Understanding and selecting monitoring equipment in anaesthesia and intensive care

C.E. Hope MB CH B FRCPC,
D.L. Morrison MD M ENG FRCPC

"I think we both became very much more skillful in our jobs than we otherwise would have become, owing to this competition, but it was particularly due, I think, to the detailed attention which we had to put upon the patient by the careful recording of the pulse rate throughout the operation." – Harvey Cushing, 1920

This quotation is taken from a letter from Cushing to F. A. Washburn, recounting the involvement of E. A. Codman and himself in an "early clinical trial" in 1894.[1] This event almost certainly laid the foundation for the future of anaesthesia record systems and the need for clinical measurement and recording and may be considered the beginning of modern monitoring as we now know it.

Patient monitoring systems serve three main functions.[2] First, they protect the patient by ensuring that variations in a physiological variable beyond an acceptable range are immediately apparent to the attending physician. Second, they indicate the pattern of response to therapy so that modifications may be introduced as required. Finally, they provide data from which advances in treatment modalities may be developed.

It is important to clearly understand the difference between "measuring" and "monitoring." To "measure" means "to ascertain the extent of quantity." To "monitor" means "to remind or give warning"; – "to maintain regular surveillance over"; – "to maintain constant observation and vigilance".[3,4] Monitoring is not merely the process of measurement or collection of data; it involves the analysis and interpretation of the data which has been collected. As yet, this cannot be carried out without human intervention.

Since the Second World War, the rapid development of medical electronics has led to the introduction of equipment which can monitor and record without the necessity for the immediate presence of the clinician. The enormous advances in computer technology have further extended the application of instrumental monitoring in clinical practice.

This paper will review the development of monitoring techniques in anaesthesia and intensive care, describe the technology which is presently available and highlight potential pitfalls of which the end-user may not be immediately aware. In addition, the direction which new developments should take will be examined, and the criteria for selecting monitoring equipment will be tabulated in order that those with the responsibility for choosing new equipment can minimise the possibility that their equipment will be incompatible with future developments.

Finally, the questions of why, what, and how we should monitor are of great importance, but cannot be addressed in this brief review. The options to be chosen and the criteria for determination of minimum monitoring requirements are, in the end, a matter for the responsible physician to decide in the light of recommendations which gain wide acceptance in the profession, perhaps with the guidance of such bodies as the Canadian Anaesthetists' Society, or the Anesthesia Patient Safety Foundation in the United States.[5]

Basic requirements for a patient monitoring process

The five basic components of a patient monitoring

From the Department of Anaesthesia, Victoria General Hospital and Dalhousie University, Halifax, Nova Scotia B3H 2Y9.

TABLE I Bio-electric potentials acquired with electrode systems

Signal	*Frequency range**	*Amplitude*	*Sample rate*
ECG	0.1–100 Hz	1 mV	200·sec^{-1}
EEG	0.5– 70 Hz	50 uV	140·sec^{-1}
EMG	10.0– 70 Hz	100 uV	140·sec^{-1}
EOG	d.c.–120 Hz	0.5 mV	240·sec^{-1}
SEP	d.c.–120 Hz	50 uV	240·sec^{-1}

ECG – electrocardiogram; EEG – electroencephalogram; EMG – electromyogram; EOG – electrooculogram; SEP – sensory evoked potentials (visual, auditory, sensory). (After Hill DW[14].)

*The frequency ranges given are those most commonly used in monitoring applications. Much higher frequencies may be indicated in research or in precise investigative and diagnostic applications – e.g. EEG related applications (EEG, SEP, etc.) = 5 kHz; EMG = 100 kHz.

process are signal generation, data acquisition, data transmission, data processing, and data presentation or display.

Signal generation – the patient

In patient monitoring systems the patient, who is the source of all monitored information, has to be connected safely and reversibly to a piece of equipment. In order to design the sensors for bio-electric signals and transducers for physiological events such as pressures and flows, it is essential that the factors which affect the functional integrity and safety of the man-machine interface are appreciated. Regardless of the sophistication of transducer technology, each system has its advantages, its disadvantages and its limitations.

Data acquisition

Data acquisition includes the collection of data and may involve both data transduction and data conditioning.

