modalities used in these two cases stopped the convulsions—that is, artificial respiration with oxygen by bag and mask, or diazepam. If diazepam did stop the convulsions, the definitive dose in man has not as yet been determined, and could be larger than that needed to stop convulsions in monkeys.

In these two cases, the doses of diazepam administered iv during the convulsions, which *may* have been the factor in aborting the convulsions, were larger than those used in monkeys, namely: 1) 0.26 mg/kg; 2) 0.13 mg; 3) 0.27 mg/kg. Perhaps the dose of 0.13 mg/kg, which was significantly smaller than the others, was effective because of the previously administered diazepam—that is, from 6:30 A.M. to 11:35 A.M. the patient received diazepam, 10 mg, po, as well as a total of 20 mg iv (0.35 mg/kg).

Systemic toxic reactions cannot be avoided, but sequelae can. These systemic toxic reactions, resulting from inadvertent iv administration of bolus doses of bupivacaine, as well as those reported to have occurred with other local anesthetic drugs, were not averted by any or all of the following: 1) premedication with diazepam; 2) a dose of the local anesthetic drug less than that recommended by the package insert—that is, 113 mg as compared with 175 mg; 3) negative aspiration tests; 4) a test dose of 3 ml of the local anesthetic solution without epinephrine, 1:200,000.[5,7,8] Therefore, to avoid complications from a systemic toxic reaction, the user of the local anesthetic drug must immediately recognize the signs and symptoms of such a reaction, and treat it promptly and effectively.

Appreciation is extended to Astra Laboratories for analysis of the arterial blood samples.

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An Inexpensive Device for Analyzing and Monitoring the Electroencephalogram

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The electroencephalogram (EEG) contains information valuable to the physician. The value lies not only in aiding neurologic diagnosis, but also in yielding information that can be important in the operating room and in the intensive care unit.[1–3]

Conventionally, useful information can be extracted from the EEG only by recording on a strip chart at high paper speeds of about 300 pages/hour and by using trained personnel to pay constant attention to the data. This is rarely feasible for monitoring in the operating room or intensive care unit. Usually the physician has little time to consult the strip-chart record, let alone continuously monitor it. Oscilloscopic tracings are even less useful, since it is almost impossible to recall traces that occurred earlier and compare them with the present trace on the screen. Thus, a

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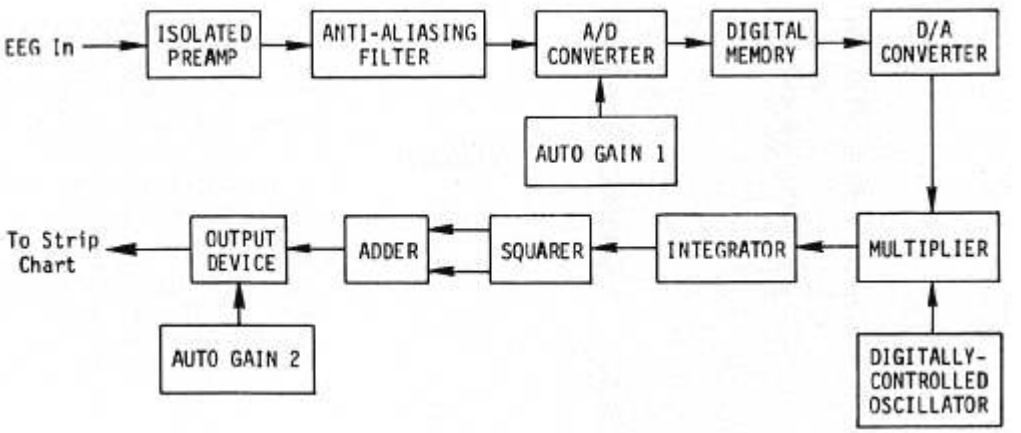

FIG. 1. Block diagram of the inexpensive EEG processor. The output device (*lower left block*) is described elsewhere.[10]

basic need for monitoring the EEG is a more concise and readable processed version, showing the relevant features of the basic data.

