portion of the cable housing through the desired range (fig. 3).

The 10¼-inch-long piece of cable housing is inserted into a piece of malleable aluminum tubing ¾ inch in outside diameter, to give the styllet rigidity. Malleable aluminum tubing was chosen to make it possible to change the radius of curvature of the styllet if desired preparatory to use.

The adapter section of the styllet is machined to accept a 15-mm tapered endotracheal tube adapter. The switch and a 9-volt transistor battery to power the light are housed in the handle.

fig. 3. Distal end of the articulated styllet in the flexed position.

Hidden Hazards of the McKesson Narmatic Anesthesia Machine

GAITHER EVERETT, D.D.S., * THOMAS F. HORNBEIN, M.D., †
GERALD D. ALLEN, M.D. ‡

This report is presented to call attention to some of the hazards of the McKesson Narmatic anesthesia machine, particularly when used in combination with the McKesson demand-flow Fluothane Vaporizer. These machines are probably the most common equipment used for outpatient dental anesthesia in the United States today. The report was prompted by the death of a healthy young adult during oral surgery. In this evaluation we make no attempt to describe comprehensively the performance characteristics of the McKesson machine, but simply to reconstruct the events that probably led to this patient's death.

The case was characterized by two episodes of cardiovascular collapse. The first occurred after approximately one hour of anesthesia. The machine had been set to deliver 40 per

*Research Fellow, Department of Anesthesiology, Harborview Hospital, Seattle, Washington.
† Associate Professor, Department of Anesthesiology, University Hospital, University of Washington School of Medicine, Seattle, Washington 98195.
‡ Associate Professor, Department of Anesthesiology, Harborview Hospital, Seattle, Washington.

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cent oxygen and 60 per cent nitrous oxide at a pressure setting of 7 mm Hg; the McKesson demand-flow Fluothane vaporizer was used at settings between 1 and 2 per cent halothane. Rather than using the demand flow system, the machine was used with the rebreathing bag in-circuit with the popoff at the patient end of the delivery hose and with ventilation assisted. This configuration is essentially a typical Magill system, but with the vaporizer placed within the breathing circuit (fig. 1). When the first episode of bradycardia and severe hypotension responded to administration of 100 per cent oxygen, anesthesia was reinstalled with 40 per cent oxygen and 60 per cent nitrous oxide at halothane vaporizer settings of 0.5 to 1 per cent and at pressure setting of 7 mm Hg. This time, ventilation was controlled manually and excess gas was vented through the tail of the anesthesia bag rather than from the popoff near the patient. About 45 minutes later cardiac arrest occurred. Attempts at resuscitation were unsuccessful.

The occurrence of two episodes of cardiovascular collapse, 45 to 60 minutes following the initiation of anesthesia, strongly implicated some aspect of the anesthetic management in
this patient's death. We investigated this incident assuming that the gas mixture being delivered to the patient from the anesthetic machine was in some way becoming progressively more noxious with time. The possibilities, singly or in combination, are progressive hypoxia, carbon dioxide accumulation, and overdosage with halothane. Hypoxia could have resulted from a low inflowing oxygen concentration at the 40 per cent setting or from carbon dioxide accumulation due to rebreathing. Rebreathing could also result in a rising halothane concentration. The nature of the McKesson Narmatic anesthesia machine with in-circuit vaporizer, when used with assisted or controlled ventilation in the rebreathing configuration, is distinctly compatible with at least two of these possibilities.

The unique feature of the McKesson Narmatic anesthesia machine is the method of delivery of oxygen and nitrous oxide to the anesthetic circuit through balanced demand valves. The pressure across each demand valve diaphragm can be regulated to alter the mix of O₂ and N₂O delivered to the system, either in response to a slight negative pressure from the patient or with a superimposed, continuous flow, determined by a knob calibrated in pressure, rather than flow, units. The machine, though originally designed for use as a pure demand-flow inhaler, has been modified so that it can be switched to a Magill-type configuration with overflow from a pop-off at the patient end of the delivery tube or from the tail of the anesthesia bag; the inflow is located between the delivery tube and bag (fig. 1). Ventilation may be spontaneous or controlled. In addition, a breathe-through halothane vaporizer, present within the anesthetic circuit, is calibrated in per cent halothane concentration, with the admonition (in fine print) “Use on demand flow machine only.”

