input-(store)-process-(store)-output model is a simplified description of how a computer functions. While these are the only stages involved in computing, they are rarely so clearly delineated as in the above example. More frequently, the stages will be repeated and will overlap each other a great deal through the course of a program. However all programs conform loosely to this model, so that it is possible to view the operation of any computer system in these simple terms.

A number of important points must be made about the model. Firstly, the output stage is the sole point at which the computer produces anything of value to humans. Thus, no matter how impressive a system may seem, without meaningful output it is useless.

Secondly, the perceived value of the output

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generated by the computer system must exceed the cost and effort of the input and processing stages. There are various criteria for value, such as patient outcome, money or time. Suffice it to state that, in their haste to computerize, decision-makers should not forget that computers exist for the benefit of humans, and not vice-versa.

Finally, the validity of the output data is strictly dependent on the validity of the input data. For instance, in a statistics program, typing in incorrect numbers produces what from the user's point-of-view is an incorrect result. In general a computer cannot determine if an entered value is the intended value, as long as it is of the correct data type.

The computer is a digital machine – which means that it can assume only a finite number of data configurations, or “states.” It follows then that the amount of information that a computer can hold is also finite. Only data that assumes one of two values (traditionally denoted as 0–1, yes–no, or true–false) can be processed. Such data is often referred to as “boolean,” and a single boolean variable (i.e., a single yes-or-no) is referred to as a “bit” of information. All data that the computer deals with are sets of bits. As a result, the computer is endowed with a certain abruptness; the grey area between distinct alternatives is not easily represented. Different patterns of bits (usually grouped together into sets of fixed size such as eight or 16) are taken to represent numbers or alphabetic characters. For example, most computers use the bit sequence 00100001 to represent the letter “A,” 00100010 for “B,” 00100011 for “C,” and so on. A group of eight bits is often referred to as a “byte.”

Basically then, the only data that a computer can deal with are bits, which can be grouped together to represent digits or letters, which can be further grouped to form numbers or words. All data must have a finite size or length. A continuous function, a picture, a sample of handwriting, or anything that contains an infinite number of points cannot be handled in its original form by a computer. Such data must be converted to a finite approximation before it enters a computer system. For example, a computer cannot store a perfectly continuous function such as temperature plotted over time since it would contain infinitely many points, but instead must measure the values at time intervals, convert them to a boolean form, and store them. In practice,

this approach is satisfactory because the measurements can be taken at very small intervals and the values closely approximated, resulting in a very accurate reconstruction of the actual function.

Computers are only capable of elementary operations, rarely anything more sophisticated than the multiplication of two small boolean numbers. These simple operations are performed one-by-one at a rate of many thousands of operations per second. If a computer is to perform a more useful task, a sequential list of instructions must be provided. This list of instructions is called a program, and one of the most useful properties of computers is that they can be programmed to perform a wide variety of different tasks. However, at present there are definite limits to the computer's usefulness: many complex tasks have eluded computerised solution.

Computer hardware

The physical devices that make up a computer system are referred to as “hardware,” and consist of four major types: input devices, memory devices, processing units, and output devices. A single device can, however, belong to more than one category, and may be referred to as a compound device – for example a computer terminal, which serves as an input and output device.

Normally a computer system will have only one processing device. This device, often referred to as the “central processing unit,” has two important functions. Firstly, it performs the data processing operations specified by the program it is executing. Secondly, it controls and supervises the operation of all other devices in the system. This second task is an intricate one, since many devices may need to be commanded simultaneously.

A computer needs memory devices in order to store both the instructions and the data that it processes. The internal memory, also known as “primary memory,” is fast and has a relatively small capacity in the thousands of bytes range. It is generally used to store temporarily the data and instructions that the computer is currently dealing with.

Permanent data and programs are usually stored on “secondary storage devices,” which are generally external to the computer itself. These devices function more slowly than primary memory, be-

cause they are partly mechanical in operation. They generally use removable media such as disks or tapes, which have a much larger storage capacity. There are two common types of secondary storage devices: disk drives and tape drives.

