A NEW PATIENT'S STATUS INDICATOR TO FACILITATE DECISION MAKING IN ANESTHESIA

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ABSTRACT

We are presenting the Vital Function Status (VFS), a new real-time indicator which continuously depicts the overall status of the patient under anesthesia. The VFS is generated by a subsystem which has been developed as a part of adaptive real-time expert system for anesthesia [20]. The subsystem can operate independently and may be implemented in other highly monitored environments.

INTRODUCTION

It is estimated that in the USA 2,000 to 10,000 patients die every year from causes related to anesthesia [1]; the morbidity rate is much higher [2]. Mishaps in anesthesia are typically caused by more than one factor. These include human errors, equipment failure, surgical events, or unexpected alterations in the patient's homeostasis. To improve patient safety and quality assurance we are developing the Adaptive Real Time Anesthesiologist Associate (ARTAA), a real-time expert system (ES) for anesthesia. We are guided by the basic concept that in highly monitoring medical environments only the operator (in this case the anesthesiologist) makes the decisions. Thus, the 'traditional' ES which suggests a differential diagnosis constitutes only a partial answer. It is equally important to transduce the plethora of information into a more effective tool to assist the operator in the process of decision making. Free access to the raw data, however, must never be deterred. Based on these premises we have tried to develop a new display to facilitate decision making in anesthesia. In discussing our concept we review the current status of monitors and computerized systems followed by an outline of the anesthesiologist's specific problems. In the last section we describe the system and the VFS.

Monitoring and computers in anesthesia - Current Status

Until thirty years ago the anesthesiologist has primarily relied on his senses while providing anesthetic. The anesthesia from an eclectic art became a medical domain based on scientific reasoning. More than 30 different physiologic parameters (e.g., heart rate, blood pressures etc.) are routinely collected by six or seven sophisticated monitors. (Though, skin color, perspiration etc., are still 'manually' collected). In spite of the technological progress, medical monitors currently in use are limited in their performance and are prone to generate false alarms, thus reducing the physician's responsiveness [3,4]. Another problem is the data display presented either digitally and/or in continuous analog waveform in various locations around the physician. The new generation of monitors integrate several monitors in one but at the expense of a congested display. All the monitors have a limited signal-processing capability, and the display, which is of short duration, is presented after a time delay. Most important, derivative parameters (e.g., alveolar ventilation, oxygen delivery, etc.) are not calculated by the monitors.

The lack of success of data management systems (for anesthesia and intensive care) may be partially related to the following flaws: deficient databases and/or decision-making capability, inability to account for patient variability, lack of learning and adaptation features, and zero or limited alarm priorities [5].

Expert systems for medicine which have been developed are not in general clinical use. These systems had limited goals and (actually) explored methods in artificial intelligence [6-8]. Progress in computer
technology enables more sophisticated performance. Indeed, more advanced ES for anesthesia and intensive care collect data in real time. These systems, however, either do not support decision making or are limited to ventilator management. PONI improves alarm detection but does not perform in real time, its display is congested and the database limited. It is important to note that a real-time and adaptive inference engine is missing in all systems which have been developed thus far. These are essential features for ES designed for medical domains.

The operator

The dynamic nature of the anesthesia environment underscores the need for prompt reaction to prevent undesired outcomes to the patient. Whereas equipment failure is still a component of accidents, the greatest number of anesthetic mishaps can be attributed to human errors. The decision-making process, which has to result in the selection of the correct treatment, is performed under strenuous mental load and in conditions of uncertainty. Stress, inexperience and fatigue further deter the human performance. Patients' variabilities and unexpected or idiosyncratic reactions contribute substantially to the complexity of the environment.

The human perceptual and cognitive limitations inflict another encumbrance in the process of decision making. One can concomitantly perceive six or seven information inputs of these only two or three can be simultaneously and efficiently processed to a higher level of abstraction. In critical situations one has a markedly greater tendency to fixate on one option, usually the first one (sometimes a wrong one), while ignoring all the other options.

According to the 'Standards for Basic Intra-Operative Monitoring' of the American Society of Anesthesiologists, the determination of circulatory vital signs is required only every 5 minutes. Gravenstein concluded that monitors need to be observed at least every 30 seconds in order for critical events to be detected at early stage. The anesthesiologist's tasks inherently entail the partition of his/her attention between treating the patient and observing the scattered and intermittent data as well as the surgical field. In actuality anesthesiologists observe the monitors less than 42% of the anesthesia time. These purport an unnecessary delay in detection of events and treatment.

Proper management of anesthetic care implies also the identification of the primary effector whenever there is a change in the patient status. The primary effector or the first physiologic parameter that deviated may reveal the patient's true problem. Inability to detect these changes may thus hinder an optimal (causal directed) treatment.

The responsibility for situation assessment, although continuously performed during anesthetic, should not be delegated to the ES. The patient has delegated this responsibility to his physicians so that they will make the appropriate decisions during anesthetic. The ES, therefore, must be perceived and accordingly operate only as an ancillary system.

Data collected during anesthetic is the essential substrate upon which decisions are made. Processing the raw data to a higher level of abstraction requires time and mental effort. It also expected that in the course of the process some information may be overlooked. Thus, from the discussion one can deduce how difficult complex (and inefficient) is, at the present, the decision-making process during anesthetic care.