For reasons of convenience, and because of space limitations, reference will be made in this review primarily to the measurement and monitoring of the electrocardiogram (ECG) and blood pressure (BP). These are commonly monitored variables, and are excellent examples of the two general classes of monitored variable.

The first class, represented by the ECG, is that which generates bio-electric potentials, and can be detected directly, usually by electrodes applied to the skin which are then attached to amplifiers (see Table I). The second class, represented by BP, is that which does not generate bio-electric potentials, but which requires specialized transducers in order to generate an electronic analogue of the signal (see Table II).

Before these variable measurements can be analyzed and interpreted, they must be prepared, or conditioned, in some manner, usually with the use of amplifiers, filters or conversion to a digital format.* Data conditioning may be considered in two stages, namely, pre-conditioning and conditioning proper.

Pre-conditioning is the process whereby a source

*From: Morrison DL. Criteria for Selection of Patient Monitoring Equipment. Canadian Anaesthetists' Society Atlantic Regional Meeting. St. John's, 1983.

TABLE II Biological signals requiring specialised transducers

Signal	*Frequency range**	*Transducer*	*Sample rate*
Anaesthetic and respiratory gases	d.c.–5 Hz	Mass spectrometer	10·sec^{-1}
Blood pressure (pulsatile)	d.c.–30 Hz	Strain gauge	40·sec^{-1}
Blood flow (pulsatile)	d.c.–30 Hz	Electromagnetic, ultrasound	60·sec^{-1}
End-tidal carbon dioxide	0.1–5 Hz	Infrared	10·sec^{-1}
Force displacement	d.c.–100 Hz	Strain gauge	200·sec^{-1}
Oxygen saturation	d.c.–30 Hz	Opto-electronic	60·sec^{-1}
Oxygen tension	d.c.–1 Hz	Polarographic	2·sec^{-1}
Pulse	d.c.–30 Hz	Opto-electronic	60·sec^{-1}
Respiration	0.1–5 Hz	Impedance, ultrasound	10·sec^{-1}
Temperature	d.c.–1 Hz	Thermistor, thermocouple	2·sec^{-1}
Ventilation (esp. high frequency)	1–20 Hz	Pneumotachograph	40·sec^{-1}

(After Hill DW[14]).

*Where analogue waveforms are pre-processed (e.g. pulsatile blood pressure to systolic and diastolic signal levels; electrocardiogram to a heart rate signal) the frequency ranges and the sampling rates can be much lower. Such pre-processing may increase efficiency but may lead to loss of detail and prevent further analysis.

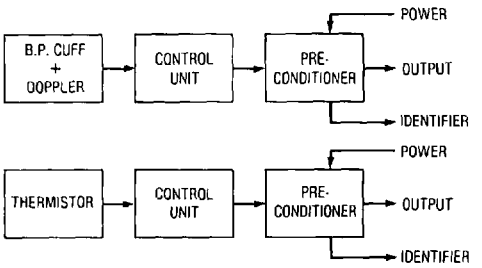

FIGURE 1 This illustration shows how the output from dissimilar transducers is converted by pre-conditioning into a standardized form, complete with an identifier indicating the source and type of information contained in the signal. There are only three intrinsic pathways between the pre-conditioner and the main monitoring system. Adapted from: Morrison DL, Criteria for selection of patient monitoring equipment. CAS Atlantic Regional Meeting; 1983.

signal is converted into a standardised format suitable for a common conditioning process (Figure 1). This is somewhat similar to the pre-amplification of signals in an audio amplifier. However, in the former case the signal may be in either analogue or digital form. The component parts of the circuitry for different transducer systems are similar, although not interchangeable. If the pre-conditioning circuity is integrated with the main monitoring chassis, the device will remain dedicated and to a degree rather inflexible or at least inconvenient to use (Figure 2A). Many stand-alone monitors follow this approach.

If the pre-conditioning circuitry, with the associated transducer control system and power supply, is integrated with the transducer itself, one has the basis for a modular system which can be easily re-configured to suit any particular monitoring requirement (Figure 2B). It is also possible to extend (or upgrade) a system as new developments occur without the need for major reorganization and expense.

Conditioning is a procedure in which a signal is operated upon for the purposes of transmission, processing (analysis), storage or display. If the signals have been appropriately pre-conditioned, they will all have the same format, and will be labelled with some form of internally coded identifier. Thus, they can all be handled in a uniform, generalized fashion by the rest of the monitor system, resulting in much greater flexibility of the overall system, while reducing its design complexity.