Bickford and his group have pioneered a processed EEG for the operating room.[4-7] Their compressed spectral array (CSA), produced by a minicomputer, involves reducing the information load by presenting the frequency-domain‡ version of the time-domain‡ EEG signal. As a result, many patterns hidden in the primary record can be seen. A further improvement of this technique was the building of a portable unit (Vital Indices Transmission and Analysis by Computer—VITAC®) for the operating room, with a telephone link connecting it to the minicomputer system in the laboratory.[6,8] These methods have been quite successful in providing data regarding the feasibility and the usefulness of spectral analysis of the EEG for the anesthetist. They have shown recognizable correlations between the EEG and anesthetic depth, as well as significant decreases in cerebral blood flow.[1,2,8]

Despite the availability of this important technique, however, few hospitals have been able to implement it. The main obstacles are expense and complexity. The CSA requires a relatively expensive minicomputer to perform the calculations, an X-Y plotter or oscilloscope to display the output, and assorted interfacing to tie these together.[9] The expense and the need for personnel capable of operating the equipment have prevented wide clinical acceptance.

MATERIALS AND METHODS

In this paper, we present the density-modulated spectral array (DSA). The DSA is implemented by two devices. Both can fit into one standard thermal strip-chart plug-in module. The first calculates the power spectrum of an EEG signal and converts the spectrum into a signal that can be displayed by the second device[9] on the strip chart in a density-modulated format with variable line darkness and thickness. The result is similar to a voice print, and allows easy visualization of frequency distribution and changes, as well as intensity changes.

The first device, which performs the computations and conversions, is a digital-analog hybrid unit consisting of about 80 integrated circuits plus a number of discrete components. The parts cost about $250, although other components such as printed circuit boards, power supplies, and packaging increase the cost to $400. The unit includes automatic gain control for the input signal, as well as an automatic gain adjust for the output. The primary goal was to produce a device requiring no adjustment other than the initial set-up. This way, no data are lost because the physician is occupied and cannot adjust gain levels.

The basic operation of the unit is shown in figure 1. The input signal, after being amplified, filtered, and scaled, is converted to digital form (512 8-bit words) and stored in memory, which consists of two serial shift registers.§

An *epoch* of the EEG signal, usually 2–4 sec, is stored at any time in a shift register. Since there are two shift registers, one register is always storing the data, while the other is performing the frequency analysis. The latter, the "calculating" shift register, outputs the data at more than 1 MHz, thereby scanning the same data many times an epoch. The data are multiplied twice by digitally-controlled sine-wave oscil-

‡ Frequency-domain refers to a display that plots the separated frequencies of a waveform against another variable, such as amplitude. Audiograms for hearing tests or stereo-amplifier characteristics are good examples of this type of display. Time-domain displays represent the more conventional time *vs.* amplitude display: for example, the electrocardiogram or arterial pressure.

§ A register is a device for the temporary storage of one or more computer words to facilitate arithmetical, logical, or transferral operations. In a shift register, the stored data can be moved to the right or left. The register may shift to the left upon application of a pulse. Then it can be used to perform multiplications and to convert serial data to parallel data, or vice versa.

