FEED-BACK MONITORING IN ANAESTHESIA
II: PULSE RATE CONTROL OF HALOTHANE ADMINISTRATION

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SUMMARY
The automatic control (feed-back) of clinical halothane administration by monitoring pulse rate is described. This form of feed-back monitoring proved satisfactory for patients on controlled ventilation; stable cardiovascular conditions were maintained and the technique was easy to use without special skill, although it required special equipment.

Automatic anaesthesia using electroencephalographic assessment of depth was described by American authors in 1951 and 1954. A first paper (Soltero, Faulconer and Bickford, 1951) dealt with ether vaporization in a closed circuit with spontaneous respiration. A second communication (Kiersley, Faulconer and Bickford, 1954) was concerned with thiopentone anaesthesia during spontaneous respiration and in the presence of partial curarization. General acceptance and indeed further development of automatic anaesthesia were probably hampered by the choice of the electroencephalogram as the only parameter. The e.e.g. is not a reliable guide to the depth of anaesthesia, not even as an indication of the presence or absence of unconsciousness (Munson, 1970). Moreover it is an unsafe parameter because no warning of respiratory or circulatory failure is given until very late. Other important drawbacks are the time necessary to set the instrument, the special skill required and the need for different “integrators” for each anaesthetic agent.

The technique of limited automatic control of steady state anaesthesia described as feed-back monitoring (Suppan, 1970) relies on the automation of generally used methods of clinical anaesthesia. The chosen variables are the pulse rate (obtained from a pulse monitor), the systolic arterial pressure (measured by the indirect method), and the respiratory rate and tidal volume. Other variables could be used but for the first version of this instrument it was decided to avoid measurements which were not in routine clinical use.

This paper presents in some detail the use of one sensor (the photoelectric pulse monitor) to control one actuator (the halothane vaporizer) during anaesthesia either when the patient is breathing spontaneously or is being ventilated artificially.

MATERIALS AND METHODS
The principle of feed-back monitoring is illustrated in figure 1: a sensor picks up information from the patient (pulse rate, blood pressure, respiratory pattern) and the value is displayed on the integrator. Two action limits are chosen on the integrator, each

![Diagram of principle of feed-back monitoring used in the present study.](https://academic.oup.com/bja/article-abstract/44/12/1263/268514)
of which controls an actuator such as a flowmeter, a vaporizer, or a drip control or injector.

The prototype instrument (fig. 2) uses two monitors, a photoelectric pulse monitor and rate meter (MIE) and a blood pressure measuring unit, which operates by means of a cuff inflated by an electric pump at predetermined intervals of between 1 and 10 min. The level at which the pulse disappears, as indicated by the photoelectric plethysmograph, is taken as the systolic blood pressure.

The values of pulse rate and systolic arterial pressure are displayed on two dials of the integrator. The pulse rate is measured continuously. Systolic arterial pressure is determined at intervals and the last value is displayed until the next reading is taken. As the same pulse monitor is used for pulse rate and systolic arterial pressure determinations the rate value is “blocked” on its latest position during pressure measurement.

Each integrator dial has a low and a high level, both variable, and each is linked to an actuator output, for example a vaporizer, which controls the inhaled concentration of the anaesthetic.

The “actuators” are at present a halothane vaporizer, injectors, a drip control and flowmeters.

The vaporizer is based on the Fluotec 3 (Cyprane) (fig. 3). An electric motor adjusts the control knob between the “off” and “5%” positions, at intervals of 0.5%. A control unit selects three positions, low, medium, and high, between which the vaporizer output will vary. The vaporizer itself can be used manually or by feed-back control, either within the circle system or outside.

The injector is an electrically operated device using 10-ml disposable syringes from which is injected a fixed volume (0.5 ml) in response to an electric signal from the integrator. In practice the syringe is linked to an indwelling catheter or a butterfly-type needle.

The drip control consists of a single piston electrically operated; the drip bottle has two outlets, each controlled by its own manual knob. One tube is left free, set to a slow rate. The second is controlled by the piston, with only two positions: “on”, or “off”. Thus two rates can be produced: the fast rate is the combination of the two outputs, the slow rate the output of the first (uncontrolled) tubing only.

