AMPLITUDE OBSERVATION DURING CLOSED CIRCUIT HALOTHANE ANAESTHESIA, WITH THE VAPORIZER INSIDE THE CIRCUIT

BY

J. R. J. BEDDARD

Royal United Hospital, Bath, Somerset, England

SUMMARY

In halothane and methoxyflurane anaesthesia pulse amplitude observation is an important clinical sign. At blood pressures above the peak amplitude pressure:

\[ \text{amplitude} \propto \frac{1}{\text{peripheral resistance}} \]

or more accurately, \( \propto \frac{1}{\text{"proximal" vasoconstriction}} \).

At peak amplitude blood pressure and lower blood pressures:

\[ \text{amplitude} \propto \text{arterial blood pressure} \]

Continuous amplitude observation correlated with periodic arterial pressure measurements make it possible to administer halothane in a closed circuit, the vaporizer being inside the breathing circuit and respiration being controlled, with confidence and safety, and without reference to the actual percentage inhaled. This is a clinical technique for giving enough halothane to produce the desired effect. Using a basal flow of oxygen the quantity of halothane consumed is about one-sixteenth of that used when it is vaporized with a gas flow of 8 l./min. Therefore in addition to producing the desired level of anaesthesia and hypotension, great economy is achieved.

Comparatively few anaesthetists use halothane in oxygen alone as a complete anaesthetic as described by Johnstone (1961). The obvious merits of halothane include the ease and pleasantness of rapid induction of anaesthesia in patients of all ages, and its capacity for providing good surgical relaxation. It is non-explosive and, for the most part, non-reactive. Its potency permits the use of a high oxygen atmosphere. The high cost of halothane means that it is economical only when used in a closed circuit, which technique is made possible by its stability in the presence of soda lime. Arterial hypotension may occur with halothane but, with the technique about to be described, this may be controlled at any desired level. Its potency may be considered disadvantageous by some, and reports about a possible hepatotoxic effect have been fully assessed (Mushin et al., 1964). Cardiac arrhythmias arising during halothane anaesthesia often cause concern, but in the author’s experience these have not been met when the anaesthetic has been given in a closed circuit with controlled pulmonary ventilation and with efficient carbon dioxide absorption, thus avoiding hypercarbia (Dundee and Black, 1960).

The use of halothane in a completely closed circuit with a basal oxygen flow of about 250 ml/min has not achieved great popularity in the British Isles. Still less popular is the use of a technique in which the halothane vaporizer is in the circuit, and in which the pulmonary ventilation is controlled. Yet to get the full benefit for surgery all these methods may need to be applied. It is the purpose of this article to describe a new clinical sign, whereby these methods may be safely used, thus making it possible to meet most of the demands of surgery by using only one anaesthetic agent.

METHOD

The author has employed the technique consisting of the use of halothane, with the vaporizer in the circuit, with controlled ventilation, the circuit being completely closed, since 1958. It has been used for the majority of patients coming for major surgery irrespective of age or state of health.

Premedication consists of pethidine 100 mg, atropine 0.6 mg given 1 hour before induction of anaesthesia. In the old and poor-risk patient...
Pethidine is reduced to 50 or 25 mg. A sleep dose of thiopentone is used to induce anaesthesia in healthy patients and this is followed by tubocurarine 15 mg. Before intubation a 4 per cent lignocaine spray is employed. Thiopentone is not used in aged or poor-risk patients, induction being achieved by use of halothane and oxygen. The glottis and trachea are then sprayed before intubation. Patients liable to vomit during induction are given suxamethonium to facilitate immediate intubation and spraying of the larynx is omitted.