Data transmission

Before the data collected from the patient can be used, it must be transmitted to the next part of the system. This can take place at several points, as the input to, within, or as the output from the "monitor." The descriptions which follow apply equally to data transmission locally within the "traditional" bedside monitoring unit and to larger integrated systems including those with remote analogue and digital processing equipment for data processing and display. Whether the data transmission should be in analogue or digital form is beyond the scope of this paper. However, the clinician should have a clear understanding of what is meant by "analogue" and "digital" and be aware of the limitations of each.

Analogue signal transmission involves the use of a physical quantity (voltage, weight, length, etc.) to

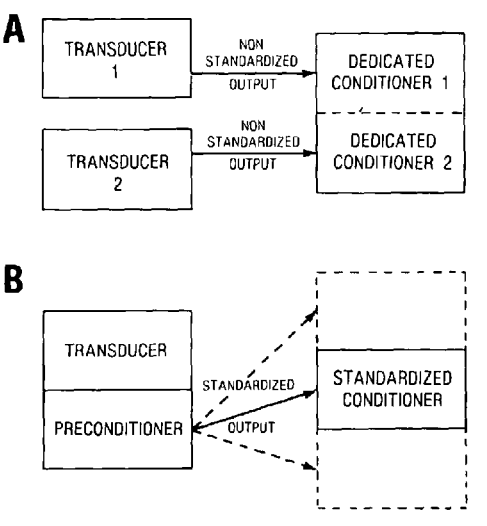

FIGURE 2 Where there is no pre-conditioning circuitry, dedicated conditioning units specific to each type of transducer are required for each data channel in the monitor system (A). Combining pre-conditioning with the transducer, its control system and power source, permits any transducer system to be used with any of the standard data channels in the monitor "mainframe", giving great flexibility to the system. Adapted from: Morrison DL, Criteria for selection of patient monitoring equipment. CAS Atlantic Regional Meeting; 1983.

represent the value of the source signal. Common examples include the electrocardiogram tracing, or the blood pressure or peripheral pulse waveform, whether they are presented as tracings on recording paper or on the screen of an oscilloscope. An analogue signal flows continuously and without interruption.

Digital signal transmission, on the other hand, involves the transmission of codes which are used to represent the "numbers" or the value of the signal. The digital representations of the source variable are usually presented at regular intervals of time. Signals transmitted in digital form are thus made up of discrete data points.

Current technology favours the digital format heavily for a number of reasons. One of the most important of these includes the opportunity to prevent "noise" and signal distortion. In addition, with digital data it is possible to correct errors relatively easily. For the physician, the digital format offers particular advantages for the isolation and protection of patients from electrical hazards. Thus, increasingly, the physician is being brought into contact with devices and equipment which operate using digital technology and logic.

Data processing – the manipulation of the acquired information

Man has a number of advantages over the machine when it comes to data processing.[6] He can make inductive decisions, can generalise from few data in new situations and can handle overload situations without disruption. However, unlike the machine, he is not efficient and not accurate when involved in computational situations such as are required for the determination of secondary haemodynamic variables from source data. He has a poor short-term memory and is unable to accept and handle high information flow rates.

These factors have to be remembered when considering the methods of data manipulation and processing and in the recording or display of the monitored variables. Inevitably the source signals have to be treated or analyzed in some way to obtain the numbers from which variations in therapy can be planned.

Electrical signals representing physiological variables are frequently contaminated by electrical interference. This interference may originate from the patient, the environment, or from the instrumentation itself. Electronic filtering techniques are used (low pass, high pass and notch filters) to remove this unwanted "noise". Likewise, when signals have been digitized, mathematical techniques (digital filters) are used to the same end. Usually this aspect of data processing is of little concern to the user, but it is important that the frequency content of the signals which are to be used for display or further analysis is known. A good example is the "monitor" filter on many ECG monitors, which will seriously distort the S-T interval, leading to false interpretation of this feature of the ECG, if the user is not aware of the filter setting.

