New Appliances

Prevention of Pollution of Operating Theatres with Halothane Vapour by Adsorption with Activated Charcoal

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Attention has been drawn to the possible deleterious effects on operating theatre personnel of breathing, over long periods of time, an atmosphere polluted with anaesthetic vapour, and, in particular, halothane.¹⁻³ Whether or not the relation of these effects to the anaesthetic vapours has been adequately proved, there is unlikely to be any disagreement that pollution of the theatre air with anaesthetics is undesirable. One method of improving the present situation is to vent the patient's exhalations from the spill from an anaesthetic apparatus either into the suction system of the hospital,^{4,5} or to the outside atmosphere of the building.⁶ Both these methods have serious disadvantages.

This paper describes a method which removes the volatile agent before it can get into the theatre atmosphere by adsorption on to activated charcoal. Some preliminary work⁷ has recently been published, but for conditions which are not representative of clinical practice.

Apparatus

The disposable canisters (fig. 1) were designed with clinical practice in view. They are cylindrical in shape, made of thick cardboard, and contain about 1 kg of activated charcoal. The proximal upper seal includes a male connector for a corrugated breathing tube. At the top is a thin layer of material of about 40 mesh and a perforated cardboard disc which serves to distribute the flow of gas and avoid channelling. Between the upper perforated disc and the inlet port is a space to allow the gases to spread over the whole of the perforated

FIG. 1—Diagrammatic section of "Cardiff Aldasorber" canister.

disc. Below the charcoal is another supporting mesh carried on a perforated disc. Holes below the perforated disc serve to vent the effluent vapour-free gas to atmosphere.

The circuit (fig. 2) for the experimental studies was as follows. Gas flowed through a Rotameter to a mark II Fluotec. The gas and vapour was bubbled through water to saturate the gases with water vapour at room temperature (to mimic expirations) and to ensure good mixing. It is important to mimic expirations in this way because experience in this laboratory suggests that complete drying of activated charcoal impairs adsorption efficiency.

FIG. 2—Experimental arrangement for testing canisters.

In the continuous-flow experiments the humid gas mixture was led directly to the canister of activated charcoal. In the intermittent-flow experiments a standard 2-litre reservoir bag and a concertina bag driven by the arm of a Beaver ventilator were switched into the circuit to mimic the pattern of ventilation. A Wright's respirometer indicated tidal volume. Gas leaving the canister passed via a mixing chamber to a dry gas meter.

The gas entering the canister and the gas leaving the mixing chamber were continuously sampled for analysis at 250 ml/min (monitored by flowmeters F1 and F2). Each sampling flow passed through calcium chloride to absorb the water vapour, then through a separate katharometer (K1, K2) to determine the halothane concentration. The outputs of the katharometers were displayed continuously on a potentiometric recorder.

The performance of the katharometers was checked by gas-chromatographic analysis of isolated samples taken from a point just before entry into the canister. The gas-chromatograph was calibrated with known standard mixtures prepared according to the method of Jones *et al.*⁸ In both cases allowance was made for the small amount of non-linearity present.

The pressure of the gas entering the canister was continuously monitored with an aneroid manometer.

Method

In each experiment a known weight of activated charcoal was sealed in a canister and the weight of the complete canister determined before and after adsorption. The resistance to flow of some canisters was determined at steady flows varying from 5 to 40 litres of oxygen per minute.

Gas, usually oxygen, was passed through the circuit (fig. 2) with the Fluotec "off" until the katharometer zeros were stable. The Fluotec was then turned "on" and the time interval up to the moment at which the concentration leaving the canister rose to 0.05% halothane was noted. This was taken as the "adsorption time" of the canister. The experiment was then allowed to continue until the effluent concentration reached about 0.5% halothane in order to observe the rate of increase in the effluent concentration. At the end of the experiment the canister was re-weighed and in some instances its resistance to gas flow was re-determined.

The flow through the canister was set on the Rotameter but measured occasionally during each experiment by means of the dry gas meter, making a suitable correction for the removal of the two sampling flows. When these corrections had been made the measurements agreed well with the Rotameter setting. Room temperature and barometric pressure were noted during each experiment so that the amount of halothane flowing into the canister could be accurately calculated (see below).

In the intermittent-flow experiments the tidal volume and respiratory frequency were deliberately set towards the upper limit of those generally found in clinical practice (at about 650 ml and 17 breaths/min). This was done to achieve the high peak flows through the canister which would be likely to lead to early failure of adsorption.

