the Boehringer PEEP valves and the effect of backpressure on anesthetic concentrations have been previously described.[6] Initial pressure measurements for this device correspond to those described for other anesthetic systems with PEEP attached.

This device extends the range of usefulness of the Bain breathing circuits by allowing the application of PEEP intraoperatively. The use of readily available components that can be assembled and interchanged easily allows for cleaning and varying PEEP levels. Boehringer PEEP valves are the most expensive component of this device, and these are relatively inexpensive. These valves can also be adapted for use in other anesthetic systems.

References

1. Bain JA, Spoerel WE: A streamlined anaesthetic system. Can Anaesth Soc J 19:426–435, 1972
2. Bain JA, Spoerel WE: Flow requirements for a modified Mapleson D system during controlled ventilation. Can Anaesth Soc J 20: 629-636, 1973
3. Bain JA, Spoerel WE: Prediction of arterial carbon-dioxide tension during controlled ventilation with a modified Mapleson D system. Can Anaesth Soc J 22:34–38, 1975
4. Patton CM, Dannemiller FJ, Reonnle AM: CPPB during surgical anesthesia: Effect on oxygenation and blood pressure. Anesth Analg (Cleve) 53:309–316, 1974
5. Wu WH, Turndorf H: PEEP valve for anesthesia machine. ANESTHESIOLOGY 43:677–678, 1975
6. Weeks DB, Comer PB: A PEEP device for anesthesia circuits. Anesth Analg (Cleve) 56:578–580, 1977

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50:543–546, 1979

Density Modulation—A Technique for the Display of Three-variable Data in Patient Monitoring

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The lack of compressed, readable displays is a major deficit in patient monitoring. Most strip-chart and oscilloscope channels are occupied with simple, function-*vs*-time displays: for example, the ECG or arterial pressure. Although these displays do provide considerable information, the limitation to two variables per channel has prevented the strip-chart recorder from achieving its full usefulness. For example, the EEG and vectorcardiogram are neglected because their display optimally requires more than two variables simultaneously. We present here a method that records three variables on one strip-chart channel and yet still allows the physician to recover the necessary information. This method described in this paper incorporates a second variable with the first and compares it with the first variable, while preserving a third variable—time—which runs parallel to the other strip-chart channels. The result is a voiceprint-like pattern that is easily read and interpreted.

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Methods

The method of display is called "density modulation," since the darkness of the tracing on the thermal strip-chart is varied in response to the second variable. Figure 1 shows how this display is formed, using the spectral analysis of the electroencephalogram as an example. The first variable is indicated by the position of the tracing within the channel, while the darkness indicates the second variable's value. Time is recorded along the length of the channel and is scaled to the paper speed. The pen position is changed by controlling the amount of time the pen remains at the selected position, or by the interval needed to transverse a small, for example, 1-mm, track.

Thus, the lengths of time taken for a complete scan of the channel width vary with the data. A new scan is not made as soon as the preceding one is finished, however, for this would cause bunching or unnecessary whiteness. Instead, we allow a constant amount of time for one complete scan by using a special "excess-time" track on the right (or lower) part of the channel. Any residual time is used to sweep the track, preventing the paper from burning. By using up unneeded tracking time, the end track also allows equal distances between scans. When large enough, the width of this end track can be varied and used to display other information.

Output Device. To implement this display, we constructed a device using about 20 integrated circuits

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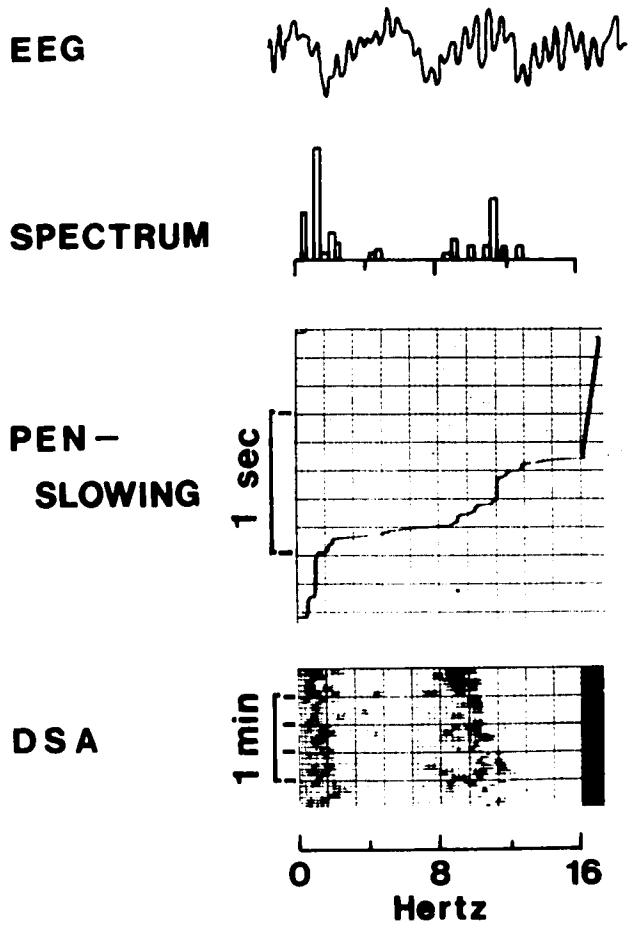