**FINDINGS AND RESULTS**

In 1958, when reports of arrhythmia of the heart beat in halothane anaesthesia began to appear (Delaney, 1958), it was decided that in all such anaesthetics the pulse should be monitored with a simple unamplified indicator of the Bishop type (Bishop, 1958) (fig. 1). While observing the indicator for pulse irregularities, significant changes in the swing (amplitude) of the microammeter needle were noted. It was decided to measure these amplitudes in geometrical degrees and to plot them on a chart together with the arterial pressure (systolic and diastolic), the respiration, the pulse, and the vaporizer settings. The change in amplitude was the important datum, but in order to display this accurately the potentiometer had to be adjusted for each patient to produce an optimum swing. This was achieved as follows: Figure 1 shows that the meter has a potentiometer scale numbered from 0 to 10. As the anaesthetic proceeds from induction to maintenance, the amplitude is observed to increase until a maximum (peak amplitude) is reached. Then, if necessary, the potentiometer is set so that a swing of about $70^\circ$ is obtained. The potentiometer setting is not then altered again during that particular anaesthetic.

It was noted that the amplitude was small during consciousness (figs. 2, 4 and 6); rose to a maximum or peak with the onset of surgical anaesthesia, and from then onwards fell with the blood pressure (fig. 6) as the anaesthesia deepened, until ultimately if an overdose was given both amplitude and blood pressure would approach zero. Moreover, if the vaporizer was turned off and the lungs ventilated with oxygen, the amplitude increased with the rise in blood pressure until a maximum (peak) reading was again recorded, and then, as the patient became very lightly anaesthetized the blood pressure would continue to rise while the amplitude would fall again towards the conscious level. Figure 3 illustrates the theoretically perfect peak amplitude anaesthetic chart, while figure 5 represents the theoretically perfect O.Y. peak hypotension anaesthetic chart.* It was discovered that peak amplitude would generally correspond with a systolic blood pressure of between 80 and 110

* The amplitude is plotted as the ordinate. If $Y^\circ =$ the value of the peak amplitude, then all other amplitudes may be expressed as a decimal fraction of $Y$. Hence we have a new way of expressing the degree of hypotension with reference to the peripheral pulse pressure.

The theoretically perfect charts are shown in order to explain the important relationship between amplitude and blood pressure, and hence the importance of amplitude observation. They may be looked upon as analogous to the theoretically perfect reactance-capacitance tuned circuits, described in electronics, where all resistance is disregarded and only reactance is considered. In this case the parallel circuits have an infinite resistance and the series circuits have an infinite electric current.
FIG. 2
Record of amplitude and systolic blood pressure during operation in a man aged 57 years for recurrent right inguinal hernia. The values of peak amplitude and peak amplitude systolic pressure were the same at the beginning and at the end of the anaesthetic. Spontaneous respiration was maintained throughout the operation.

FIG. 3
A theoretical chart showing the pattern of an ideal example of an anaesthetic maintained at peak amplitude.
Record of amplitude and arterial pressure during anaesthesia in a woman aged 36 years operated on for varicose veins. This is an anaesthetic maintained near peak amplitude. Spontaneous respiration was maintained throughout the anaesthetic.

Upper record, systolic blood pressure.
Lower record, amplitude.

A theoretical chart showing the amplitude rising to peak, and the systolic blood pressure falling to peak amplitude systolic blood pressure. Thence both fall to O.Y. peak amplitude and O.Y. peak amplitude systolic blood pressure respectively. They are maintained at this level, and on lightening the anaesthetic the process is reversed.
The practical application of fig. 5. The chart of a woman aged 44 years, who was given halothane hypotension for a Wertheim hysterectomy. Controlled respiration was maintained throughout the operation.

Upper record, arterial pressure. Lower record, amplitude.

mm Hg, depending on the patient's normal blood pressure. This was called the peak amplitude systolic blood pressure (figs. 2, 4 and 6). Peak amplitude systolic blood pressure was remarkably constant for a given patient (fig. 2) providing that the operation was not too lengthy or severe. If these two factors were present, the peak amplitude systolic blood pressure would give a lower value on lightening the anaesthetic at the end of the operation. Figure 6 shows all the useful changes in amplitude related to systolic blood pressure, and it will be noted in this case that the final rise (peak) in amplitude was not as great as the initial one, for the operation, a Wertheim hysterectomy, was long and severe.