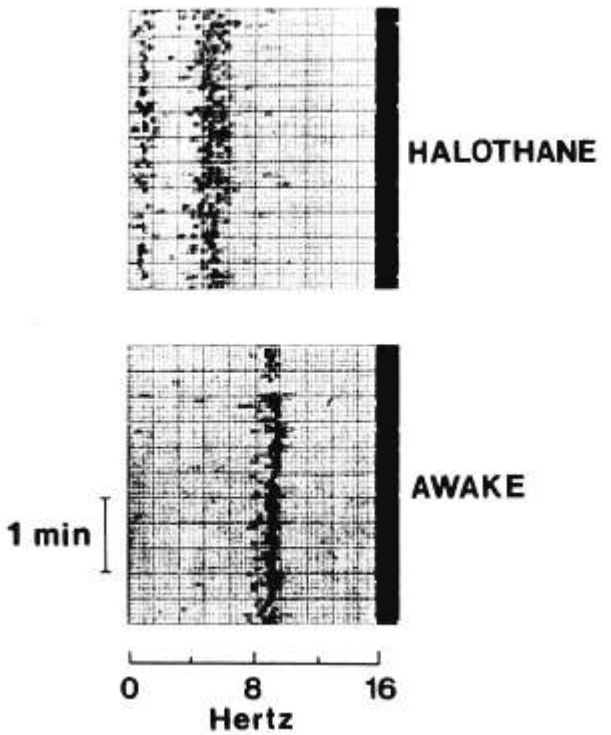

FIG. 2. Density-modulated spectral arrays (DSA) of a volunteer subject awake and during halothane anesthesia. The different patterns are easily distinguished. Time is along the vertical axis, frequency is along the horizontal axis, and power is represented by the darkness of the pattern. Paper speed is 0.25 mm/sec.

lators; once with the sine wave starting at zero (sine term) and once with the sine wave initially at its maximum voltage (cosine term). The products are then integrated, squared, and added. The result is the power value for one frequency.[¶] The other frequencies are similarly computed. As each frequency is calculated, it is passed to the output section. At this time, the density-modulation principle[10] is used to create a voice-print type of pattern. A thermal strip-chart pen sweeps across the channel, its velocity varying according to the calculated power of the given frequency. Thus, the dominant frequencies in the original signal appear darker on the strip-chart trace, with darknesses graduated according to the power levels of their contributions.[4] For each epoch another trace is made close to the preceding one, using the last epoch of data just collected. Thus, a large number of frequency analyses are packed together to form patterns that the eye can recognize and learn to associate with different events and patient conditions.

Other important features of the device include: 1) an optically isolated input preamplifier to protect against high-voltage transients; 2) a very sharp-input low-pass filter (elliptical) for preventing higher frequencies from aliasing** back into the examined frequencies; 3) input automatic gain control before the analog-to-digital converter to keep the input signal

[¶] Those interested in the details of this Fourier analysis technique are invited to contact the senior author.

** Aliasing is a digital sampling error that causes higher frequencies to appear artifactually as lower frequencies in the analyzed output. Aliasing can be seen in the wagon spokes in a Western movie. When the frequency of spoke movement is less than the sampling rate of the movie film, the spokes will appear to move in the proper direction. When the two rates equal each other, the spokes appear to stand still. When spoke frequency exceeds the sampling rate, an aliasing phenomenon occurs and the spokes seem to move backwards.