Trends, prognostic techniques which develop indices representing a patient's condition, and trend prediction using mathematical modelling are precise, complex mathematical and statistical processes which should not be used lightly. If the manufacturer's representative suggests that "trend" plots are available, it is important that the user understands what is meant. Often "trend" is used loosely; usually all one is being offered is a simple graph.[7]

Data presentation and display

Data presentation and display deals with the machine–man interface, and relies on the use of vision and audition as the main interface sensory channels. Display itself may be accomplished either by visual presentation of the measured variables on a display screen (oscilloscope, cathode ray tube (CRT), etc.), or as "hard-copy" as a paper recording or print-out.

In the early days of monitoring, analogue techniques were used to display both the source waveforms and any initial transformations. Oscilloscopes used either "bouncing-ball" or prolonged intensity or storage display techniques; meters (voltmeters, ammeters) were fitted with appropriate scales to permit direct read-out of rates, pressures, and temperatures. Flashing light displays were often fed current varying in intensity with the variable being displayed, thus permitting an analogous visual presentation. More recently, the emphasis has been on the use of digital technology regardless of whether the presentation is in "analogue" or "digital" form.

Analogue to digital conversion

Analogue to digital conversion is carried out with an analogue to digital converter (ADC). It is the ADC

which converts the source analogue signal to a digital representation of the original. While there are many processes involved, and while many different types of ADC exist, the most important factors to be considered are the rate or frequency at which the conversion occurs and the degree of discrimination which is possible during the conversion process.

Analogue signals represent a continuous measure of the variable signal. When such continuous signals are fed to an analogue to digital converter, they are sampled at a frequency determined by the program controlling the ADC (in modern monitoring equipment this is usually chosen or decided by the equipment manufacturer).

In order to faithfully represent an analogue periodic waveform in digital form, it is necessary to sample the waveform at a rate which is at least twice as fast as the highest component of the waveform which must be preserved. Thus if it is accepted that the majority of information of value in the electrocardiogram is contained in the 0–100 Hz spectrum, then it would be necessary to sample this waveform at a rate of at least 200 Hz. It should not be higher than is necessary for the task desired, in order to avoid overloading the processing system both with regard to temporary or permanent storage requirements or unnecessary data reduction techniques. To minimise the likelihood of what are known as aliasing errors, it is usual to include a low-pass filter in front of the ADC to remove signal components with a frequency content in excess of those required.[8]

In addition, it is necessary to keep the analogue signal within the limits of the ADC to ensure that no data are missed (Figure 3). Furthermore, many analogue to digital converters have full scale input ranges spanning 10 V, while the analogue signal to be sampled may be obtained from a module with a 1 V full scale analogue output. The actual signal amplitude may be less than this. In such situations, conditioning is required to ensure that the signal can use the full range of the ADC. In order to avoid the need for operator adjustment, an ADC with a bit length* which will provide sufficient resolution of low amplitude signals is used.

*A "bit" is a BInary digiT. In the binary number system, only the digits 1 and 0 are used. From a string of bits, all numbers can be represented. A binary number of four bits (1111) can represent 16 decimal numbers, 0 through 15.

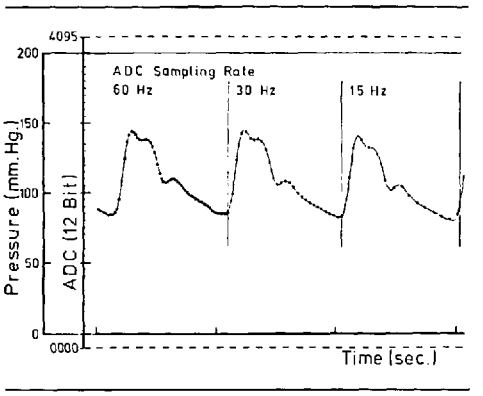

FIGURE 3 Three BP waveforms are used to illustrate the process of analogue to digital conversion. The abscissa ("X" axis) is in seconds. Of the two ordinate ("Y" axis) scales, one represents the 4096-point resolution of a 12-bit ADC. The second shows a pressure scale of 200 mmHg, aligned within the limits of the ADC, for accurate measurement over the 0–200 mmHg range. The dots represent sampling times. Joining the dots with straight line segments would emphasize how lower sampling rate results in inaccurate reproduction of the information. It can also be seen that the fast-rising ascending part of the waveform requires faster sampling to obtain sufficient data for reproduction or analysis.