In figure 2 peak amplitude was the same at 65° and the peak amplitude systolic blood pressure was also the same at 120 mm Hg at the beginning and at the end of operation, thus showing that the patient's cardiovascular system was little affected by the operation for recurrent right inguinal hernia.

These changes in amplitude can be controlled and kept close to any desired magnitude by simply applying controlled ventilation and manipulating the vaporizer settings accordingly. Thus it is that a continuously steady degree of hypotension can be maintained and checked by occasional blood pressure readings.

The vaporizer used latterly was a modified Goldman Mark II* (fig. 7) fitted with a worm and ratchet fine adjustment control. The worm wheel is most advantageous because it prevents the setting from being accidentally altered as well as giving 75 very fine and precise settings, any of which can be selected with great accuracy. By checking the arterial pressure every 5 minutes and maintaining a steady amplitude, the patient can be kept at a safe level of anaesthesia and hypotension. It was found that an amplitude of 0.5 peak corresponded to a satisfactory level of hypotension. Amplitude observation differs from blood pressure readings in that it is a continuous process and it is observed throughout the administration of the anaesthetic. When anaesthesia is deeper than the level of peak amplitude anaesthesia, a further fall in amplitude indicates the need for an immediate check on the blood pressure, and if an excessive hypotension is noted, one of the following methods to raise the blood pressure may be adopted according to the needs of

* See acknowledgments.
Modification of the Goldman Mark II halothane vaporizer. The instrument is turned on to a setting of 1.8. In closed V.I.E. anaesthesia with controlled respiration a setting of between 1.8 and 2.5 maintains a steady level of hypotension. The halothane is “ventilated out” of the patient, and within half a minute or so the amplitude will increase, and this is followed by a rise in arterial pressure. The vaporizer must be readjusted and the lungs ventilated accordingly. It must be remembered that sufficient ventilation must be given to keep the alveolar carbon dioxide at a normal level. The author tries to over-ventilate; aiming in the average adult at a minute volume of about 10 l./min by compressing the 1 litre reservoir bag about 20 times a minute, it being half emptied with each stroke. Controlled ventilation is carried out manually so that there may be co-operation with the surgical manoeuvres in the thorax or upper abdomen: often a faster rate with a smaller tidal volume will hinder the surgical technique less. A raised intrathoracic pressure will impede the venous return and so possibly add to the hypotension; one must refrain from over-distending the bag or from over-inflating the lungs. Efficient ventilation across active soda lime will cause a lowering of the plasma carbon dioxide level, and this will help to reduce the amount of anaesthetic (halothane) required (Robinson and Gray, 1961; Robinson, 1961). It will be remembered that hypotension by earlier methods left a trail of disasters, so that this technique is not for the “occasional anaesthetist”, but colleagues wishing to learn it will discover that, in a matter of moments, they have tremendous power over the patient and that there is great economy in halothane. It is advised that they do not aim at profound hypotension until, by careful amplitude observation and repeated checks on the arterial pressure, they can maintain anaesthesia, so that systolic arterial pressure is kept steady at 70 to 80 mm Hg. If the head has to be elevated, as in certain operations on the head and neck, the arterial pressure should not be allowed to fall below 70 mm Hg.

Even with the modified Goldman vaporizer it is possible to build up a percentage of halothane equal to vapour saturation for the working temperature. Using an extra bag instead of the patient and circulating oxygen round the circuit by alternately compressing the bags, it was found (with the Goldman halothane vaporizer fully turned on) that after 30 seconds a sample analyzed by gas chromatography contained 10 per cent halothane. The use of a rapidly-acting halothane meter might form an added safety factor.
However, patients vary in their resistance to halothane and reliance on such analyses should not replace the observation of an experienced anaesthetist using the clinical test of amplitude observation and frequent blood pressure checks. The author's experience with the technique has now exceeded 4,000 administrations and there have been no complications causing permanent disablement. Postoperatively many of the patients have been visited by the author, and all have been under the close and critical scrutiny of the surgical faculty. Complications have been looked for and none reported. Theorists might think that retinal and cerebral thrombosis, or reactionary haemorrhage would occur, but in fact there have been no such complications during this period.