Disk drives store and retrieve information from disk cartridges which can have a storage capacity of many millions of bytes ("megabytes"). They are classified as "random access" storage devices, because they can retrieve information located anywhere on the disk platter with equal speed. As a result, disks are often used for storing large record-files.

Tape drives work on exactly the same principle as conventional tape recorders but store digital information. To read information from a tape or record onto it, the tape drive must position its read/write head at the desired position, and then proceed to read or write the information in a serial manner. Changing from one region of the tape to another causes significant time delays, as the tape must first be repositioned at the new region, which is a very slow process. For this reason, tape drives are classified as "serial access" devices, and generally are only used to store large amounts of information which will be stored and retrieved in a serial fashion.

Input devices are simply any devices in a computer system that allow data to be introduced into the system from an external source. This includes devices used by humans – such as a terminal – and electronic measuring devices linked to a computer system.

Output devices present the results generated by the computer system. Terminals and printers are the most common output devices; the former provides a temporary copy of information, the latter a permanent one (or "hard copy"). Graphical plotters "draw" rather than print, and generally produce much higher quality output than printers. They usually draw on paper, but many are also capable of generating overhead transparencies. Plotters are able to present numerical results in a visual format (such as pie charts or bar graphs) that is more readily digested by the user. The popularity of graphical output has resulted in plotters becoming increasingly common components of computer systems. In addition, many terminals now have graphics capability.

Types of computer systems

It has been found useful to classify computer systems into three main categories: microcomputers, minicomputers, and mainframe computers. Classification is based mainly on the capacity of the central processing unit, the complexity of the system, and the cost. However, advances in technology will tend to blur these distinctions.

Microcomputers include "personal" and "home" computers. They process data more slowly than larger computer systems, and usually have smaller memories. Microcomputers were originally intended to support only one user or process at a time, although many can now adequately support multiple processes. For the most part they are sufficiently powerful to handle applications where limited simultaneous demands are made of the system. In addition, microcomputers require less user expertise than larger systems, and are considerably cheaper. Because of their simplicity, microcomputers appear to have the best success rate in anaesthesia applications.^{2,3}

The minicomputer is capable of supporting several active users simultaneously. In order to do this it must have the ability to "time-share," a technique by which the computer divides its attention among all active processes or users of the system. The advantage of time-sharing is that it allows expensive resources (such as information or peripheral devices) to be more effectively shared among different users. However, care must be taken to avoid resource contention problems.

Mainframe computers are capable of supporting several dozen users simultaneously. Aside from this increased capacity, they are very similar in their internal operation to minicomputers. They are, however, centralized systems, intended to be shared by many different user groups, under the direction of professional computer staff. The resulting lack of user control has made mainframe computers unpopular among many users, who rarely have unsupervised access to anything more than a terminal and printer.

In theory, a mainframe hospital computer could be used to provide a unifying link between the various groups using it. Such a system could allow valuable exchanges of information, which would be of great administrative and medical value. Unfortunately, such systems have often proved to be unworkable in practice.³

Mainframe computers are no longer necessary for most applications. Indeed, technological trends favour the decentralized approach offered by micro and mini-computers.⁴ As computers become smaller, cheaper and more powerful, the concept of the "computer centre" as an area with a large mainframe computer to which users bring their work is rapidly becoming obsolete.⁵ There is a growing perception in medicine that the computer is best exploited by a decentralized effort which recognizes the individuality of each project.⁴

Networking, a recent development in computer technology, is likely to allow the best features of both the centralized and decentralized approach. A computer network is a group of interconnected computers which are able to communicate with each other, while at the same time retaining autonomy. Thus network members are able to share information, messages, output and storage devices – without obligation. Early local networks allowed only a single vendor's equipment to be linked together, but now many are becoming available that will hook up to any manufacturer's equipment.⁶ On a larger scale, many regional, national and international networks already exist for specialized groups, and membership costs are quite low.

It is already possible for individual departments within a hospital to possess their own decentralized computers, all of which belong to the same local network. This would allow each department complete control over its own projects, yet at the same time making inter-departmental resource sharing a possibility.