Flowmeters for oxygen and nitrous oxide are electrically controlled (fig. 3). The position of the float is determined by light beams and photoelectric cells. Two modes of operation are available: in most cases it will be enough to keep these flows steady at a predetermined level.
When respiration was to be spontaneous, thiopentone was followed by suxamethonium 75–100 mg for intubation. Thereafter either a circle system or a semiclosed system (with partial rebreathing) was used. A dextrose-saline intravenous drip was started in all cases.

Immediately after induction and intubation the sphygmomanometer cuff was placed around an arm and the photoelectric pulse monitor positioned on a finger on the same side.

When a clinically satisfactory steady state was achieved, the integrator was switched on and the first pulse rate reading taken. This steady state value was then used to select the high and low limits; the vaporizer positions were selected to correspond to each of these limits. As long as the pulse rate remained within these limits, the original medium setting of the vaporizer was not altered. With the halothane vaporizer controlled by alterations in the pulse rate, the lower limit of the dial was linked to the low vaporizer position, so that a fall in the heart rate would lead to a reduction of halothane output (table I).

<table>
<thead>
<tr>
<th>Plan</th>
<th>Low (%)</th>
<th>Medium (%)</th>
<th>High (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled respiration</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Spontaneous respiration</td>
<td>3</td>
<td>1.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

The limits (i.e., the values of pulse rate that controlled the vaporizer setting adjustments) themselves depended on the steady state readings and on the stability of the parameter (table II). As long as the pulse rate remained within the limits the actuator
was unaltered at the steady state level, in this case the medium position of the vaporizer. Other actuators which only control two positions (such as the injector and drip control, not reported here) remained at their original positions as long as their only controlling limit had not been reached.

**TABLE II. Integrator limits (the values of pulse rate that controlled the vaporizer setting adjustment) used in two studies: the first with values close to the steady state reading (st. st.), the second with limits (especially the low limit) far from it.**

<table>
<thead>
<tr>
<th></th>
<th>Low limit (%)</th>
<th>High limit (%)</th>
<th>Steady state values (μA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study 1</td>
<td>2.5-5</td>
<td>5-10</td>
<td>41.2</td>
</tr>
<tr>
<td>Study 2</td>
<td>10-12.5</td>
<td>5-10</td>
<td>42.5</td>
</tr>
<tr>
<td>10 cases in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>study 1</td>
<td>39.5</td>
<td>44.2</td>
<td>10 cases in</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>8</td>
<td>study 2</td>
</tr>
<tr>
<td></td>
<td>below st. st.</td>
<td>above st. st.</td>
<td></td>
</tr>
<tr>
<td>10 cases in</td>
<td>38.0</td>
<td>45.6</td>
<td>42.5</td>
</tr>
<tr>
<td>study 2</td>
<td>10</td>
<td>7.5</td>
<td></td>
</tr>
</tbody>
</table>

Upper figures, planned difference from the steady state value, in % below (low limit) and above (high limit).
Lower figures, actual differences in ten cases in each study (mean value and % below and above).

Anaesthesia was maintained by feed-back monitoring with the pulse monitor as sensor and the Fluotec vaporizer as actuator during a variety of procedures, mainly gynaecological and ophthalmic. Premedication and induction have been described. For patients having controlled ventilation, several muscle relaxants were used, since it was important to assess their effects on the pulse rate. The sequences chosen were:

1. Gallamine (160 mg) followed by increments of tubocurarine (5 mg).
2. Alcuronium (20 mg, increments of 5 mg).
3. Pancuronium (4 to 6 mg, increments of 2 mg). This drug was studied in a larger number of patients because pulse rate stability was anticipated.

Records were taken from minute to minute during the whole procedure on special charts as shown in figures 5, 6, 7. These show the working of the automatic instrument between its three positions ("low", "medium" and "high"), while the values for pulse rate read on the integrator dial are entered on the lower part of the record. Blood pressure was determined manually using the indirect method.

