EDITORIAL

Monitoring, Instrumentation and Anesthesia

MONITORING the clinical condition of the anesthetized patient has been an integral part of the practice of anesthesia since the time of Crawford Long, Horace Wells, and Morton; but until the early days of the present century, such monitoring consisted mainly of the anesthetist's use of his own five senses and powers of observation to appraise the situation of the patient in terms of skin color, quality of pulse, respiratory activity, and the like. The use of instrumentation to facilitate monitoring was introduced by Harvey Cushing, who, on a trip abroad to Padua, discovered a simple blood pressure recording instrument in use in Riva-Rocci's clinic. On returning home to Boston, he utilized this device during the course of neurosurgical operations and then reported his technique of monitoring in 1903 in a paper entitled *The Routine Determination of Arterial Tension in Operating Room and Clinic.* It is an interesting coincidence that the basis of modern instrumentation in anesthesia occurred at almost the same time through DeForest's development in 1907 of the triode vacuum tube, which has permitted the construction of electronic equipment that could amplify the weak electric signals from the body (the heart and central nervous system, for instance) to usable voltages.

Thus, as long as fifty years ago, the essential ingredients of a modern monitoring system in anesthesia (sensing units, amplifiers, and recorders) were being developed; yet it has been only in the past decade or so that the fruition of these developments has permitted the widespread employment of such apparatus. Indeed, even ten years ago, the use of the electrocardiograph in the operating room was a rarity; today, this usage is almost commonplace, and the electrocardiograph is being joined by the electroencephalograph, the ventilometer, the oximeter, the carbon dioxide analyzer, and a whole host of new instrumentation. Waters' classic dictum that the responsibilities of a department of anesthesia are to provide clinical service, to teach, and to engage in research, in that order, have been totally reversed in the development and use of monitoring equipment. Almost all of these instruments have been employed first for research; then later to demonstrate certain points for teaching purposes; and only finally to monitor the normal clinical conduct of anesthesia. Nevertheless, while it is true that such equipment has been developed and employed first for research and in the large teaching hospitals, it is also true that it is the history of research instruments that, if they meet a common need, they will become simplified and applied to the day to day practice of medicine.

The philosophy of instrumentation and monitoring in anesthesia has had varying origins. One approach has been toward the development of instruments that would monitor automatically certain physiological parameters which ordinarily are recorded by the anesthetist himself in any event, and thus serves either to free the anesthetist of the task or to permit other members of the surgical team to check on the condition of the patient during operation. This is the approach contained in the multitude of pulse detectors that now are flooding the market; and it was also the basic philosophy inherent in the "physiological monitor," developed several years ago by the Bureau of Standards for the Veterans Administration, which recorded blood pressures, pulse rate, respiratory rate and volume, and the occurrence of arrhythmias.

A second, and perhaps less sterile, approach has been the application of available instrumentation from other fields of biology and medicine to the problem of monitoring in anesthesia. The measureable physical phenomena during anesthesia include: mechanical (heart and pulse beat, muscular tone and movement, movements of respiration); acoustical (heart and chest sounds); temperature (body and skin); pressure (arterial and venous blood pressure, respiratory pressure); light and radiation (dye dilution techniques for blood volume or cardiac output; oximetry); radioactive and nuclear (tracer dilution techniques for blood volume or cardiac output); magnetic (reactions in magnetic fields, as in the mass spectrometer); electrical (action potentials of heart, brain, nerve, or muscle; impedance plethysmography); and physico-chemical (blood *p*H; optical and electrical effects of oxygen and carbon dioxide in inhaled and exhaled air).

A third and neglected, but necessary, approach, which is only beginning to be undertaken, is the development of instrumentation for the monitoring of parameters that are of specific and unique usefulness to the anesthetist. Tremendous advances were made during and following World War II in basic and physical sciences, and the gap between technology and its medical application has widened enormously—particularly in the areas of sensing, recording, and telemetering of data. These technical advances will permit the development of methods of monitoring physiological and biochemical moieties for which the anesthetist may find an urgent need in the future on the basis of a new and broader knowledge of the effects of anesthesia and the trauma of surgery. Techniques for the continuous monitory of blood volume and cardiac output, for instance, are close to realization; and the monitoring of total peripheral resistance is surely a development of the near future. Above and beyond such foreseeable progress, however, is the fact that the final, definitive explanation of the anesthetic state may well be found to depend upon the interference with cellular enzyme systems produced by anesthetic agents; under such circumstances, it will become mandatory to the intelligent conduct of clinical anesthesia to monitor the patient in terms of the movement of such ions as potassium, sodium, calcium, and magnesium. These ideals are far closer to the possible than most anesthetists realize: the other disciplines, of biochemistry, physiology, physics, electronics, and engineering, are capable of adding a great deal more to the monitoring of the patient under anesthesia than they have been called upon to contribute up to the present time.

There are special problems involved in the development of instrumentation in anesthesia which must be solved before adequate monitoring systems can be made practicable. Space is at a premium in almost any operating room, and miniaturization of equipment is essential: the present unfortunate tendency of manufacturers is to attempt to adapt shelf models of their products to the unique needs of the anesthetist, and thus to clutter the already cramped space surrounding the operating table with a variety of cabinets, consoles, and carrying cases. Closely related to this problem is the combined nuisance and hazard of multiple leads and cables which are now the ubiquitous faults of monitoring systems in anesthesia: these can be resolved by either the application of telemetering or the construction of conduits, in the architectural design of operating rooms, which will contain the necessary wires for transmission in the floors and walls. A final, and more devastating, problem is the fact that many of the most commonly used, potent anesthetic agents are highly explosive; and that much, if not most, of the monitoring equipment in present day usage is electronic. The problem is by no means insurmountable, but it does require constant recognizance of the almost statutory edicts of the National Fire Protection Association. One solution has been to enclose electronic instrumentation for operating room use in casings that are tantamount to battleship steel in construction, which, while not guaranteed to prevent an explosion, are more or less certain to ameliorate and contain such an explosion; quite aside from the considerable expense of such cast-iron enclosures, their weight and size are the direct antithesis to desirable space saving miniaturization. A second solution has been to pressurize the interior of cabinets incorporating electronic monitors so that a constant egress of air will carry explosive vapors and/or gases away from the vicinity of the possible ignition source; this method, again, leads to increase in size of the instrumentation, and has also resulted in additional cords and hoses to encumber the operating room floor. Another approach has been to keep all voltages below the six to eight volt limitation; but of course all loss in gain of voltage is correspondingly associated with an increase in difficulty of development of such instrumentation. A fourth solution has been to remove all but the sensing units from the range of the explosive atmosphere; but in many instances this has also obviously served to remove the monitor itself from immediate usefulness. One little explored possibility is that of pneumatic instruments: in the field of industrial instrumentation and control, pneumatic instruments are available for measuring pressure, temperature, flow, force, movement and position, composition, and other parameters. They are said to be simpler, more rugged, and less expensive than electronic equipment—they certainly warrant the anesthetist's attention.

Monitoring has always been part of the anesthetist's art; instrumentation is now his necessary advancement to science.

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