THE VITAL FUNCTION STATUS

Reduction of anesthetic mishaps implies the improvement of the anesthesiologist's performance. Based on the knowledge of the domain's specific problems we have set the system's main goals:

Improving the operator's control during anesthetic.
Early identification of the anesthetized patient's physiologic changes.
To suggest differential diagnosis to the clinical problems incurred under anesthetic.
The Vital Function Unit (VFU) is the subsystem which has been developed to account for the first two goals. The approach in developing the VFU is based on the fundamental concept of homeostasis. The patient is not an aggregate of independent subsystems (e.g., cardiovascular, respiratory etc.); these interact and function harmoniously with each other. A malfunction of one may cause other subsystems to follow, yet other may react to balance these infictions. What the operator perceives is a set of physiologic parameters which have deviated. (Sometimes unmeasured physiologic changes like skin color, perspiration and others may also be detected.)

The next step is the conceptualization of the problem, or in other words processing the available data to a higher level of abstraction. The operator first attempts to evaluate the patient status and to conclude whether the patient improves or deteriorates, also to what extent and how fast these changes occurred. The assessment of severity should not be confused with the diagnosis which is the next step (and requires more time). In performing the process all the parameters are equally important and, therefore, all should be considered [19]. In assessing the severity of the of the patient's status the same weight is attributed to the direction of deviation of a specific parameter; however, the extent and the rate of change are more important. The direction of deviation is more meaningful in selecting the correct diagnosis, and the extent and rate of change are less important.

The system's block diagram is presented in Figure 1. It consists of: the Data Acquisition Module (DAM), the Feature Extracting Module (FEM), the Reference Value Unit (RVU), the Vital Function Unit (VFU), the Adaptive Inference Unit (AIU), and the display [20]. The system has been developed on a 386/33Mhz platform equipped with 80386 math. co-processor, 6 Meg. RAM and 80 Meg. hard drive; the system operates in Quarterdeck multitasking C environment.

![Figure 1: ARTAA - BLOCK DIAGRAM](image-url)

The medical monitors are interfaced with the system via the DAM. The DAM runs as a separate background module which collects and transfers the data to the FEM. The FEM extracts relevant features (e.g., maximum value, minimum value, etc.) from all input values (heart rate, blood pressure, etc.). Additional derivative parameters (e.g., lung compliances, cardiac indices, oxygen delivery, oxygen arteriovenous difference, etc.) are calculated either every second or whenever sufficient data is accumulated. All
the data collected and computed is transferred further to the AIU and to the vital function unit (VFU); it is also stored to generate later the anesthesia report.

The primary task of the VFU is to produce a new indicator, the Vital Function Status (VFS). Another task is to highlight the first parameter which deviated from baseline. The measured and the calculated values of all the physiologic parameters are compared to reference values which reside in the Reference Value Unit (RVU). The values in the RVU have been preimplemented in the system; different values have been assigned for different age groups or specific problems (e.g., hypertension etc.). The operator will be able to select specific reference values for a specific parameter. In other words, if the patient is a young adult and hypertensive the system will utilize for blood pressure the appropriate reference values for hypertension; yet, the other parameters will be compared with values which correspond his age group. Each parameter is assigned one of six levels of danger. The levels of danger range from "0" to "5" according to the following scale:

0 - no danger
1 - cautious
2 - alert
3 - serious
4 - severe
5 - critical danger

![VITAL FUNCTION STATUS](image)

Figure 2: The Vital Function Status

All the assigned values are merged to produce the VFS, a numeric indicator whose values range also from "0" to "5," using the same scale. The VFS then is displayed graphically and provides a semiquantitative overall assessment of the patient's status. The display consists of two plots (Figure 2). The upper plot describes the actual evolution of the VFS during the current two minutes and is updated every second. The lower plot, updated every 20 seconds, depicts the trend of the VFS during the last 30 minutes. Each plot is a rectangular divided into six equal horizontal arrays; each array has a different
color. A text massage appears in a third window; it indicates the first detected parameter which deviated from base line.

At this stage we have developed the second prototype of the subsystem. We evaluated the algorithm on 17 patients undergoing different surgical procedures. The study has been approved by the Institutional Review Board for Human Studies. The total run time was more than 10 hours of general anesthesia. The calculated sensitivity is 99.61% and the specificity 100%. No false negatives have been found. Most of the false positive events were generated by power surge or by mishandling the monitors. The duration of the false positive events never exceeded one second. These were reflected as an isolated spikes on the upper plot.

The VFU can operate independently from ARTAA at any site where monitors are being used. We believe the features of the system are of major importance in clinical practice. The physician would be able to detect and to conceptualize at an early stage the nature of a problem in evolution; moreover, any undesired evolution can be anticipated and treated in time. Most of the computed physiologic parameters are not calculated in practice because of time constraints (especially in anesthesia). These can be retrieved at any time and evaluated. The system presents data at higher level of abstraction and does not hinder the accessibility to routine data (the routine monitors are still in use). On the contrary more data per unit of time is being considered. We expect the system will reduce a part of the anesthesiologist's overload and will enable a more optimal treatment. To conclude, although the system is promising further development and clinical trials are required.

BIBLIOGRAPHY