Results

Preliminary experiments using different size canisters led us to adopt the 1-kg size as the most likely to be satisfactory in clinical practice. Of the three grades of charcoal that were originally investigated grade C4-8* gave the least resistance to flow and the shortest adsorption time, grade C8-16 gave the greatest resistance and the longest adsorption time, while grade C4-16 from which the C4-8 and the C8-16 grades are derived by separation, gave only a small increase in resistance compared with grade C4-8 and only a slightly shorter adsorption time compared with grade C8-16. The main investigations were consequently performed on canisters containing 1 kg of C4-16 activated charcoal.

The results from four continuous-flow experiments are listed in table I. The "adsorption time" shows a fair amount of scatter with a mean of 174 min. This scatter is probably partly due to variation in the conditions of the experiments, particularly experiment 3. We have calculated (see footnote to table I) the amount of halothane adsorbed by the end of the "adsorption time"—that is, when the effluent concentration was 0.05%. This shows a mean of 257 g (138 ml) with proportionately less scatter. The remaining scatter may well be largely attributable to variation in the packing of the canisters, since this was done in the laboratory for all these experiments and was not closely controlled. We also calculated the amount of halothane adsorbed by the end of the experiment and compared this with the measured weight gain of the canister; the agreement was quite good.

In the first eight intermittent-flow experiments (table II) the flow of fresh gas and the concentration of halothane were similar to those in the continuous-flow experiments, but the mean weight of halothane adsorbed was only 211g. This is significantly less than in the continuous-flow experiments and

*The charcoal is graded in a manner similar to soda lime—that is, according to the mesh size through which the granules pass. Thus C4-8 means that granules vary from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch in size.

TABLE I—Results of Four Continuous Flow experiments

Experiment No.	Flow Through Canister (l./min)	Concentration of Halothane (%)	"Adsorption Time" (min)	Calculated* Amount of Halothane Adsorbed		Measured Weight Gain of Canister at End of Experiment (g)
				At "Adsorption Time" (g)	At End of Experiment (g)	
1	7.40	2.64	180	280	322	304
2	7.45	2.65	157	244	297	261
3	6.60	2.40	219	278	309	303
4	7.50	2.65	140	225	291	283
Mean	7.24	2.59	174	257	305	288
S.E. (S.E. as % Mean)			17 (9.8)	13 (5.2)	7 (2.3)	10 (3.5)

$$*W = VCT \times \frac{P_b - P_{H_2O}}{761} \times \frac{273}{273 + t} \times \frac{197.4}{100 \times 22.4} \text{ g}$$

where,

W = Weight of halothane adsorbed (g)
V = Flow (l./min) (column 2)
C = In flow concentration (vol. %) (column 3)
T = "Adsorption time" (T₁ column 4) or duration of experiment (T₂) (min)
P_b = Barometric pressure (mm/Hg)
t = Room temperature (°C)
P_{H₂O} = Saturated vapour pressure of water at t°C (mm/Hg)
For the amount adsorbed by the end of the experiment, W was multiplied by 1 - 0.25 (T₂ - T₁)/CT₁ to correct for the halothane which passed through the canister unadsorbed after the effluent rose above 0.05%. The correction assumes a linear rise of effluent concentration from 0% at T₁ to 0.5% at T₂ which is sufficiently accurate for the purpose.

TABLE II—Results of 11 Intermittent Flow experiments

No. of Experiments	Flow Through Canister (l./min)	Concentration of Halothane (%)	"Adsorption Time" (min)	Calculated* Amount of Halothane Adsorbed		Measured Weight Gain of Canister at End of Experiment (g)
				At "Adsorption Time" (g)	At End of Experiment (g)	
8 Mean (S.E.)	7.50	2.47	142	211 (8)	288 (8)	249 (7)
1	2.00	4.12	300	199	216	260
1	2.60	3.95	250	207	243	230
1	7.50	1.00	350	207	207	191

*See footnote to table I.

is probably due to the high peak flows through the canisters which occur in these circumstances. The remainder of table II refers to single intermittent-flow experiments at other fresh gas flows and concentrations. Clearly the changing conditions do not materially affect the amount of halothane adsorbed.

To test how well the measured weight gain of the canister reflects the amount of halothane adsorbed, as opposed to the possible adsorption or release of other substances, such as water vapour, the difference between the measured and calculated weight gain at the end of each experiment was deduced. The mean difference for all the experiments listed (calculated weight minus measured weight) was 24g with a standard deviation of 26g. Thus, under the conditions of the experiments, the weight gain of the canister provides a useful guide to the degree of exhaustion of the canister.