Software

A computer must be provided with a program before it can function. Conventional programs organize information on two levels: instructions and data, with the instructions acting on the data to produce results. The rules, or syntax, governing the way in which programs are written depend on the particular computer language employed. In essence, computer languages have much in common with human languages. One difference is that the former are considerably simpler – they consist of commands to the computer to perform relatively simple operations. Another difference is that computer languages are precise. Syntax rules must be obeyed whereas in human languages these can sometimes be disregarded without loss of meaning.

There are many different computer languages, and most computers are capable of understanding more than one. Unfortunately, the lack of standardization in these languages often impedes transfer of programs from one system to another. Like their human counterparts, different computer languages manifest different properties; some are simpler than others, some more precise, some more technical, and so on. Computer programs cannot be written in a human language because so far human language comprehension cannot be described in the manner necessary for a computer. However, progress is being made in this area of research.

Programs are referred to as "software," and are stored in the computer system's memory. Because a computer is useless without software, any computer system will come equipped with some general purpose programs that allow the user to perform such fundamental tasks as text entry and system operation. However, it is normally left to the user to acquire the appropriate software for a particular application.

The cost of a program will depend largely on how many people are interested in it, rather than on its complexity. A very complex program such as a word-processor may cost the individual user less than \$100 because the developmental costs are being shared by thousands of users, whereas a simpler program written by a software firm for a specific individual may cost many thousands of dollars.

The above considerations dictate that the user attempt wherever possible to purchase general software "packages" that are commercially available, rather than "customized" software. Moreover, the former are immediately available, whereas the latter requires time for development. Unfortunately, it is rarely possible to buy a general software package that will suit one's more specialized applications. For example, it is highly unlikely that a software package could be found to efficiently handle the record-keeping requirements of a hospital anaesthesia department. As a result, for most specialized applications it is necessary to pay for "customized" software.

Artificial intelligence

Artificial Intelligence (AI) is the most controversial area of computer research, and is of increasing importance to the field of medicine. AI programs

attempt the integration into the computer of thought processes similar to those of a human. They differ from conventional programs in that they deal with problems for which algorithmic solutions do not exist, and judgement is required. This judgement is usually guided by empirical rules, which help to limit the possibilities. Thus, AI deals with the types of problem solving and decision making that humans continually face in the real world.⁷

Structurally, most AI programs differ from conventional programs in that they organize information on three, rather than two, levels: instructions (or control), data and knowledge.⁸ The explicit provision for knowledge make AI programs much more complex and powerful. It also presents researchers with a major and as yet unresolved difficulty: how best to depict knowledge in the form required by computers.

Current AI research is mainly focused on three areas: vision systems, natural language systems and expert systems.⁹ In the first two fields, progress has been slow due to the great complexity of the problems. Computer systems designed to see images, hear sounds and recognize speech are still in fairly early stages of development.⁸ However, their potential application is clearly enormous.

Expert systems are of particular importance to medicine. Their aim is to develop a specific intelligence – to match human performance in some specialized and limited domain.¹⁰ In this field, practical results have already been obtained: problem-solving expert systems already exist that can reach a high level of competence in certain limited medical domains. Application areas included medical diagnosis and prescription, and medical knowledge automation.⁸

The development of an expert system is a substantial undertaking, involving numerous man-years of work. Most of this effort goes into the construction of the "knowledge base" – that is, the transfer of expertise from a human expert to the program. Since the domain expert often knows nothing of programming, a human programmer will normally act as the intermediary. However, successful attempts have been made to streamline the process.¹¹

AI programs face considerable obstacles to progress. Problems such as knowledge representation remain unresolved. The cost of software development is extremely high, and demands on instruction

execution speed and memory capacity often exceed the most advanced technology. Nevertheless, AI research has already reached a level of development where it is productive, although not yet economical, to start applying techniques to real-world problem domains such as medicine.

Record management

Record management involves the computerized storage and processing of anaesthetic records. Computer records can contain two types of data: discreet (such as patient identification, date, type of procedure, duration of anaesthetic) and continuous (such as measurement of physiological functions over time). Because the latter requires considerable memory resources and either excessive data entry or expensive, sometimes temperamental electronic signal capture, it is usually excluded. A number of successful microcomputer-based systems which include readings from non-invasive instruments in a full computer record have been reported.¹² However, even in successful data capture systems, the cost is high in comparison with the value of information gained.² While continuous data is useful for individual case studies, it is too detailed and unwieldy to allow easy computerized analysis of groups of records.