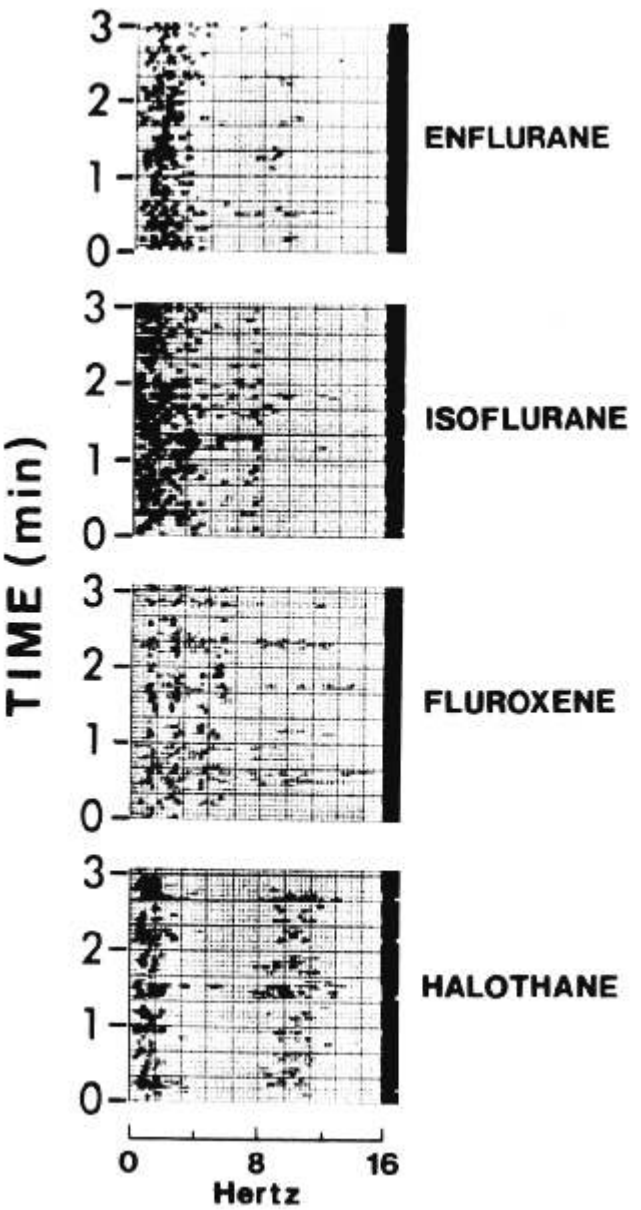

FIG. 3. Density-modulated spectral arrays (DSAs) of eucapnic volunteer subjects receiving four anesthetic agents. The lead placements are C_4O_2. All concentrations are equipotent at 1.0 MAC.

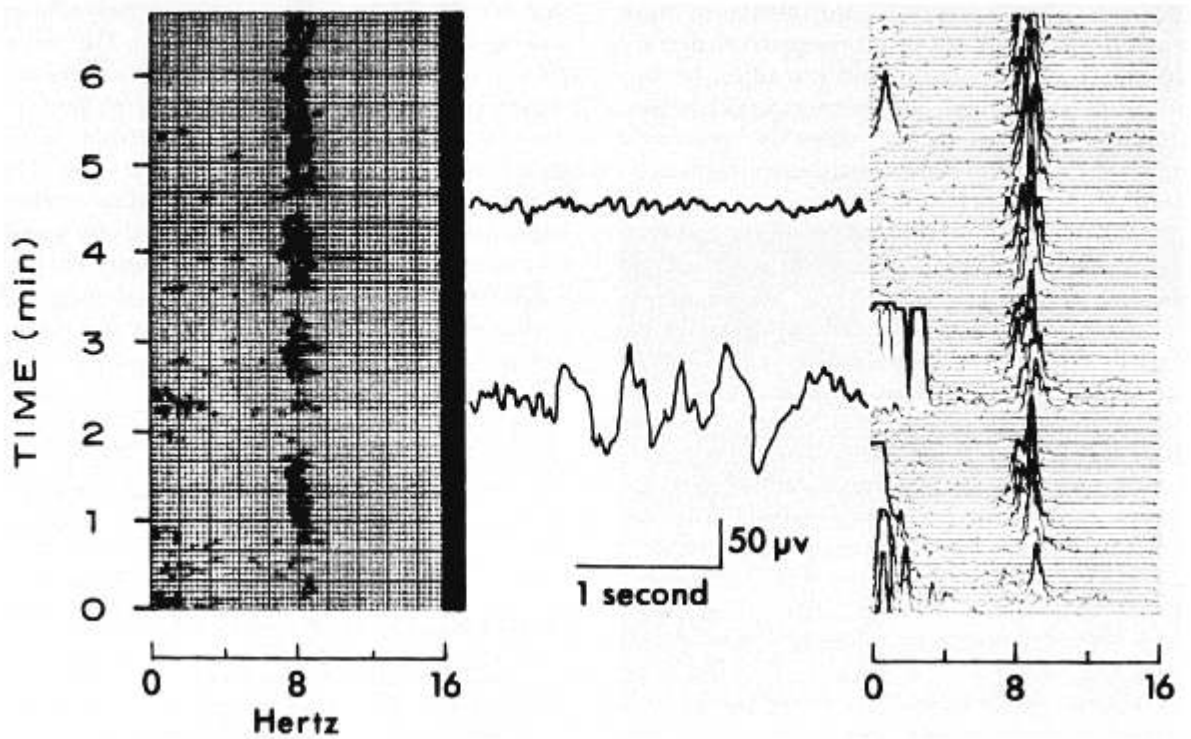

FIG. 4. Comparison of density-modulated spectral array (DSA) with primary data and the compressed spectral array (CSA) obtained from a waking patient. The lead placement is C_4O_2. These examples show the persistence (*sic*) error sometimes caused by the hidden-line suppression of the CSA, and yet not present in the DSA. The lower primary trace shows the effects of a muscle artifact on both displays. The large peak on the CSA blocks subsequent peaks. The upper primary trace (*center panel*) shows a low-intensity period, which the DSA shows as a gap, while high-intensity alpha appears to persist in the CSA. The vertical scale is time at 4 sec/mm.

within voltage range; 4) crystal-controlled sampling frequency for accuracy; 5) automatic gain control at the front end of the output section to prevent a frequency with a large amount of power from overwhelming the other frequencies.

