Computers in Critical Care and Pulmonary Medicine

Edited by P. M. Osswald

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Edited by P. M. Osswald
in Cooperation with
O. Prakash, H.-J. Hartung and H. J. Bender

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Table of Contents

Application of Computer Systems in Critical Care
K. GEIGER 1

On-line Cardiovascular Applications of Microcomputers in Intensive Care
C. PRYS-ROBERTS 8

Organizing and Analyzing Clinical Information Using Table-Based, Graphics-Oriented, Interactive Computer Systems
B. J. RANSIL 17

An Attempt to Solve the "Information Explosion" in an Intensive Care Ward
D. J. PRICE, J. MASON, and S. SNOWDEN 23

Towards a Coherent Structure of the Anesthetist – Computer Interface
S. TRISPEL, H. KLOCKE, G. RAU, and R. SCHLIMGEN 29

Effect of Different Ventilation Patterns on the Intracranial Pressure in Neurologic Patients with Mechanical Ventilation
K. M. EINHÄUPL, C. GARNER, G. SCHMIEDER, G. KERSCHER, and R. WIECZOREK 38

Computer Applications in Pulmonary Function Testing
M. HEITZ 43

The Assessment of Gas Exchange by Automated Analysis of O_2 and CO_2 Alveolar to Arterial Differences: 3 Years Experience in Respiratory Clinical Physiology
P. PAOLETTI, E. FORNAI, A. G. NETO, R. PREDILETTO, S. RUSCHI, and C. GIUNTINI 57

Computers in Experimental Pathophysiological Research
R. SCHOSSER, H.-P. ENGEL, and K. MESSMER 66

Data Bases in Acute Medicine
T. J. STAFFORD, and R. BURNEY 75

Computerized Clinical Records in the Neurosurgical ICU with Self-updating of Some Biological Data
R. URCIUOLI, M. KNAFLITZ, G. BALESTRA, M. A. ARBINOLO, M. L. BELLERO, R. BERTINO, C. FRANCO, M. GESSA, and A. GUARNACCIA 78

Organization and Analysis of Data from Patients with Trauma and Hemorrhage
W. KELLERMANN, K. PETER, U. JENSEN, Y. SUMMA, and D. NEUMEIER 82

Computer Assisted ICU Monitoring
T. OYAMA, H. ISHIHARA, A. MATSUKI, M. YAMASHITA, K. ISOZAKI, and T. SUZUKI 96

Automatic Signal Analysis and Prediction in Intensive Medical Care
A. SWOBODA, and E. EPPLE 100

Artifact Processing in a Computerized Intensive Care Unit
W. BLEICHER, E. EPPLE, M. KOPP, and H. JUNGER 107

Personal Computers for Gas Exchange Measurements in the ICU
G. WIESSPEINER, S. SCHUY, H. METZLER, and W. LIST 116

Integration of a New Computer HP 9816S in the Pulmonary Calculator System HP 47804S. Advantages of Using the Screen for Graphic Presentation of Flow-Volume Curves
K. ERDMANN, and J.-P. JANTZEN 123

Measurement of Oxygen Uptake with a New Method
H. METZLER, G. WIESSPEINER, and W. F. LIST 130

A Microcomputerassisted System for the Monitoring of Cardiorespiratory Variables in the Critically Ill
K. HANKELN, and H. MICHELSEN 134

Selective Lung Ventilation
H.-J. HARTUNG, P.-M. OSSWALD, and H. J. BENDER 138

Automated Anesthetic Record Keeping
N. TY SMITH 147

Computer Aided Methods to Predict Perioperative Risks
U. FELDMANN, P.-M. OSSWALD, H.-J. HARTUNG, and H. LUTZ 162

New Tasks for Medical Informatics?
C. O. KÖHLER 184

Artificial Intelligence: the Expert Systems Approach to Medical Consultation
E. H. SHORTLIFFE, and L. M. FAGAN 190

Expert Consultation Systems in Medicine
P. L. MILLER 198

The Importance of Using a Computer to Provide Pediatric Anesthesia and Emergency Drug Information and Treatment Regimens in the Clinical Setting
D. J. ESSIN, D. L. WARNER, M. JAGODOWICZ, and S. N. STEEN 207