This potential limitation is not seen to any significant degree with modern monitoring equipment using full digital technology and modular design. To attempt to perform such processes with an ADC of less than 12-bits might lead to loss of vital information (Figure 3). Examples of common signals and their frequency content and minimum ADC sampling rates are given in Tables I and II.

Analogue versus digital display

The question which must now be answered is: "What is the most useful display for the observer who has the responsibility of reacting to changes or trends in the value of the measured variable?" The technology used to obtain the display is largely irrelevant; the presentation, however, is not!

Analogue displays vary in time continuously, simulating the source variable or transformation which they represent. Thus the movement of a needle or pointer across a scale or the height of a bar-graph type of display varies according to the magnitude of the source variable. Good examples of analogue displays are seen in sphygmomanometry – the height of the mercury column, or the position of the needle on the aneroid manometer:

these give a clear image of the magnitude of the blood pressure, without the need for much interpretation.

Digital displays, on the other hand, present numbers to the observer, and these numbers usually flash or change repeatedly and at regular intervals. The frequent output of such numbers may be confusing in that the trend of a variable, if it exists, may be lost in the detailed representation of naturally occurring homeostatic fluctuations. This is in part due to the fact that man tends to have a poor short-term memory for digital information, particularly when high information flow rates are involved. Moreover, he must mentally, or physically, reconvert the data into a graphic form to interpret the trends. For such activity, machines are much more efficient.

Thus, for variables in which the absolute value is of greater importance, or changes with time are minimal, digital display is optimal. For values which are changing rapidly, or for which comparison with previous measurements or patterns are more informative, analogue display is preferable.

Patient data management systems – the potential for automation

The purpose of transferring waveforms, graphs and trends of monitored variables to a paper recording system is to obtain a permanent record for archival purposes and as a baseline from which future events, and the processes leading to them, might be assessed. The 12-lead ECG, or the rhythm strip, is an example which has been available for many years.

Twenty-five years ago, it appeared inconceivable that the technological power would become readily and economically available to provide automated patient information systems, as large main-frame computers were required, together with cumbersome storage devices such as tape recorders, for even a few bed locations.

With the advent of micro-computer technology, and in particular the Large Scale and Very Large Scale Integrated Circuit (LSI, VLSI) technology, micro-processor and micro-computer techniques are now utilised at all levels of data acquisition and processing. Very compact high speed devices which store enormous amounts of information are proliferating. It is now practical, and cost-effective, to plan for and to create patient data management systems which will not only accept all electronically measured variables and laboratory data, reports, and demographic data, but also interpret and analyze this information. Through database, spreadsheet, and mathematical and statistical transformations, critical events can be identified and differential diagnoses suggested. The calculations required for detailed and complex therapeutic regimes involving antibiotics, fluid and electrolyte balance, and vasoactive drug manipulations, can be done automatically.

Many hospitals are now actively developing computer-based management information systems, with patient database technology replicating, if not replacing, the traditional hospital chart. The interested and informed physician can use these systems to the advantage of both himself and his patients, if the equipment obtained to measure physiological variables in areas such as the operating room and the intensive care unit has the capacity to link with these wider database systems.

The technology exists to permit monitoring systems to interact with other biomedical equipment such as automatic lung ventilators and infusion pumps in a manner which would permit these devices to respond to physiological changes outside a given pre-set range. However, discussion of these exciting possibilities is beyond the scope of this review.

Safety, standards, and the future

The anaesthetist is intimately involved in the setting of standards for anaesthesia equipment and for safety in the anaesthetizing location. Similarly, it is essential that the anaesthetist, the intensivist, and others who are intimately concerned with the application of electronic monitoring techniques remain involved in the research, the development and the identification of standards for future monitoring equipment.

The standards which are of vital importance to the physician are not always those that regulatory bodies demand of the manufacturer. The standards which are of importance to the physician are the separate functional standards which will result in an effective and manageable man–machine interface, which in addition will be both safe and cost-effective (Tables III and IV).