During maintenance of anaesthesia, the success of the technique depends on an airtight circuit, a basal oxygen flow of 200–300 ml/min, omission of nitrous oxide, and fresh soda lime. Muscle relaxants are not necessary, and a partly paralyzed patient with a flickering reservoir bag will be liable to develop pulse irregularities and their sequelae. For anaesthetics given near to or above peak amplitude, it is not necessary to control pulmonary ventilation, and in figures 2 and 4 spontaneous respiration was used throughout.

It was the chart of figure 2 which led the author to understand the pattern of the amplitude during halothane anaesthesia, but of course many other factors will affect the amplitude, e.g.: 

(a) A battery which is nearly exhausted (the life of the $7\frac{1}{2}$ volt battery approaches its shelf life, as very little current is consumed).

(b) The application of the microphone to the pulp of the digit; firm but not tight contact is desirable.

(c) Extreme flexion of the elbow will reduce the peripheral pulse in the fingers.

(d) Tight bandaging of the upper extremity to which the microphone is attached.

(e) Elevation of the patient's head, or the limb attached to the microphone.

(f) The change to the Trendelenburg position.

(g) If the microphone is in contact with the patient's chest the respiratory movements can be superimposed on the pulse beat.

By a little attention to detail, these factors can be kept constant or reduced to a minimum without much difficulty, and then the changes in amplitude will be related to the peripheral resistance and the arterial pulse pressure as previously described.

When using halothane in a closed circuit with control of ventilation and with the vaporizer in the circuit, measurement of arterial pressure at 5-minute intervals is insufficient. In some patients the systolic pressure has been observed to fall from 80 mm Hg to zero in half a minute. However, turning the vaporizer off and ventilating the lungs with a high inflow of oxygen has always rapidly restored both the amplitude and the pulse pressure.

The same observations also apply to methoxyflurane given by the same technique. However, this anaesthetic agent is slower in producing hypotension and the re-establishment of normal blood pressure by ventilation with oxygen is also slower. The anaesthetist would be well advised to avoid profound hypotension with this drug; however, it is a better drug than halothane to use in closed circuit (V.I.C.) with spontaneous respiration, and to date no pulse irregularities have been noted during its use.

DISCUSSION

The use of halothane with the vaporizer in circuit and with an oxygen flow of 1 l./min and spontaneous respiration has been described by Marrett (1959), and of halothane in oxygen 4 l./min with controlled respiration was described by Murtagh (1960). The advantages claimed for the use of halothane in a completely closed circle circuit (V.I.C.) with controlled pulmonary ventilation are that complete control over the depth of anesthesia is possible, upon which the amount of relaxation and then the degree of hypotension depends; relaxation has been found to be fully developed before profound hypotension occurs.

In addition there is a very considerable economy in the amount of halothane consumed; if closed circuit halothane was adopted in the hospital group in which the author works, the annual bill for halothane would be reduced to one-sixth of the present figure. Over the whole of the British Isles it would be expected to result in a saving of about £250,000 annually. This would bring halothane into favourable economic competition with other anaesthetic techniques.
Axioms.
When using amplitude observation in halothane (and methoxyflurane) anaesthesia the following axioms hold good:
(1) A small amplitude and a normal or slightly lower than normal blood pressure indicates vasoconstriction and light anaesthesia. Excessive vasoconstriction will occur in conscious patients who are apprehensive or who have cold extremities. Here the amplitude may be very small or absent.
(2) A maximum amplitude and a systolic blood pressure of between 80 and 110 mm Hg indicates light third stage anaesthesia. This is anaesthesia at peak amplitude and it can be used with confidence in the poor risk case.
(3) A small amplitude and a low systolic blood pressure indicates hypotension, and this can be regulated according to the surgical need by adjusting the vaporizer, and ventilating with either an increased or a decreased halothane vapour concentration.