FIG. 1. The density-modulation technique, as demonstrated by the spectral components of an electroencephalogram (EEG). The top section shows a four-second segment (epoch) of the EEG, which is broken down into its spectrum (second section). The pen-slowing (third section) represents one line of density modulation. The paper is moving up at 25 mm/sec, while the pen moves to the right at a velocity inversely proportional to the spectral power. The paper is moving slowly (0.25 mm/sec) in the bottom section, demonstrating the voiceprint type of pattern.

and costing around $100 in parts. A block diagram of the device is shown in figure 2. The variable of interest starts as an analog voltage (representing the additional variable) whose time axis represents the first variable. This is converted to digital form and stored. One at a time, these stored values are retrieved from memory and used to control the slope of a ramp generator. When the ramp attains a threshold voltage, a new digital value is retrieved. This ramp is added to a voltage proportional to the position along the strip-chart width. This sum voltage drives the strip-chart pen.

We divided the strip-chart channel width into 64 segments, thus limiting the horizontal resolution of 1/64, sufficient for monitoring applications. The density resolution needed is even less, since the human eye sees six to ten shades of grey.

An automatic gain control section eliminates adjustments necessary to compensate for varying input levels. It stores the largest input voltage each epoch and scales the output so that this voltage produces the darkest grey scale. This preserves a large grey-scale range in each scan and eliminates unnecessary adjustments. On the other hand, one loses any feeling for absolute changes in the variable being displayed. We have compensated for this by adding an absolute-value end track to the same channel, using the same pen (Fleming RA and Smith NT: Unpublished material).

An example of such a display is shown in figure 3. Two waveform displays are shown there. They are both from the same signals, but one is formed by dots and the other by continuous shading. The left display is formed by stopping the pen at each spot and varying the holding time to vary the darkness. The right one continuously varies the pen motion and leaves no gap (See fig. 1). Any type of trace between and including these two extremes can be obtained, as well as "overtrace," where the width of each segment is greater than its allotted space and extends into adjacent segments. The dot tracing requires a greater bandwidth in the recorder. At a distance, however, the eye provides the same slurring in line provided by a recorder with less bandwidth.

DISCUSSION

New methods of on-line display are needed to organize and compress data used in patient care. To increase the usefulness of displays for the operating room and the intensive care unit, the displays should be:

1) Integrated. Two or more measurements should be combined to facilitate the recognition of important patterns, while preserving the information found in single measurements *vs.* time.

2) Packed. The display should occupy as little space as possible, both to keep a considerable amount of data readily available and to increase the likelihood of detecting patterns. Human pattern recognition is very dependent upon packing density and unused space. In addition, the more compact the final copy is, the easier it is to handle and store.

3) Permanent. A hard-copy record must be provided for comparison with earlier records or with similar cases.

4) Inexpensive. Only large hospitals, usually university-connected, can afford to buy and use state-of-the-art display systems. The majority of hospitals must wait until purchase and operating costs are low. Perhaps totally new displays will be used in the future,