Safety requires that total patient electrical isolation is achieved between the pre-conditioner and the

TABLE III General selection criteria for monitoring equipment

Accuracy
- all measured variables should have accuracies of 1% or better

Analogue outputs
- source analogue signals should be available for output to other equipment – particularly recording and digital computing equipment. This is particularly vital in facilities where research is contemplated
- control signals should be available for such purposes as cardioversion, intra-aortic balloon counter-pulsation and lithotripter synchronism
- any delays in signal processing which are inherent in monitor design should be identified. Should these lead to delays in the availability of synchronization pulses, interfacing may be problematic

Approval
- should have the local government's designated inspection process completed, e.g., Canadian Standards Association (CSA), Ontario Hydro inspection, etc.

Baseline stability
- devices such as pressure transducers should have baseline drifts of less than 1% per day, and should normally be self-correcting. Drift rate limits should be specified

Cautery suppression
- all data paths, not just ECG, should be protected against electrical interference, particularly electrocautery and bipolar cautery

Digital features
- should have 16-bit architecture for speed and accuracy
- should interface readily to PC type microcomputers via both RS-232-C and LAN communication
- should interface to patient information systems
- should interface to the user's hospital patient information system simply and directly
- software and data protocols should be available to the end-user and should conform to international standards – e.g., ASCII, DIF, etc.

Display formats
- both digital and analogue displays should be available on the display screen. Both must be large enough for plain viewing at a distance
- display intensity should automatically adjust for room brightness
- high resolution colour displays will help decrease confusion between adjacent channels

Hard copy
- provision should exist for hard copy output or recording of both digital and analogue data and waveforms. This should be available through standard interface cable connectors on the rear of the monitor chassis

TABLE III Continued

Information preservation
- momentary power failures can lead to loss of any stored data in the memory system of a monitor, or it may be necessary to disconnet a monitor in order to move it. Stored information (alarm limits, trend data, etc.) must be maintained for a reasonable time period in this event

Modular design
- a measured variable should be capable of accessing any data channel
- should normally have 6 data channels as a minimum, and be easily expanded from basic configurations to an expanded configuration as required
- should be sufficiently flexible to accept all foreseeable future advances without major replacement of basic monitor being required

Power isolation
- patient connections should all have full optical isolation or an equivalent totally non-conductive pathway for patient electrical safety (See Table V)
- patient connected devices should have fully isolated power systems for each transducer which is connected to the patient

Rugged construction
- units must be able to stand up to the rigours of the operating room and the intensive care unit. (Units will inevitably be bumped, have solutions spilled on them and be dropped on the floor – if all else fails)
- units which can be easily wiped clean for disinfection, with no obstructions such as buttons and knobs have definite advantages

Service
- rapid servicing should be available by simple replacement of printed circuits, etc., which should be available locally

Signal conversion
- analogue to digital conversion should use at least 12-bit conversion technology
- conversion or digitization rates (sampling rates) must allow for accurate waveform representation on all data paths. This will require a sampling rate which is at least twice the highest harmonic of interest times the fundamental frequency (Table II)

Transducer
- should accept a range of transduceers, not only those of the original equipment manufacturer

remainder of the system. As more invasive monitor techniques are used, along with more electronic surgical instrumentation, the risk of patient morbidity related to electrical shock increases. Catheter systems which create potential conductive pathways directly to the heart, such as the balloon flotation catheter, are a serious concern. The potential danger will increase with each electronic device connected to the patient, unless each and every instrument is fully electronically isolated, whether or not it is a monitor. "Microshock" – currents in the range of 10 uA to 10 mA can be fatal when applied directly across the myocardium. This may occur when central pressure lines placed in or near the heart act as a pathway for fault or leakage currents arising in one or more of the instruments connected to the patient. Various techniques used to improve electrical safety are outlined in Table V.

The utilization of non-invasive modalities whenever possible will further reduce the risk of increasing morbidity or mortality from the monitoring process itself, whether due to the electrical hazards, or other dangers such as infection.

Design standards which require that the source signals be transformed into standard data formats through pre-conditioning circuitry, and communication protocols which conform to standards established in the wider and larger computer communication field, such as those for local area networks (LAN) would simplify interconnection of diverse monitor equipment of various manufacture.