Definition of pulse and examination of the amplitude changes.
A pulse is a rhythmic change, and it may be defined as the difference between maximum and minimum events in the rhythmic change.
The arterial pulse pressure is the difference between arterial systolic blood pressure and arterial diastolic blood pressure. The peripheral pulse pressure is the difference between peripheral systolic blood pressure and peripheral diastolic blood pressure. The arterial pulse is sited in the large arteries whose walls mainly consist of elastic tissue.
It is true that there is no sharp line of demarcation between the arterial pulse and the peripheral pulse, for the former shades into the latter. It is also true, however, that the typical peripheral pulse occurs in the centre of the vasomotor area. That is, it will have contractile, smooth, muscle-coated arteries, both proximal (“heart side”) and distal (“tissue side”) to it. Vasoconstriction of the proximal peripheral arteries will have a damping effect on the arterial pulse pressure, so that when the pulse arrives at the point where the peripheral pulse is recorded, the peripheral pulse pressure is much reduced, and therefore the swing of the microammeter needle is much reduced. The early effect of halothane and methoxyflurane inhalation on the peripheral pulse pressure is to increase it by causing a dilatation of the proximal peripheral arteries and so remove the damping effect of their vasoconstriction. The later effect of halothane and methoxyflurane inhalation, as the vapour concentration is further increased, is to dilate the blood vessels (Enderby, 1960) distal to the point where the peripheral pulse pressure is recorded and so cause a fall in the peripheral pulse pressure by increasing the distal vascular capacity. This fall in peripheral pulse pressure is shown by a steady decrease in the amplitude of the microammeter and is now proportional to the arterial pulse pressure.
As halothane and methoxyflurane produce first a relaxation of striated muscle and then a relaxation of smooth muscle, it is only logical to assume that, at a deeper plane of anaesthesia, it weakens the contraction of the cardiac muscle and this will also contribute to the fall in both arterial pulse pressure and peripheral pulse pressure.
The peripheral pulse may be conveniently measured in the pulp of any digit by applying a microphone and noting the swing (or amplitude) in geometrical degrees, of the microammeter needle.
If the amplitude is observed throughout the administration of a halothane or methoxyflurane anaesthetic, the same sequence will occur in every instance, providing the microphone (in this case a carbon button type) is protected from outside mechanical interference. First the amplitude will rise to a peak (3 or 4 times that seen during consciousness) and this is called peak amplitude; then it will fall in direct proportion to the arterial pulse pressure. The initial rise to peak is brought about by vasodilatation of the proximal arteries referred to above. These changes occur gradually and may remain constant for a given concentration of halothane. They can be kept constant by adjusting the vaporizer and by manual compression of the reservoir bag. The amplitude can be maintained close to any chosen value for a given patient, providing the vaporizer has a fine adjustment and is regulated accordingly.
The following “law” is discovered:
At blood pressures above peak amplitude blood pressure:
\[
\text{amplitude } \propto \frac{1}{\text{proximal vasoconstriction}}
\]
At peak amplitude and blood pressures below:

amplitude \( \propto \) arterial pulse pressure

The peripheral pulse pressure is now dependent on the cardiac stroke output and the "distal" vasoconstriction.

Hence an accurate estimation of the depth of anaesthesia and hypotension is provided for when halothane or methoxyflurane is used in a closed circuit (250 ml/min) with the vaporizer in the circuit and controlled respiration. This "law" has now been put to the test for estimating the depth of anaesthesia in over 4,000 administrations of halothane and a small number of methoxyflurane anaesthetics, so the technique has been well tested.

With amplitude observation, frequent arterial pressure measurement, and using the modified Goldman vaporizer described, the use of halothane with oxygen in a completely closed circle circuit, with the vaporizer included in the circuit appears to be safe and to have the advantages described.

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