Computer Systems in Artificial Ventilations (New Techniques)
W. KOLLER, A. ALOY, N. MUTZ, and G. PAUSER 212

Series Dead Space Volume Assessed as the Mean Value of a Distribution Function
G. WOLFF, and J. X. BRUNNER 221

Evaluation of Indices for Respiratory Mechanics from an Automated System
B. FRIBERG, M. FORSSBLAD, S. BAEHRENDTZ, J. HULTING, K. EKENBÄCK, M. JOHANSSON, and G. MATELL 228

Mathematical Modelling for Prediction of Optimal Ventilator Settings
R. RUDOWSKI, G. MATELL, K. EKENBÄCK, C. SPANNE, and B. OSSMER 235

Indications for the Application of Closed Loop Systems in Perioperative Medicine
R. D. WESTENSKOW 247

Glucose-Insulin-Potassium Therapy Guided by a Glucose-Controlled Insulin Infusion System in Acute Myocardial Infarction
G. MÜLLER-ESCH, P. BALL, U. BEKEMEYER, H. DJONLAGIC, A. HAUPTMANN, K. HEIDBÜCHEL, A. PETERS, R. TYBUSSEK, W. G. WOOD, and P. C. SCRIBA 252

Changes in Monitoring Methods Caused by the Use of Intelligent Bedside Equipment
E. EPPLE, W. BLEICHER, M. KOPP, and H. JUNGER 259

Automated Arrhythmia Detection in Intensive Care
C. ZEELENBERG, S. H. MEIJ, M. R. HOARE, and P. G. HUGENHOLTZ 265

Monitoring Intracranial Pressure – Nuisance to, or Advantages for, Ward Personnel
K. WIEDEMANN, G. SCHMIDT, and M. MÜLLER 280

Computerized Neuromonitoring
M. R. GAAB 290

Computer-Assisted Monitoring of Intracranial Pressure in Stroke
A. HAASS, T. MADLER, and K. SCHIMRIGK 307

Microprocessor-Controlled Registration and Evaluation of Respiratory Pressure-Volume Diagrams in ICUs
W. KELLERMANN, Y. SUMMA, and K. PETER 311

NAPROS – A semiautomatic and easy to use anaesthetic record system
D. WINTER, and P.-M. OSSWALD 319

A Real Time Pattern Recognition Program for Continuous Processing of Cardiovascular Biosignals
M. MAIWALD 329

Microcomputer-Assisted ICP Monitoring in Neurological Patients
G. SCHMIEDER, C. GARNER, K. M. EINHÄUPL, K. SIEGL, and G. KUFNER 334

Application of Computer Systems in Critical Care

K. GEIGER

During the past decade innovations in biomedical computing have produced hardware and software systems that now enable monitoring of critically ill patients on a much more extensive and useful level than was possible before. Intensive care unit computer systems were designed initially for monitoring vital signs such as heart rate and blood pressure from bedside hardware, but increasing numbers of signals are now being demanded and no end is yet in sight. The technological imperative is partially responsible. Advances in electronic monitoring devices have paralleled progresses in information processing and miniaturization of microprocessors. Clinical and experimental medicine has responded by examining new parameters of monitoring which can be employed more efficiently in patient assessment. A great number of intensive care units in Germany are still equipped with noncomputerized monitoring systems. Such systems have some inherent problems which encroach on the efficiency of patient management:

1. They cannot perform quantitative analyses or present the data in a variety of formats. Current noncomputerized monitoring systems have no storage capacity, making trend analysis of any of the patient's physiologic parameters impossible. Such information is important, helping the clinician to assess the patient's status and determine the necessary therapeutic measures.
2. They lack the capability of automated logging and data retrieval. Significant events are recorded solely by manual charting. Such systems do not allow the setting of priority alarm conditions according to previous events. Neither is it possible to recall and display past data in an easy and convenient manner.

Present-day computerized monitoring systems provide continuous or intermittent monitoring of many input data. Clinically relevant ICU data center on cardiopulmonary function. The physiologic parameters commonly monitored nowadays are as follows:

Systolic, diastolic, and mean *blood pressure* are displayed. An automatic calibration system for blood pressure transducers has been described (Martin et al. 1973). A computer algorithm has been developed to detect the distortion of arterial blood pressure wave forms caused by blood clots or air bubbles in the catheter.