Computerized record-keeping normally involves the additional step of copying the appropriate portions of the anaesthetist's hand-written record into the computer. This task, often performed by secretaries, increases the risk of error. But once stored, the accuracy of computerized processing is considerably better than manual processing.² An alternative is to have computer terminals at every anaesthetic location into which data could be fed at the time of procedure, and from which a printed record would be produced at the end of the service. But such systems presently involve a prohibitive cost and technical complexity.

The computer is supreme in the areas of information storage, manipulation and retrieval.¹³ By virtue of its processing speed and storage capacity, the computer is able to provide in a matter of minutes data that would require many days of manual compilation. The key to computerized record management is the highly organized and detailed manner in which records are stored. Indexing information is included to allow fast access to individual records according to different selection

criteria. The collection of records and related indexes is known as a "database."

Database interrogations can supply a wide variety of useful information, such as the number of patients treated, average time and time breakdowns, as well as departmental or individual case totals and information for billing purposes. They can facilitate quality control by providing statistical trends, and discovering inconsistencies in the treatment of given conditions. In addition, they can provide individual anaesthetists and residents with useful feedback on their own work.

A successful anaesthetic record management system using a microcomputer has been developed at the Department of Anaesthesia, Foothills Hospital at the University of Calgary.³ It provides useful record retrieval functions in addition to the ability to enter, delete, and modify records. Immediate display of any anaesthetic record is achieved by specifying a patient number. Departmental statistics can be compiled (and depicted graphically) on a monthly or yearly basis. In addition, the system allows statistics and a list of record numbers to be compiled for a group of records that meets selection criteria. A similar, but less flexible, system using a mainframe computer has been in operation at Karolinska Hospital, Stockholm for a number of years.¹⁴

Computerized record management raises a number of important issues. First is the question of data accuracy. As long as records are being copied manually into the computer system, a certain level of human error is unavoidable. This can be minimized by having the computer perform data verification wherever possible, and ensuring the comfort and motivation of the entry clerk. Data loss due to operator error or (less commonly) system failure is another problem. Although it occurs relatively infrequently, failure to guard against it can prove disastrous. Backup copies of all important data must be made periodically and safely stored. Security of data from perusal, analysis, or alteration by unauthorized individuals must also be provided for. Password verification provides some security, but security is best ensured by restricting physical access.³

For anaesthetists, record management is a relatively simple and rewarding computer application. One reason is that a great deal of work which is readily adaptable has already been done in other

areas, notably business. For example, many "database packages" (which greatly simplify the programmer's task of setting up a database) are presently commercially available. But, by and large, anaesthetists have been slow to take advantage of the groundwork provided.

Departmental organization

Typical uses of the computer as an organizational aid at the departmental level are inventory control, operating room (OR) scheduling, and billing. As inventory control involves accounting functions that are not specific to anaesthesia, it will not be discussed here.

OR scheduling programs allow fast and accurate assignments to be made automatically. However, since scheduling procedures often require imprecise improvisations, computerization may prove inappropriate. An attempt by the authors in 1982 was abandoned after a month of program development, when it was found that exceptions outnumbered the routine assignments.

If a suitable algorithm can be devised, a scheduling program will reduce the tedium of manual assignments. The computer must be provided with a list of active staff, the days on which they work, holidays, and similar data.¹³ It can then automatically print out scheduling assignments days or weeks in advance. Manual adjustments must be allowed for, as the computer cannot easily handle exceptional cases in any other manner.

An extensive scheduling system will include a database in which past scheduling information is stored. This may be used as a basis for determining popular and unpopular assignments (such as night duty), so that fair treatment can be established over the long term.

Computerized billing is normally a derivative use of a record management system.¹⁵ It is a natural extension since most anaesthetic records will already contain much of the information required for billing. The computer simply prints out billing slips and keeps track of patient accounts. In general, it seems that this and similar applications are quite realizable, but may not on their own result in a time-saving sufficient to justify the expense of a computer system.