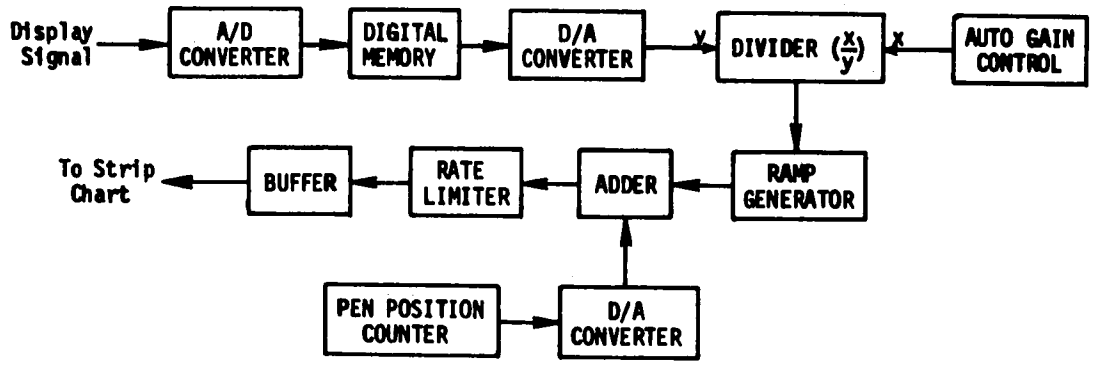

FIG. 2. Block diagram of the output device that moves the strip-chart pen.

but for a system to be useful today, it must interface with existing equipment or be so inexpensive that conversion will be feasible.

5) Automatic. Any new display should save time by easing recognition of patterns, not waste time by forcing the physician to make continual adjustments. Medicine has been offered many gadgets capable of wondrous feats, but requiring so much expertise and manipulation that they are never used.

6) Reliable.

The display described here satisfies the above criteria. One of its major features is the use of available equipment in a more efficient manner. Currently, only strip-chart recorders and oscilloscopes are used for real-time display in the operating room. Of these two modes, usually only strip-charts permanently store the data. The strip-chart recorder, however, is presently limited to one variable *vs.* time per channel and to one paper speed at a time, even though individual measurements display best at different speeds. As a result, many useful measurements are not made, many measurements are worth less because the paper speed is unsuitable, and interrelationships among variables have to be surmised instead of visualized.

Another advantage of the method is that combining more than one function *vs.* time into a density-modulated display forms patterns that are often much easier to recognize than the original signal. In fact, some data that would not be apparent in conventional displays can be revealed. With the slow chart speed possible with density modulation, conventionally displayed variables can accompany the density-modulated ones, thus preserving a complete anesthetic record to be saved as part of the patient's chart.

There are many other ways of using density modulation to produce displays. Several are presented here to stimulate thought in this direction. Certainly the most viable application of density modulation is the display of the electroencephalogram. This is presented in detail in a companion paper.[1] The vectorcardiogram (VCG)—the combined display of two ECG leads showing differences in timing and shape—has seldom been used in real-time displays due to its complexity and three-dimensional nature. One of the many ways to use density modulation would be to reduce the two ECGs to a vector with a vector length and a vector angle. The angle could be broken down into 64 segments and represented on the width, with vector length displayed by density differences. Epochs could be one per heartbeat, with the display continuing as the strip-chart moves, thereby establishing patterns for the physician.

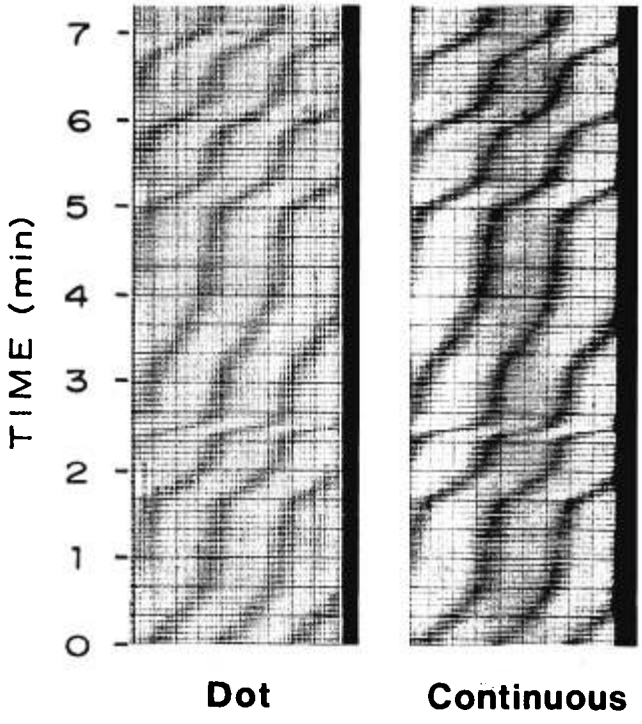

FIG. 3. Two methods of density modulation. The "dot" display holds the pen on a spot for a variable length of time, while the "continuous" display moves the pen smoothly and varies the pen speed (See fig. 1.).