When nitrous oxide or carbon dioxide was used instead of oxygen as the carrier gas, there was no discernible difference in the amounts of halothane adsorbed.

Though the effects of room temperature or barometric pressure were not deliberately investigated, it was apparent that, when taken into account in calculating the amount of halothane adsorbed (footnote to table I), they had no appreciable effect on the results.

The effect on adsorption when the charcoal was packed by the manufacturers to various densities is shown in table III. In canister A the charcoal was simply poured in and levelled. In canister B it was "substantially tapped down," while canister C was vibrated for 15 minutes. Clearly loose packing (A) leads to short adsorption times. Provided the charcoal is fairly well packed (B, C) the exact density is less critical. All but one of the previously listed experiments were conducted with canisters packed in the laboratory. The density of the packing

TABLE III—Effects of Packing of Charcoal on Duration of Canister Use in Intermittent Flow experiments

Canister	Closeness of Packing of Charcoal		Flow Through Canister (l./min)	Concentration of Halothane (%)	"Adsorption Time" (min)	Calculated* Amount of Halothane Adsorbed		Measured Weight Gain of Canister at End of Experiment (g)
	Volume Occupied by 1 kg (l.)	Density (g/l.)				At "Adsorption Time" (g)	At End of Experiment (g)	
A	1.83	546	7.85	2.40	50	75	176	157
B	1.73	578	6.60	2.45	135	174	245	251
C	1.64	610	7.60	2.30	160	224	299	258

*See footnote to table I.

was not measured, but the results (table II) were intermediate between those of canisters B and C. The last experiment listed in table II was performed with a canister packed by the manufacturers to the same density as canister B.

The resistance to gas flows of canisters packed by the manufacturers are shown in fig. 3. In all cases the resistance was less than 1 cm H₂O per litre/sec. In packing canisters in the laboratory it was found that if the charcoal was at all crushed considerably higher resistances resulted. Therefore, both on the grounds of adsorption efficiency and of resistance, skilled packing is essential.

FIG. 3—Flow resistance of various densities of charcoal packing.

Discussion

The experimental results confirm that halothane is adsorbed by activated charcoal. Since the amount of halothane adsorbed by the canisters is little affected by the flow and concentration passing through (table II), it is possible to calculate the "adsorption time" to be expected in various clinical circumstances. The effluent concentration of halothane from an anaesthetic circuit lies somewhere between the inspired and expired concentrations. In common clinical practice, it usually lies in the region of 1%. With this concentration and a fresh-gas flow of 7.5 l./min the adsorption of 200g of halothane would correspond to an "adsorption time" of about six hours. This is roughly a day's usage in an average operating theatre. With the same concentration and a fresh-gas flow of 2.5 l./min—that is, with CO₂ absorption—the "adsorption time" would be about 18 hours. This would correspond roughly to three days of clinical usage.

In working conditions the life-span of these canisters would vary with individual clinical practice. We have shown, however, that the weight gain of the canister is a useful indicator of the extent to which the canister has been used. In clinical practice, therefore, the canister could occasionally be weighed (a simple balance would be adequate) and discarded when it reached a critical weight marked on the canister.

Charcoal is made from coconut shell and is activated with superheated steam and the canister packed under controlled circumstances. The canister is supplied in a sealed polyethylene container. After use the canister should be once more sealed in its container and disposed of by incineration or some other appropriate means. In view of the substantial amounts of halothane adsorbed (over 100 ml each canister), the possibility of commercial recovery should not be overlooked.

Needless to say, a suitable valved connector is necessary to deflect the effluent gases and vapour from the anaesthetic breathing circuit to the canister without interfering with the normal working of the anaesthetic apparatus. Some of these connectors have already been described,^{5,9} and a range of connectors suitable for the commoner anaesthetic apparatus and ventilators in the U.K. will be made available by the distributors of the canisters.

The activated charcoal is also effective in adsorbing ether,⁹ trichloroethylene, which is used in many industrial processes, and methoxyflurane.⁷ The quantitative data for these agents could easily be determined by using the method we have described.

The cannisters, to be known as the Cardiff Aldasorber, are prepared commercially by Messrs. Shirley Aldred and Co. Ltd., of Worksop, and are marketed by Longworth Scientific Instrument Co. Ltd., of Abingdon. We are grateful to Mr. D. W. Kelley and Mr. P. B. Tann of the former company and Mr. R. Sugg of the latter company, for their co-operation and interest in bringing our experimental work to practical fruition. We also thank our colleague Mr. E. K. Hillard, chief technician in this department, for his help in the laboratory and for preparing the illustrations.

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