The displayed frequencies are solely dependent on the A-to-D converter sampling rate and the total epoch time. For an epoch time of T, the frequency range displayed will be: 1/T to 64/T Hz in increments of 1/T Hz. The standard EEG epoch is 4 sec, giving a bandwidth of 0.25–16 Hz. The lower frequency range is virtually unlimited, although the display may become unusable as an epoch time becomes very large. The upper frequency is essentially limited by the calculation speed of the device. A frequency of 100–200 Hz is probably the upper limit for use with this display, although an instant display could conceivably extend the range to 1,000 Hz.

Although this device processes only one channel of the EEG, its calculation speed is high enough so that it could be expanded to four or more channels with the addition of more shift-register memory and with output multiplexing. Also, the spectra of other biological signals, such as the ECG or phonocardiogram, could be measured and displayed with this unit.

RESULTS

Examples of the use of this technique are shown in figure 2–4. Figure 2 shows the DSA of a volunteer subject awake and during halothane anesthesia. The patterns are distinct and do not require an expert for interpretation. Figure 3 shows DSAs for volunteer subjects receiving four anesthetic agents at a level of 1.0 MAC. The patterns differ in recognizable ways. Although more work must be done in this area, the possibility exists that the effects of different agents can be separated by their spectral signatures.

Figure 4 shows the effects of artifact and sudden large increases in signal amplitude on records obtained by use of both methods. In this case, the hidden-line suppression of the CSA conceals subsequent information, while the DSA just shows very dark spots. It should be noted that the patterns are more clearly defined in the DSA, while the CSA shows intensity levels more clearly.

DISCUSSION

The development of the relatively inexpensive density-modulated spectral array would prove useful in displaying the EEG in the operating room and inten-

sive care unit. The display, self-controlled as to input range and display intensity, produces patterns that are easy to detect and recognize, and can often be correlated with physiologic or pharmacologic events. Continuous inspection is not necessary, yet rapid changes in the EEG are displayed almost immediately. The routine use of spectral EEG monitoring can, in most cases, permit detection of the first signs of cerebral abnormalities early enough to allow corrective action.[2]

That the DSA can be recorded alongside other monitored variables on a strip-chart recorder allows a permanent record of the surgical operation. Correlations between the EEG and other variables written on the chart will be easier. In addition, this combined monitoring increases the potential for the development of a mechanized anesthesia record. With the strip chart moving at slow speeds, considerable data can be recorded together within easy reach of the anesthetist for comparison with past data. The EEG, heart rate, vascular pressures, temperature, end-tidal anesthetic and CO_2 concentrations, and DSA can all be plotted together, possibly with another channel used for automated alphanumeric annotations. This kind of display could be stored in the patient's record.

Four main characteristics differentiate the DSA from the older, more standard, CSA: 1) The CSA can block subsequent data occurring behind a large peak. This can be especially disturbing when artifacts exist; large low-frequency components can block out a section of a trace for as long as several minutes. 2) The CSA sometimes gives the impression that peaks are occurring at a given time when, in fact, they occurred several epochs before. There are methods for reducing both of these effects, however, such as decreasing the CSA gain, clipping large components, increasing the separation between epochs, and most importantly, artifact detection and rejection by the computer. 3) The resolution of the DSA is less than that for the CSA, since the eye can only distinguish among six to ten shades of grey. 4) The automatic gain control features of the DSA compensate for changes in EEG levels, so that absolute power comparisons between epochs cannot be made, since total gain is reduced as the input levels increase. This absolute intensity information can be displayed on the end-track, however, by varying the end-track width according to the total EEG power, as outlined above.

Finally, the DSA can be implemented on other types of displays. Levy†† has displayed it on an oscilloscope, with considerable success.

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