Technique

A miniature digital millivoltmeter for measuring intestinal transmural electric potential difference

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Transmural electric potential differences exist throughout the gastrointestinal tract, but hitherto clinical applications have been proposed only for proximal measurements (for stomach by Helm, Schlegel, Code, and Summerskill, 1965; Andersson and Grossman, 1965) and for distal measurements (for colon and rectum by Edmonds, 1970). Compared with these areas, the transmural potential difference (pd) across the small intestine is small, usually less than 10 millivolts, requiring sensitive electrometers for accurate measurement. Besides being bulky and expensive, such devices do not generally conform to safety criteria (Hospital Technical Memorandum, 1969) for clinical use, not being designed for this purpose. A simple millivoltmeter, both safe and portable, specifically designed for measuring rectal pd (Edmonds and Cronquist, 1970), lacks the sensitivity required for small intestinal work.

The positioning of a mucosal electrode in the lumen of the small intestine by peroral intubation is simple but slow; once in position, observation over a period of hours rather than minutes may be desirable. Thus there are obvious advantages in a robust, pocket-sized instrument which avoids the need to tether the subject to a static machine for long periods. Fortunately, recent advances in digital electronics make this feasible; the instrument reported here satisfies these requirements as well as the requisite electrical parameters of sensitivity and high impedance.

The instrument is small (overall, $10 \times 7 \times 3$ cm) and lightweight (200 g); since read-out is by light-emitting diodes (LED), there are no internal moving parts susceptible to shock. The external casing, of lightweight polystyrene, is in two parts which may be separated for replacement of the power source (two 9V PP3, and two 1.5V U16 dry batteries). The visual display is operated by a thumb-button, and

these, together with the input terminals, are grouped at one end of the instrument so that it may be used while, for example, it is resting in a coat pocket. Beside the display are two input terminals, which are miniature BNC locking coaxial sockets (Suhner Electronics Ltd) allowing the use of screened input leads. A small port on each side of the instrument gives access to screw adjustments for zero and calibration error. The general appearance of the instrument, connected for use to two sealed calomel reference electrodes, is shown in figure 1.

The operation of the instrument, illustrated in fig. 2, exemplifies the digital measurement of voltage. High-input impedance is obtained by buffering the inputs with a field effect transistor (Edmonds and Cronquist, 1970; Barry and Wallis, 1969), which has an input current of 10 picoamperes, giving an input resistance of 2000 megohms. To reduce noise at the input, the frequency response of the amplifier is limited by a feedback network with a time constant of 0.2 seconds; this provides 'damping' which, in a moving-coil galvanometer, derives from mechanical inertia. The amplified signal passes to the analogue stage where it is applied, in alternation with a reference voltage from a zener diode, to the integrator; switching, controlled by an oscillator, occurs every 2000 pulses. The integrator voltage is first increased by the amplified signal at a rate

Fig. 1 Miniature digital millivoltmeter. The instrument (right) is shown connected to two calomel reference electrodes (left).

Fig. 2 Block diagram of millivoltmeter circuitry

proportional to the signal magnitude, and then diminished by the reference voltage at a constant rate. When the integrator voltage returns to zero, this is detected by the comparator, and the count reached is stored in the read-out store. The digital stage provides the switching and timing waveform for the analogue stage, and the control waveforms for the LED display.

The read-out is provided by two pairs of LEDs separated by a space representing a decimal point. Direct read-out on the prototype instrument is from -9.99 mV to $+19.99$ mV, the negative sign being indicated by the numeral 2 in the first LED. The numerals 4 to 6 in the first LED indicate positive or negative input overload, while a flashing digit indicates an open circuit. Further models will operate in the range 0.0 - 200.0 mV, or incorporate dual range switching. A shorting lead allows the zero to be checked; battery exhaustion is indicated by zero instability.

Tested on preparations of isolated rat and canine intestine, the instrument has given values for transmural pd which were identical with simultaneous readings on a mains-operated digital voltmeter and a Vibron 33B electrometer. A pilot study (Wingate, Hayward, Johnson, Marczewski, Petty, and Wilson, in preparation) on human subjects has shown that small changes (<1 mV) in human jejunal transmural pd are easily detected.

The high gain in the prototype instrument is appropriate to the pd range found in the small intestine, and a lower gain may find wide application in the monitoring of transepithelial DC potentials from stomach, colon, and skin. Studies are in progress to enable the output to be recorded on $1/8$ in. tape on a miniature AM recorder of similar dimensions.

Outside the medical field, advances in electronics have brought low-cost miniaturization to the point where pocket-sized electronic calculators are promoted as Christmas gifts. This instrument has utilized these advances for clinical measurement, where the safety factor of battery power is an added bonus, and it may be predicted that low-cost miniature digital equipment will be widely introduced into medical measurement in the next decade.

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