ARE CARBON DIOXIDE MONITORS THAT DO NOT SHOW THE WAVEFORM OBSOLETE?

A Carbon Dioxide Monitor That Does Not Show the Waveform Has Value

Markku P. J. Paloheimo, MD

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ABSTRACT. The author argues that a simple analog needle display can provide the anesthesiologist with the essential information he or she needs when monitoring carbon dioxide in the patient airway. He argues that essentially the most important information is virtually a binary, or all or none, phenomenon; in other words, carbon dioxide is either continuously present in the breathing circuit or is absent. Thus, circuit disconnects and undesirable endotracheal tube locations are readily identified. He relates the analog display of information to that of an automobile speedometer or the hands of a standard wrist watch. The author also compares analog meters with those used by pilots in aviation. He concludes with the argument that the carbon dioxide analyzer provides necessary information without the need to resort to expensive microprocessed displays that would include the waveform and trending, but would substantially increase the cost of the instrument.

KEY WORDS. Monitoring: carbon dioxide; displays. Equipment: capnometers.

CAPNOMETRY

Continuous measurement of carbon dioxide concentration in the respiratory gases is called capnometry [1]. To be clinically useful, the device must detect the inspiratory and expiratory gas levels, as well as the rates of concentration changes. The first capnometers intended for clinical use were designed with analog electronic techniques and showed the concentration changes on a modified voltage meter. The meter scale was designed so that the normal CO_2 concentration range was at about the middle of the total scale. It was customary to express the concentration in percentages with one decimal accuracy. Thus, in most devices the scale ranges from 0 to 10%, which corresponds to 0 to 76 mm Hg (during 760-torr barometric pressure), and is very close to 0 to 10 kPa.

CAPNOGRAPHY

Recording of CO_2 concentration changes on paper is called capnography [1]. In some European countries it is recommended that one record CO_2 concentrations dur-

From the Department of Anesthesiology, School of Medicine, University of Louisville, Louisville, KY 40292.

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Address corespondence to Dr Paloheimo.

ing the entire anesthetic procedure, a practice that invariably leads to problems in anesthetic record filing. Currently, trends of maximum and minimum values may be stored effectively on magnetic media. I believe that capnography will remain solely for research purposes.

CAPNOSCOPY

"Modern" capnometers are provided with a continuous display of the concentration changes on oscilloscope (CRT) or light-emitting diode (LED) displays for capnoscopic evaluation. In commercial exhibits we see true waveform displays with good pixel resolution and, conversely, poor displays where the real rates of CO_2 concentration changes cannot be distinguished. Most LED displays cannot show subtle cardiogenic variations that can be easily noted with CRTs or needle meters.

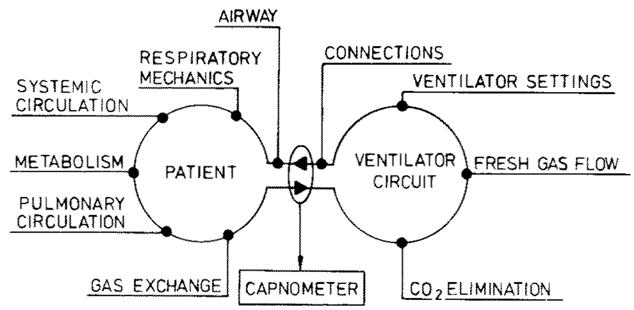
NUMERIC DISPLAYS

Whatever graphic waveform display is used, a separate numeric display must be added onto the screen, since it is virtually impossible for the observer to determine the end-tidal value from the curve itself. The accuracy of the obtained number depends highly on the analysis algorithm, which must be clever enough to detect eventual pressure peaks, cardiogenic variations, or "curare clefts." Partial rebreathing systems are a real challenge, since their use results in a variety of expiratory and inspiratory high and low values, which depend on the fresh gas flow, respiratory rate, and the ratio of inspiratory to expiratory time [2,3]. Therefore, I would agree that CO_2 monitors that *only* show a numeric end-tidal value are worthless. A simple bouncing bar display appeals to many anesthesiologists, but I think it cannot substitute for an analog meter because of the commonly low resolution, which also requires numeric clarification of end-tidal values.