Patient monitoring

Computerized patient monitoring is emerging as a

major application area. Anaesthetists appear to have great interest in this field.² The aim is to have the computer measure physiological functions, perform any appropriate interpretative calculations, and then output these results in the most convenient format. In addition, the computer must detect radical changes or discrepancies in incoming data and issue appropriate warnings. It is this interpretative function that distinguishes monitoring from simple data capture.

Because of its great speed, a computer can provide almost instantaneous status information on both measured and derived variables. The simpler biological functions – such as ECG and blood pressure – are easily and accurately recorded and displayed using existing technology, including analogue to digital converters. More complex signals are more meaningfully represented when the signal has been processed – for example, by Fourier transformation.¹⁶

Unfortunately, computers are unable to perform effective quality control of incoming variables because of their present inability to recognize patterns.¹⁷ The solution of this difficulty will probably be provided by advances in artificial intelligence research.

Computerized monitoring is a very demanding application, partly because it involves the computer acting in real-time. Such applications always require considerable engineering and programming expertise, including sophisticated provisions for program or system failure which are unnecessary for *post facto* processes such as record management. The cost of both hardware and software is high. Mainframe systems in particular require a great deal of expensive technical support. As a result, such systems are usually developed at sophisticated research centres and may subsequently be made available commercially.

It would appear that the best arrangement is a network of stand-alone systems if many patients are to be monitored simultaneously. The use of a centralized system is prone to total collapse, and does not allow for indefinite expansion.¹⁷

Some electronics firms have made commercially available pre-packaged systems that perform limited patient monitoring functions, both invasive and non-invasive.¹⁸ For example, a micro-computer based monitoring system has been developed to simultaneously monitor a number of haemodynam-

ic variables, including vascular pressures, cardiac output, blood temperature and pulse rate. From these primary measurements, the computer automatically derives and displays information that is used to make patient management decisions. This frees the anaesthetist from performing these calculations by hand, thus saving valuable time and reducing the chance of error. A review of this system¹⁹ found it highly promising, but too costly.

More ambitious systems have tended to be plagued by technical, financial and staff-related difficulties. A minicomputer system designed to allow simultaneous monitoring of cardiovascular and respiratory variables at four sites was unsuccessful.² It was hoped that the stored data would improve patient care, reduce staff workloads, and prove useful in teaching and research. However, these benefits were not realized in practice, and after two years a decision was made to terminate the application in view of high on-going costs for system operation. The system was reported to be unfriendly, and difficult for non-technical staff to use. Moreover, it produced output that was sometimes inaccurate (because of measurement errors in the bedside monitors), and more cumbersome than the worksheets that had previously been produced by the nursing staff.

Computerized patient monitoring remains an ambitious application area, with a high risk of failure. However, successful systems have been reported.²⁰ Methods of trend detection and predictive monitoring need to be developed for further substantial progress to be made. But continuing research in artificial intelligence coupled with hardware advances hold out great promise for the next decade.

Automated anaesthesia

Automated anaesthesia involves computerized control of the process of drug administration during surgery. It is an application area of growing interest to anaesthetists.²¹ Automated process control is already a well-developed field, with many industrial applications which have relevance to anaesthesia. Nevertheless, in anaesthesia it raises a number of complex technical and medico-legal issues which have yet to be resolved.

Many predominantly mechanical anaesthetic systems – such as lung ventilators and anaesthetic

machines – have severe limitations which may be overcome by their successful submission to computerized control.¹⁶ The main difficulty lies in devising a control strategy suitable for computerized control. Closed loop control presently seems to hold the most promise for computerization; both open loop and hybrid systems are generally regarded as unsuitable.¹⁶

Closed loop control is already highly developed and reliable, but is dependent on the measurement of meaningful output variables.¹⁶ Unfortunately there is no easy choice for measurement of depth of anaesthesia.²¹ Moreover, not all drugs produce effects which are easily measured or controlled. Given the computer's need for precise instructions and data, this creates considerable difficulties. Probably best is to rely on the measurement of physiological functions which provide an inferential guide to the adequacy of anaesthesia.¹⁶

An anaesthetic machine has been developed with computerized control of fresh gas flows. Oxygen, nitrous oxide, and vapourizer flows are automatically adjusted by the computer using mass flow control devices. Flow rates are optimized by the computer using feedback techniques.