The choice of action limits on the integrator was planned in two series: one with the limits (especially the lower limit) set close to the steady state value, the second with these limits far from it (table II). All pulse rate values are given in μA, as read on the integrator dial. This is more accurate than the pulse rate per minute indicated on the pulse monitor, but a conversion diagram is provided in figure 4.

**RESULTS**

The results obtained from a series of 33 patients from whom accurate records were kept are reported here. For these 33, the total operating time was 30 hr 51 min, (the shortest case was 26 min, the longest 122 min, excluding the five operations for detached retina), of which 25 hr 54 min (84%) of anaesthesia was controlled automatically.

**Sensor behaviour.**

In some cases the pulse rate obtained from the photoelectric pulse monitor was unsteady, suggesting that cardiac arrhythmia was present, although a regular radial pulse could be felt. It has not been possible to explain this. Local factors are probably the most important and include: poor capillary filling, vasoconstriction (rare under halothane anaesthesia) and accompanying low skin temperature. If such an unsteady pulse rate is found once a steady state has been established, the sensor should be set on another digit or phalanx to obtain a reliable signal. "Freak" pulse rate variations occasionally occurred after the instrument had been in use for some time. In all such cases the displayed rate dropped, leading to a switching of the vaporizer to its low position. The system thus retained its fail-safe behaviour. If
FEED-BACK MONITORING IN ANAESTHESIA—II

D E

POSITION OF VAPORISER

H
M
L

1267

POSITION

TIME

min

0
10
20
30
40

50

PULSE RATE

μA

45

40

A
B
C

50

A
B
C

Fig. 5. Record of a case under feed-back monitoring showing pulse rate decrease following the temporary increase after gallamine. The integrator limits had to be reset 20 min after induction (12 min after reaching a steady state).

(A) Induction (sodium thiopentone 400 mg, gallamine 160 mg).
(B) Tubocurarine 5 mg, pentazocine 15 mg.
(C) Peritoneal closure.
(D) Start of feed-back monitoring. Limits set at 52 and 46 μA. Halothane vaporizer setting: High 1.0%, medium 0.5%, low 0%.
(E) Resetting of integrator limits to 45 and 40 μA.

The switchings of the vaporizer to the low position at about 29 min were accounted for by interference with the pulse monitor.

The signal remains unsteady, it is best to change the photocell to another digit.

Another problem investigated was the possibility of interference caused by electrical appliances in the operating room. The only such interference found was that caused by the electrocautery, which sometimes led to an increase in the pulse rate reading. Although this meant that the vaporizer was switched to its “high” position the time factor was always very short and the result therefore not dangerous. So far it has not been possible to determine why the electrocautery produced this interference on the pulse monitor.

These problems are not inherent to feed-back monitoring but to the sensor itself investigated in this series.

Induction—steady state interval.

The time between induction and the development of a steady state before setting up the instrument was on average just under 9 min. The shortest interval was 4 min and the longest 15 min. The longer intervals were attributable to unsteady rates on the pulse meter and to the necessity to move the pulse monitor to another digit. No delay was ever occasioned to the start of surgery during cases under controlled ventilation.

Selection of integrator limits.

The steady state pulse rate was found to be high initially and to decline progressively. This is shown by the example in table III. Automatic working thus

<table>
<thead>
<tr>
<th>Reset after (min)</th>
<th>Steady state value Medium 0.5%</th>
<th>Integrator limits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>8</td>
<td>46</td>
<td>45</td>
</tr>
<tr>
<td>15</td>
<td>39</td>
<td>35</td>
</tr>
</tbody>
</table>

Gallamine 160 mg was used in this case during induction. Pulse rate values in μA.
requires the lower limit to be set rather low relative to the steady state reading, while the upper limit can be set close to it. With this arrangement resetting may not be necessary for periods of 30 to 40 min and more. Thus in a case in which the steady state value was 46 μA, with limits set at 40 and 47 μA, it was necessary to reset after 36 min. In another (steady state 36 μA) with limits at 32 and 39 μA the settings were unchanged for 40 min (until the end of the operation) and might have been suitable for longer.

Effects of muscle relaxants.