CAPNOMETRIC INFORMATION

During routine clinical work, the anesthesiologist is mainly interested in two pieces of capnometric information:

First, the continuous presence of CO_2 in the expiratory gas indicates trouble-free connection of the breathing circuit with the patient's airway. Application of capnometry immediately after an attempted endotracheal intubation offers objective proof of correct placement of the tube [4,5]. Sudden loss of CO_2 at the sampling site



Sites in the patient–anesthesia circuit complex where carbon dioxide, if intelligently used as a marker substance, reveals clinically significant problems.

should result in an aggressive search for a potentially dangerous malfunction within the anesthesia machine-patient complex. A capnometer is the only single monitor that can indicate problems in such a variety of sites (Figure).

Second, the end-tidal concentration of carbon dioxide gives a fairly good estimate of the arterial P_{CO_2} [6]. Large arterial to end-tidal gradients indicate diseased lungs [7]. The end-tidal value is a simple leading indicator for ventilator adjustments. Patients tend to produce more CO_2 at the beginning of an anesthetic, and it is a common finding that minute ventilation must be decreased considerably after induction to maintain normocarbia (end-tidal CO_2 about 5.3%) [8]. Partial rebreathing circuits, in particular, may not be appropriate without continuous information of the CO_2 level in the patient [3]. In general, unforeseen increases or decreases of the end-tidal CO_2 should lead to careful exploration for the causes, and possibly to decisions to apply more invasive monitoring methods [9].

The rate of the expiratory CO_2 concentration change invariably includes some information as well. The concentration first increases rapidly as alveolar gas reaches the measuring site. Thereafter, the concentration increases slowly, as during the latter part of expiration pulmonary venous blood constantly brings more CO_2 into the alveolar space [10]. A less sharp transient from the fast to the slow phase may indicate uneven gas distribution due to lung diseases [7] or partial one-lung ventilation (uneven mixing of gas from both lungs). Extra swings are indicative of changes in the direction of gas flow, possibly resulting from the patient's own respiratory efforts [11]. If the ventilatory rate is low, the expiratory flow ceases and cardiac activity causes the gas at the measuring or sampling site to move slightly back and forth, a phenomenon that is detected by the sensitive instrument [12,13].

CAPNOMETER DESIGN

The basic requirements of a clinically useful capnometer are stability and accuracy (minimal drift, stable calibration), simple and versatile patient interface, simple and unmistakable display, and affordable price.

The analog devices were abandoned because of the demands from the marketplace. Field sales representatives told the manufacturers that physicians were requiring digital displays, bars, fancy colors, waveforms, and "whistles and bells." Research and development groups implemented analog-to-digital converters, microprocessors, and expensive displays and spent many engineering years writing and debugging programs that would perform the simple job of continuously displaying CO_2 concentrations. The basic measuring techniques remained mostly unaltered. Who pays for the development expenses and the extra material costs? The customer. Unfortunately, we can only blame ourselves.

The present generation of practicing anesthesiologists has grown up in a world of analog meters. The arms of an old-fashioned watch give a comprehension of time at a glance without our having to read the actual minutes and hours. Most automobile speedometers indicate the velocity with a needle, whose angle on the scale indicates an approximate velocity that can be pinpointed more precisely if necessary. We are also able to easily approximate the rate of an indicator change, and the direction of movement can be discerned at a glance. In aviation, where instrument design is based on ergonomic and psychophysiologic studies instead of marketing trends, some data are still presented with analog meters. They are arranged in a logical order and designed to show normal values in the same direction. Numeric displays are useful when several digits are needed for the required accuracy or when a piece of information must be referenced instantly.

Microprocessors undoubtedly are here to stay. However, I believe that the development of stand-alone monitor displays may have proceeded in the wrong direction. If the purpose of a capnometer is to provide the user only with essential information, an analog meter is perfectly adequate. The software may still include routines for intelligent alarms and even provide for digital and analog data output.

If capnometry is integrated into a multivariable monitor, it is natural to show a CO_2 waveform display with an end-tidal value. Application of the same display techniques into stand-alone monitors may not be justified if it adds significantly to the user's cost. The price may not play as great a role in the United States as in less developed countries, where the resources for medical care are limited and useful monitors in an average operating room are scarce.

The availability of economically priced, simple capnometers could increase the overall standard of anesthetic care in those parts of the world. I admit to having encouraged digital data processing and the development of simple data transmission. This progress has been essential for the application of easier research techniques in respiratory physiology and clinical studies. The microcomputer era allows everyone to be a researcher, if he or she is interested. The ambitions for waveform displays may have resulted into skewed weighing of the information provided by capnometers. I would like to see the needle swing again and herald a trouble-free anesthetic.

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