Computer-controlled anaesthesia offers a number of advantages over manual drug administration, at least in theory.¹⁶ The primary advantage is that the control of the drug effect is more precise. Additional benefits could include a reduction in the amount of drug used, fewer side effects, and speedier recovery. Automated anaesthesia could be especially useful for controlling the effects of drugs for which there is considerable variation in sensitivity among patients.

Despite nagging difficulties, automated anaesthesia has already started to produce concrete results. Considerable progress is to be expected in the next few years.

Clinical computer modelling

Computer modelling of physiological systems is used increasingly as a clinical aid. The computer is provided with a mathematical model of the behaviour of the subject, which it can use to predict the effects of a given course of action. Such models may be used to derive information which cannot be obtained directly, and they can be used for predictive purposes. Thus it is possible to explore the

likely results that will accrue from the different courses of action available before clinical decisions are made.

A program called "MacPuf" has been developed to model the effects of variations in ventilation on blood gas changes.²¹ A number of other programs have also been developed for both anaesthesia and intensive care.²² A computerized model of respiration in intensive care patients was found to be sufficiently accurate to be of limited use in patient management.²² Two highly developed models of the respiratory system have been developed.^{23,24} Computer simulations have also been used to study gas exchange during anaesthesia.²⁵

There are, of course, definite limitations to mathematically based computer models. Because so many variables – such as psychological factors – are essentially unquantifiable, accuracy will always be partial at best. The key to further substantial progress in computer modelling would seem to lie in advances in artificial intelligence research.

Computer-assisted learning

Computer-assisted learning (CAL) programs may be used to simulate clinical practice, to present educational material, to provide questions, to respond to students' answers and to score their performances. Programs vary in complexity from textual information presentation to complex case simulations.

Simple instructional programs (such as multiple choice questions, or information presentation) can be produced at the local or departmental level without incurring excessive programming costs. Moreover, any computer will prove adequate to cope with such applications. But while the demands made of the computer and programmer may be small, a considerable effort is required from the person assembling the information or questions.¹

Case simulations involve the use of computer modelling in much the same way as clinical modelling. The user has complete control over a number of variables (such as drug dosages), much as he would in real life, while the computer continuously determines the status of the patient according to the mathematical model provided. This type of simulation is already in widespread use in other fields.

The use of computer simulations allows a degree

of realism not possible with other CAL methods. While computer models are generally not accurate enough to have more than a limited clinical role, they are certainly good enough for educational purposes. Moreover, these programs are able to simulate clinical conditions that cannot always be experienced by the learner in practice. However, in view of their idealized nature, it is important not to let computer simulations serve too great a role as a substitute for actual operating room experience.

Case simulations require sophisticated programming, which means that the expense involved will be hard to justify unless it is shared among many users. As a result, such an application is best undertaken at the departmental level only if it is likely to be used by a large number of students. A possible alternative lies in professionally produced software packages. These are already available,¹ but tend to be over-priced. However, with increasing demand and competition, the cost of such software is likely to drop considerably.

CAL has numerous advantages over a conventional teaching arrangement. Firstly, the computer is a tireless teacher, which will work at the student's convenience, and perhaps reduce the required teaching time.¹ Teaching programs can usually be used with a minimal knowledge of computers, and the visual presentation of information on a screen has proved to be highly effective.²⁶ In addition, students can learn at their own rate and the anonymity of the situation avoids embarrassment when in error. Moreover, there is evidence that teaching programs can improve clinical decision-making ability.²⁷

Computer-aided instruction is probably best used as a supplement to traditional teaching methods, rather than a strict replacement. This allows for the fact that, by their very nature, such programs tend to present information in a factual, unqualified form which is remote from the realities of clinical practice.²² Moreover, not everyone responds well to this type of learning. Those who are unaccustomed to keyboard interaction with a computer may find the whole process cumbersome.