The effects of different muscle relaxants on the pulse rate varied. With gallamine the steady state pulse rate value was high and declined early, so that the integrator limits had to be reset within 10–15 min unless the lower limit was set more than 20% below steady state reading. This is inadvisable as the actual decline in pulse rate in individual patients cannot be forecast with sufficient accuracy.

Pancuronium gave the most stable readings and thus appears to be the most suitable agent for feedback monitoring. An average adult dose of 6 mg was needed to provide satisfactory conditions for intubation but this did not produce adverse cardiovascular effects affecting the settings of the integrator. Pancuronium in 1 or 2 mg increments did not alter the pulse rate significantly in either direction and this again confirms its value when feedback monitoring is used. Tubocurarine produced a slight decrease which was not significant if the integrator limits were
Fig. 7. Pulse rate and respiratory rate during a breast operation with spontaneous respiration. The decline in respiratory rate is not followed by a similar change in pulse rate (steady state 39 μA, maximum 41 μA). Note that position of the vaporizer did not change during the whole procedure lasting 46 min.

(A) Induction (sodium thiopentone 400 mg, suxamethonium 100 mg).

(B) Incision.

(C) Start of feed-back monitoring. Integrator limits at 42 and 32 μA. Vaporizer settings: High, 2.5%; medium, 1.5%; low, 1.0% halothane.

Spontaneous respiration (fig. 7).

The pulse rate tended to remain fairly stable over long periods despite the higher vaporizer settings (1-1.5-2.5%). The rate did not respond to surgical stimulation as satisfactorily as respiratory rate, and it is felt that in patients breathing spontaneously respiratory parameters should be used to control the halothane vaporizer. Pulse rate and blood pressure limits could then be used to control other actuators such as the drip control or alarm units.

In the case illustrated respiratory rate declined progressively 40% from steady state value. Pulse rate declined at first but then remained steady very close to the steady state reading (reaching a maximum of 41 for a steady state value of 39 μA).

DISCUSSION

Feed-back monitoring using a pulse monitor as sensor and a Fluotec vaporizer as actuator provided very satisfactory control of anaesthesia in patients with controlled ventilation. In patients with spontaneous respiration this form of control was not ideal, and probably the use of the respiratory patterns will provide better feed-back control of halothane anaesthesia.

In the patients with controlled ventilation cardiovascular stability was a remarkable feature with the vaporizer settings at “Off”–0.5–1%. Pulse rate varied within narrow limits and blood pressure remained unaffected by long periods at 0.5% halothane. Despite the low concentrations used no awareness was
reported. This confirmed the reliability of the feed-back system based on pulse rate, since the fall in rate following minimal surgical stimulation often occurred towards the end of an operation and led to long periods at the low (Off) vaporizer position.

The aims of this limited automatic control of anaesthesia are twofold:

1. To perform continuous control of some aspects of a long or special procedure. This may allow the anaesthetist to deal with other aspects of patient care or to control automatically a special procedure such as induced, arterial hypotension.

2. To provide automatic control during prolonged administration of an anaesthetic agent.

It is important to emphasize that feed-back monitoring does not aim to keep a constant level of anaesthesia, but to maintain a steady state of a vital physiological variable which is influenced by the anaesthetic agent or by another agent used during the procedure.

It is a matter of individual choice whether to use the pulse rate, the blood pressure, or any other variable for automatic control. Thus feed-back monitoring could be used to control the administration of halothane during induced arterial hypotension, quite regardless of any anaesthetic level achieved. Drugs used during anaesthesia other than anaesthetic agents, for example ganglion blockers or neuromuscular blockers, can be administered under similar continuous automatic control.

Although feed-back monitoring uses the same variables as does non-automatic anaesthesia one aspect needs some comment. The variations of the actuators are limited to a small number of positions, in this first study to three positions of the vaporizer, whereas the anaesthetist has available all the positions of his instrument. The choice of these three positions for feed-back monitoring is therefore extremely important. Similarly only two limits are available on the integrator for any one variable once the steady state has been achieved. With these limitations feed-back monitoring must be considered as a technique somewhat different from non-automatic anaesthesia. However, the reasonably short time between induction and steady state (about 9 min in this series) allows the technique to be used for a large variety of cases, even quite short procedures (20–30 min). No special skill is needed, particularly when external (non-invasive) sensors are used, and this is in contrast to the limitations of the technique based on the electroencephalogram.