Finally, the economics of monitoring have to be considered. If the above requirements for compatible data and communication protocols are fulfilled, the best possible level of compatibility between monitoring equipment of different types and from different manufacturers will be assured. This should optimise the capital, operating and

TABLE IV Selection criteria for monitors – specific measurement features

ECG
- full multi-lead selection
- automatic indication of which lead is off or broken, or automatic selection of an alternate lead
- electrocautery suppression for operating room use
- arrhythmia detection for ICU use

Gases
- end–tidal carbon dioxide should give accurate information regardless of the anaesthesia or lung ventilator circuitry which is used
- inspired oxygen analysis should be available
- pulse oximetry or arterial oximetry should be available, should continuous measurements of oxygen uptake be required
- anaesthesia gas concentrations would be a desirable feature

Haemodynamic monitoring
- pressures, measurement of cardiac output, blood temperature and blood gas saturation data should be combined automatically to produce commonly used haemodynamic indices

Neurological data
- EEG with compressed spectral array and/or evoked response technology should be available for cerebrovascular anaesthesia for specialised applications

Pressure
- range, label and alarm flexibility to allow for arterial, pulmonary, intracranial or other pressure measurement. Alterable time delay and amplitude alarm systems for certain variables (e.g. ICP). Should be provision for non-invasive pressure measurement

Temperature
- should be available either separately, or from other sources such as pulmonary artery catheter and urinary catheter temperature transducing systems

TABLE V Safety techniques for electrical hazards

Battery powered equipment
- battery powered equipment which is not connected to power lines, ground returns or data lines has a greater safety potential provided the battery voltages are low enough to preclude significant fault currents

Equipotential ground systems
- these seek to keep return pathways all at the same potential, so that no fault currents will tend to flow through alternate return pathways connected to the patient. They are difficult to implement, cumbersome to use, and are usually defeated by the presence of magnetic induction fields

Isolation transformers and ground fault interrupters
- these protect against "macro-shock" hazards (>10 mA) and electrical spark hazards which might cause explosions in the presence of flammable agents. They do not protect against "microshock"

Optically coupled isolation units
- these probably have the greatest safety potential, provided the same degree of isolation is provided for the power supply as for the data path. This is usually achieved by an air core induction coupling mechanism. Equally important, there must be full physical isolation, to preclude the possibility of conductive materials (e.g., IV fluids) bridging the gap

maintenance costs of the system, however it is configured, and will facilitate growth and expansion rather than requiring regular and costly total replacement.

The need for regular routine inspection and maintenance to ensure that monitoring equipment continues to function reliably, accurately, and safely at all times, is essential, and cost allowance for this must be included as part of the hospital budget. Neglect of this policy invites legal action, with far greater costs.

Choosing equipment – some guidelines

It is difficult to give specific guidelines as to which monitoring equipment to purchase, given the number of suppliers. One major consideration should be the local availability of repair service for monitors. If local service is not available, suppliers should be willing to provide the hospital biomedical engineering department with a set of back-up modules on site, and the necessary training program to allow the hospital personnel to provide servicing. Even so, it is still desirable that the supplier have a strong local organization. The frequent response of "only a few hours by air" is, in practice, inadequate.

This paper has one main objective, namely, to give the reader the basic background required to ask appropriate questions which will assist in making correct decisions, concerning monitoring equipment. It is always appropriate to seek advice from biomedical engineers concerning the technical points, but the anaesthetist or intensivist must retain the prerogative to choose those monitor systems which best fill his needs. A number of monographs which deal with monitors in some detail are included in the references.[9–13]

As an aid to organizing a comparative "check list", Table III is included to outline most of the general features to look for. A number of specific and more specialized features are shown in Table IV. One should always be wary of "comparative" lists prepared by manufacturers, which are often biased to emphasize those features possessed only by their product. Frequency of repair statistics should be available, and should preferably be verified directly by other users of the equipment. Reliability, versatility, and adaptability should outweigh initial cost, as monitoring equipment must increasingly provide very extended service.

Summary

Techniques for sensing, acquiring, processing and displaying physiological variables used to assist the process of monitoring in anaesthesia and intensive care have been reviewed. The role of instrumental monitoring in clinical practice and the comparative effectiveness of Man versus Machine has been outlined. Future developments in monitoring in clinical practice have been identified. It is important that physicians stay abreast of developments in the technology of measurement and monitoring instrumentation so that they not only assist in the development of standards but also have a complete understanding of the precision and real usefulness of any given item of equipment. To this end, guidelines have been tabulated which may permit those who have the responsibility for acquiring updating or using monitoring equipment, to more completely examine the features of any apparatus which is being considered for purchase.

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