CAL is a widely acknowledged tool in many fields, including medical education. Although its use in anaesthesia has so far been limited, it is likely to increase dramatically in coming years. The ready acceptance of a computer-based learning program has been reported.²⁶ At a meeting in Australia, 90

per cent of anaesthetists were favourably impressed by the teaching programs that were shown.²⁷

Consultation systems

Despite the growing role of computers in many areas of medicine, they have yet to assume a major active role assisting the physician in planning the medical management of his patients.¹¹ However, advances in artificial intelligence research promise to change this. Expert systems have already been developed that can perform quite accurate medical diagnoses within limited domains. In such programs, the computer attempts to simulate the physician's decision-making process in order to arrive at similar conclusions.

MYCIN, which diagnoses blood and meningitis infections, was the first medical expert system developed. It uses a relatively small set of IF ... THEN production rules to link observation with conclusion. An evaluation showed that its diagnoses were judged equal or preferable to those of four doctors in cases for which it had production rules.²⁸ Another early diagnostic system, modelled strongly on MYCIN, is PUFF. It uses patient data as well as measured values from a patient's inhalation into a tube to infer a respiratory diagnosis using a number of IF ... THEN production rules.

While early medical consultation systems tended to emphasize diagnosis, more recently there has been greater interest in critiquing. It is clear that computers will not be able to diagnose all problems within a given domain for a considerable time. Thus, critiquing programs, which suggest possible alternatives to a given management plan rather than dogmatically stating a single plan, seem a reasonable course. This allows physicians to make their own decisions, but then methodically checks the management plans, suggesting alternatives where appropriate. The advantages of critiquing over diagnosis are many.²⁹ Firstly, the computer is likely to be perceived as an ally rather than a competitor. Secondly, the physicians will only turn to the computer after forming a conclusion, and they make the final decision. Finally, critiquing recognizes that medicine is as much art as science, and allows for individual styles of practice.

Anaesthesia offers a number of advantages as a domain for a consultation system.¹¹ It has a single major decision point before the start of the operation where a number of management decisions must be

made. Moreover, the management alternatives are limited in number, with many options presenting clear-cut risks and benefits in the presence of particular diseases. In short, the nature of anaesthetic decision making is relatively well-suited to the centralized, binary personality of the computer.

ATTENDING^{11,29} is a consultation system which critiques a preoperative plan for anaesthetic patient management. The program accepts as input the patient's medical problems, the planned surgical procedure, and the anaesthetic management plan, outlining the agents and techniques to be used at the different stages of the operation. ATTENDING then produces a critique of the plan in English prose, including a discussion of the underlying management principles involved. It mentions both positive and negative aspects of the plan, suggesting alternatives where appropriate. The program can accept almost any plan and still produce an organized, focussed critique.¹¹ Like all expert systems, ATTENDING took a considerable amount of time to develop, and has definite limitations – notably in the range of techniques and underlying medical problems that it can deal with. But in spite of these limitations, it has been found clinically useful.¹¹

Anaesthetic consultation systems are still in their infancy, and many problems have yet to be resolved. Again, the answers must come from advances in artificial intelligence research, and further advances in traditional computer technology. But while such consultation systems are presently too costly to be put to widespread clinical use, it is clear that the first step in this direction has already been taken.

Conclusion

The potential use of the computer in anaesthesia is clearly enormous. Conventional applications, such as record management, department organization, and computer-assisted learning, are already well-developed. Although their use is not yet widespread, such applications are well within the limitations of current computer technology. They can generally be undertaken economically, and – given careful and realistic planning – with a reasonable chance of success.

More exotic application areas, such as patient monitoring, automation of anaesthesia, and consultation, are still in the early stages of develop-

ment. Although limited success has been achieved, these applications are clearly not ready for widespread use. There remain a number of technological, medical, legal, and economic obstacles that need to be overcome before feasibility can be established. Foremost amongst these is the relatively undeveloped state of artificial intelligence research. Advances in this field will hopefully provide many of the requisite capabilities such as knowledge representation, learning, pattern recognition, and natural language comprehension.

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