ECG is continuously monitored. The ECG wave form can be sampled at a rate of 250 or 300 per second and the R waves identified on the basis of their amplitude and the steepness of the downslope. The data points can subsequently be analyzed to give the R wave widths. A computer program may than sort the beats into various categories such as normal, premature, wide and late. Preprocessing computer programs like the *Aztec* inaugurated by Cox (Cox et al. 1968) have been developed for the efficient sorting of ectopic beats. This system accurately detected 78% of ventricular ectopic beats; however, movements artifacts and/or conduction defects are associated with significant error rates. Most arrhythmia-detecting systems use measurements of QRS width, offset, amplitude, and area to classify complexes into morphological families. Another approach combines the major elements of cross-correlation of QRS signals, as well as grouping of complexes into families and clusters. Westenskow (1982) recently described a system that uses both esophageal and surface electrodes to detect cardiac arrhythmias in the operating room. A strip chart recorder provides a permanent record of ectopic beats and the computer's interpretation of these. He reported a false-positive rate of 0.034% and a false-negative rate of 0.107%. A typical application of such systems could be the monitoring of the efficiency of antiarrhythmic therapy.

Cardiac output is commonly determined by thermal dilution. Warner et al. (1968) developed a method, of measuring cardiac output that was not dependent upon analysis of the indicator dilution method. They attempted to estimate stroke volume from central aortic pressure analysis. This method is based on an application of signal-processing techniques in which the computer is programmed to identify critical points on the central arterial pressure contour. Since the arterial vascular system possesses elements both of resistance and capacitance, only a fraction of the blood expelled from the left ventricle during systole will leave the large vessels of the arterial system during systole. A considerable portion of the blood ejected from the heart stays within the elastic reservoir of the vascular bed and leaves large vessels during diastole. In Warner's analysis the stroke volume can therefore be separated into systolic drainage and diastolic drainage. The final mathematical equation involves a constant which relates pressure to volume in the aorta and is in practice obtained for each individual by a single measurement of cardiac output using the indicator dilution method. In general, this technique appears to be a reasonable measure of cardiac output which can be obtained on a beat-by-beat basis in many clinical situations. However, it has recently been shown that major changes in the constant may occur in individual patients during their postoperative course (Kouchoukos et al. 1969).

When it is required to monitor *cardiac function* apart from cardiac output, a computer can be used to follow changes occuring in systolic time intervals.

Respiratory rate can be monitored directly or indirectly from the pressure fluctuations observed on the central venous pressure or from the variations in the height of the R waves of the ECG. Detailed accounts of computer-based bedside monitoring and respiratory system analysis have been given by Osborn (1975) and by Peters' group (Peters and Hilberman 1971). In their approach a pneumotachograph is placed in the respiratory line. This may be at the endotracheal tube for an intubated patient or in a face mask for a patient breathing spontaneously. This sensor has been modified to permit measurement of airway pressure as well as flow and to allow continuous sampling of the gas mixture passing through the pneumotachograph. In this way respiratory flows, pressures, and gas composition can be continuously monitored, gas analysis being carried out by rapid analyzers carbon dioxide and oxygen. The computer program permits the computation of respiratory mechanics and gas exchange, including oxygen consumption, carbon dioxide production, respiratory quotient, and the physiologic dead space. By manual, digital entry of the arterial and central venous blood gases and hemoglobin it is possible to obtain estimates of the cardiac output (using the Fick method) as well as the percentage of venoarterial admixture across the lung. These data as well as pressure-volume curves can be displayed at frequent time intervals and pulmonary work per minute, compliance and resistance computed along with the ratio of dead space to tidal volume. Such techniques provide the means to identify those points in the chain of ventilatory events at which defects have appeared and to give quantitative information helping to rectify the clinical problems. Peters (Peters and Hilberman 1971) has developed indices that may be used to warn in advance of deterioration of pulmonary function. There is, however, a continuing need for the development of error detection and on-line multivariable pattern recognition algorithms which can delineate significant trends while rejecting artifactual transients.

A new generation of microcomputer-controlled ventilators has just emerged. They incorporate the features of a versatile lung ventilator and a lung function testing unit. Complex breathing maneuvers for a variety of single- and multi-breath lung function tests can be automatically performed. If equipped with a gas analyzer, the devices can function as "demand" ventilators allowing for set-point control of end-tidal PCO_2 and PO_2.