Finally, apart from clinical anaesthesia, feed-back monitoring may find an application in intensive care and in special therapeutic procedures. Soltero, Faulconer and Bickford (1951) mentioned that automatic anaesthesia could be helpful if prolonged maintenance of narcosis should have therapeutic value. Such prolonged administration has been used to control the convulsions of eclampsia (Lee and Atkinson, 1968) and in status epilepticus (Brown and Horton, 1967). Recent work on the inhibition of mitosis by anaesthetic agents with the aim of synchronizing cell division in given cell groups (Nunn, Lovis and Kimball, 1971) may also lead to the clinical use of prolonged anaesthesia. In these instances it is likely that owing to the concentrations used, vital parameters such as the pulse rate and blood pressure will provide more reliable control of automatic administration than the use of the electroencephalogram.

ACKNOWLEDGEMENT

The instrument design and development was undertaken in co-operation with NP Consulting, Longmead, Coombe Bissett, Salisbury, England.

REFERENCES


“FEED-BACK MONITORING” AU COURS DE L’ANESTHESIE.

II: CONTROLE DE LA FREQUENCE CARDIAQUE SOUS HALOTHANE

SOMMAIRE

Le contrôle automatique (en circuit "feed-back") de l'administration d'halothane en clinique, par enregistrement de la fréquence cardiaque, est décrit. Cette forme de "feed-back monitoring" s'est avérée satisfaisante chez des malades soumis à une respiration assistée. Des conditions cardio-circulatoires stables ont été maintenues et la technique a été facile à mettre en œuvre, sans dextérité particulière, bien qu'un équipement spécial ait été nécessaire.
FEED-BACK MONITORING IN ANAESTHESIA—II

SELBSTREGULIERUNGS-ÜBERWACHUNG IN DER ANAESTHESIE
II: PULSFREQUENZKONTROLLE UNTER ANWENDUNG VON HALOTHAN

ZUSAMMENFASSUNG

BOOK REVIEWS


Although extensively revised, this little book remains eminently readable—as indeed it should be, considering the reputation of the senior author.

One wonders, however, if time has not now overtaken it. When first published it was common practice not only for students to give anaesthetics but in certain circumstances to do so unsupervised. The latter was certainly the case for young doctors shortly after qualification and this book filled a need for them, being primarily concerned with practical advice on simple forms of anaesthesia.

Happily a new era has now arrived and unsupervised "amateur" anaesthetists are extremely rare. As a result, undergraduate teaching has moved towards teaching students about anaesthesia rather than how to give an anaesthetic. They therefore receive useful revision of respiratory and cardiovascular physiology and a large slice of applied pharmacology as well as an opportunity to watch skilled anaesthesia. This book lacks many of these aspects of teaching and would hardly form the basis for a course in anaesthesia for students.

However, there are many countries where the basic instruction set out so clearly in this book will serve a useful purpose. Minor complaints include the use of the word "anoxia" when "hypoxia" is meant, the lack of any mention of head position (i.e. full extension) in regard to maintaining a clear airway, the statement that pancuronium has no effect on pulse rate, the advocacy of rectal tap water for patients "not severely shocked", and the assumption that pethidine is less emetic than morphine.

D. B. Scott


"Handbooks" are a popular feature in medical literature in the U.S.A. They contain a large amount of factual information in the smallest possible space.

Dr Catron has now produced one for anaesthetists. It can be kept in the anaesthetic machine and should be useful for quick references, either to solve a problem or settle an argument. It could also be used with profit by the examination candidate for last-minute memory jogging.

Quite naturally it is orientated towards anaesthetic practice in the U.S.A. and contains many arguable points. Nevertheless it achieves its object admirably.

Unfortunately, the price here is considerably more than it should be for a paper-back of 150 pages.

D. B. Scott