Inflating oxygen concentration was measured using a Beckman C paramagnetic oxygen analyzer. The oxygen concentration in the system was measured during cyclic ventilation at a tidal volume of 0.5 l and a frequency of 16/min, achieved using a Harvard ventilator to simulate the patient's breathing. The inflow setting was 7 mm Hg, the value used during the actual anesthetic procedure. Hysteresis was apparent, with lower oxygen concentrations observed as the setting on the dial was increased from low oxygen concentrations than when it was decreased from 100 per cent oxygen. Even so, at the 40 per cent oxygen setting the delivered concentration was always in excess of that indicated. This finding means that an inadequate inflowing concentration of oxygen was not the cause of the difficulty. Still, the great variability between oxygen setting and delivered oxygen concentration indicates that the mixing principle of the McKesson Narmatic cannot be regarded as a very reliable means of regulating oxygen concentrations. We found more hysteresis and a greater tendency to falsely low O₂ concentrations at higher pressure settings, especially during continuous rather than cyclic flow.

Rebreathing is dependent on several factors: the location of gas inflow and outflow from the system, spontaneous vs. positive-pressure ventilation, and the rate of gas inflow in relation to the patient's minute ventilation. With spontaneous ventilation at a pressure setting of 7 mm Hg, the configuration is a classical Magill system and probably would have been nonrebreathing. This setting yields an inflow of 7.8 l/min with no back-pressure (although at a setting of 5 mm Hg the flow drops to 1.5 l/min). With positive-pressure breathing, flow decreases as back-pressure on the diaphragm increases, ceasing essentially when this pressure exceeds the setting on the dial. Thus, both positive-pressure ventilation and
slight errors in dial-setting could drastically reduce inflow and facilitate rebreathing.

In addition, positive-pressure breathing, either assisted or controlled, would result in the delivery tube’s becoming additional mechanical deadspace. Using the Harvard ventilator in place of the anesthesia bag, a simulated lung was ventilated at a tidal volume of 0.5 l, a frequency of 16/min, and an end-inspiratory pressure of 15 cm H₂O. Metabolic carbon dioxide production was effected by an inflow of 200 ml/min of CO₂ into the lung. With gas being vented at the popoff at the patient end of the delivery tube, lung PₐCO₂ rose over 15 to 30 minutes, to plateau at about 70 mm Hg. At vaporizer settings between 1.0 and 2.0 per cent halothane, the lung halothane concentration, measured with an ultraviolet halothane analyzer (Analytic Systems), reached concentrations between 2 to 2.5 times those indicated. This hazard of controlled ventilation when the halothane vaporizer is within the anesthetic circuit is well known, but it was overlooked in the present situation, perhaps because of a sense of security instilled by the calibrations on the dial. Halothane accumulation results simply from the to-and-fro passage of diluted gas across the liquid halothane, picking up more vapor with each successive journey. How much anesthetic will reach the patient depends on the relationship between the volume of each breath, the volume of the breathing apparatus interposed between vaporizer and patient, and the inflow rate. Thus, during the period prior to the first episode of hypotension, moderate hypercapnia might have been associated with halothane concentrations in excess of 4 per cent.

After the patient recovered from the initial episode, ventilation was controlled with overflow from the tail of the bag rather than the popoff near the patient (fig. 1). A different pattern of rebreathing would have occurred. The delivery tube would contain exhaled gas only, undiluted by fresh inflowing gas. The bag would be added to the rebreathed volume, though the CO₂ within it would be partially diluted by the inflowing gas. Under these conditions the model produced a lung PₐCO₂ of 170 mm Hg after 20 to 30 minutes. The rate of rise of PₐCO₂ in the patient might have been slower than that of the model because a portion of the CO₂ production was taken up by tissues as the PₐCO₂ rose. On the other hand, much of the excess halothane resulting from rebreathing was eliminated through the tail of the bag, for the lung achieved halothane concentrations only slightly greater than the settings indicated on the dial. The second episode of collapse then appears to have been the result of simple asphyxia, a high PₐCO₂ and subsequently low PₐO₂ resulting from rebreathing.

The observations presented here simply confirm what could have been anticipated prospectively. This death probably resulted from failure of the anesthetist to appreciate the hazard of the rebreathing inherent in current models of the McKesson machine. This machine was originally designed as a demand-flow device for nitrous oxide–oxygen mixtures. As such, it functions reasonably, though not with the stability and accuracy one should demand of anesthetic instrumentation at the present time. Incorporation of an optional bag or bellows and in-circuit vaporizer has provided additional hazards for anaesthetists unsophisticated in the ways of rebreathing systems. The McKesson Narmatic can be used safely in the rebreathing configuration only during spontaneous ventilation if inflow, which is not calibrated in liters per minute, is sufficiently high. Positive-pressure ventilation will, if maintained long enough, result in the patient’s expiring from inspiriting expired air. We recommend that the McKesson Narmatic anesthetic machine not be used in any other fashion than for demand flow, or better yet, that it not be used at all.

References