Computer systems have been successfully utilized in the analysis of *blood gases* and *acid-base status* (Maas et al. 1972; Neff et al. 1970; Valbona et al. 1971).

Attempts have been made to analyze the *EEG* with respect to frequency and wave shape. Computer-aided EEG monitoring has been employed in guiding barbiturate therapy in intracranial hypertension (Hjrth 1970; Myers et al. 1973; Sebel et al. 1983).

Enormous efforts are being made to develop new computer systems to fulfill *other functions*, including management of pharmacologic interventions, evaluation of the effectiveness of various modes of therapy, and repeated analyses of patient status. Automated systems have been developed to deliver prescribed and programmed treatment, such as the administration of appropriate and adequate amounts of blood or of a pharmaceutical agent to maintain specific physiologic conditions in a patient. There have been several attempts to computerize the control of specific pathophysiologic situations.

In appraising the use and value of computer technology in critical care, other aspects of patient care must also be considered.

A potentially valuable application of computer technology is in the delineation of physiologic models. The principle behind the application of mathematical modeling to physiologic systems is to obtain more information from the observed data by fitting them with a set of equations that can be used to describe quantitatively particular aspects of the system. Mathematical representations of biological signals have often been developed into true functional models in an attempt to characterize various aspects to the system generating the signal. Such models can be considered as attempts to describe the general biochemical or physiologic functions of the system in circumstances where it is difficult to develop or test sufficiently detailed mathematical expressions of the mechanical or physiochemical properties, or control mechanisms that are aspects of the system. Such techniques have successfully been used in defining compartment models.

Another important area where computer technology may be extremely useful in solving critical care problems is simulation. Simulation has been mainly confined to physical models because of their preciseness in describing biological phenomena. A valuable application of this approach is the description of behavioral models of different body systems. Siegel (Siegel and Farell 1973) has used it to study how changes in cardiac output and alveolar ventilation and their respective distributions interact in the patient with acute post-traumatic pulmonary insufficiency and thus find out how the transitions between the typical pathophysiologic states can take place. The most exciting prospect of this technique is the possibility of effective clinical computer simulation of different forms of treatments in the critically ill patient. This application may help to identify the best therapy with greater sophistication and with a better chance of success.

Computers have also been applied in student instruction and medical education. Computer-assisted learning is a versatile and stimulating means of acquiring knowledge, forming a useful adjunct to traditional methods. However, it should not be used as a substitute for traditional teaching methods, because by its very nature, it tends to provide information in an unqualified, factual form which is often remote from the realities of clinical practice. At present there is only limited experience in the evaluation of such programs in terms of quantitative and qualitative knowledge. It appears, however, that computer-assisted learning offers the opportunity of an earlier introduction to intensive care problems and the possibility of continuing self-evaluation.

Comprehensive automatic monitoring systems have proved to be effective in increasing the efficiency of ICU staff. For example, by relegating routine, well-defined, repetitive tasks of these systems, nurses have been able to concentrate on direct patient care. Compared to the ususal manual methods of measurement, automated measurements are more accurate, more reliable, and more consistent. Furthermore, once these data are stored in the computer memory, they can be retrieved more quickly and can be presented to the personnel to indicate trends in the various measurements, enabling the staff to assess the patient's condition more accurately.

The various applications of computer systems have the potential of providing a better understanding of the patient's clinical problems and a better outcome. The most successful aspect of the use of computer technology in critical care has been its demonstrated capability of assimilating and processing enormous amounts of physiologic data in a short period of time. This may enable the intensive care staff to relate the present pattern of patient response to past experiences in a quantitative manner. By using new types of data correlation it may contribute to enhancement of diagnostic ability and recognition of clinical patterns and their therapeutic implications.

There are, however, still many problems regarding the application of a useful and efficient monitoring system in the intensive care unit environment. The most significant ones do not involve available technology. The establishment of prescribed medical procedures that can be programmed and turned over to an automated approach is the greatest challenge of all. Successful application of computer technology to the monitoring of critically ill patients requires definitive, quantitative descriptions of signal characteristics and specific conditions that must be detected. It is the explicit nature of programming the computer that imposes such demanding specifications. The development of computer programs with sufficient sophistication to recog-