Another use for this display technique is related to the EEG processor display—display of the spectrum analysis of other physiologic variables. Possibilities include the phonocardiogram, the electromyogram, the arterial pressure waveform, and the ECG. Still another application of density modulation is to display annotations across the strip-chart channel (optimally 10–20 characters) by using raster alphanumerics similar to television displays. Events concerned with surgical procedures and anesthesia, such as drug injection, position change, or hemorrhage, could be displayed, along with physiologic variables, by use of a small keyboard.

References

1. Fleming RA, Smith NT: An inexpensive device for analyzing and monitoring the electroencephalogram. ANESTHESIOLOGY 50:456–460, 1979

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Halothane–Nitrous Oxide Anesthesia in a Patient Receiving High-dose Propranolol

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Kopriva *et al.*[1] reported that maintenance of propranolol therapy until five to six hours before anesthetic induction in patients with coronary-artery disease did not produce adverse hemodynamic changes during nitrous oxide–halothane anesthesia. In their cases the doses of propranolol averaged 140 mg/day and never exceeded 240 mg/day. They pointed out that hemodynamic responses might be different in patients receiving higher doses of propranolol. Therefore, we felt it important to describe uneventful nitrous oxide–halothane anesthesia in a patient receiving propranolol, 960 mg/day.

Report of a Case

A 50-year-old, 55-kg, 157-cm woman with renovascular hypertension was scheduled for an elective right-renal-artery-bypass graft. Medications included propranolol, 960 mg/day, triamterene–hydrochlorothiazide, and chlordiazepoxide. Resting supine and standing blood pressures were 180–220/100–120 torr. Heart rate was 66–72 beats/min. Preoperative electrolytes, chest radiograph and electrocardiogram were normal.

Intravenous infusion of physiologic saline solution 200 ml/hr, was started at 6:30 PM the evening before operation. The last dose of propranolol, 240 mg, was given at 10:00 PM. Preanesthetic medication was morphine, 10 mg, and atropine, 0.4 mg, im. After arrival of the patient in the operating room, diazepam, 10 mg iv, was administered prior to placement of a radial-artery catheter and a Swan-Ganz catheter.

Isoproterenol, 4 μg, iv, did not change awake heart rate or blood pressure. Subsequent anesthetic induction was with thiamylal–succinylcholine, followed by tracheal intubation and controlled ventilation. Sodium nitroprusside, 100 μg, iv, was administered 15 sec before beginning direct laryngoscopy for tracheal intubation. Anesthesia was maintained with 60 per cent nitrous oxide and 0.25–0.75 per cent inspired halothane, plus *d*-tubocurarine for skeletal muscle relaxation. Residual *d*-tubocurarine effect at the conclusion of the operation was reversed with neostigmine, 2.5 mg, combined with atropine, 1.0 mg. Total operative time was 200 min. Intraoperative fluids were lactated Ringer's solution, 2,800 ml, and 5 per cent dextrose in water, 500 ml. Urinary output was 1,200 ml and estimated blood loss 300 ml.

Hemodynamic responses to induction, tracheal intubation, and anesthetic maintenance are summarized in table 1. Arterial blood propranolol concentration just before anesthetic induction was 118 ng/ml (40–85 ng/ml considered therapeutic).

Discussion

This report describes uneventful anesthesia of a patient maintained on high doses of propranolol until near the time of operation. The presence of significant beta-adrenergic receptor blockade at the time of anesthetic induction was suggested by the absence of heart rate or blood pressure changes in response to a bolus injection of isoproterenol. Romagnoli and Keats[2] reported this dose of isoproterenol increased heart rate 30 beats/min and systolic blood pressure 30 torr in patients who had not received propranolol or in patients from whom propranolol was withdrawn 24–48 hours preoperatively whose blood concentrations were less than 23 ng/ml. The lack of response to isoproterenol in our patient was consistent with the concentration of propranolol in blood, 118 ng/ml, at the time of anesthetic induction. Coltart and Shand[3] have suggested that complete beta-adrenergic receptor blockade will be produced by more than 100 ng/ml propranolol in the blood.

Despite the presence of significant beta-adrenergic receptor blockade, the circulatory responses during anesthetic induction and maintenance were not different from responses observed in patients not receiving propranolol. The decreases in mean arterial

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