

## AN ASSESSMENT OF THE REVELL CIRCULATOR

PETER J. ROFFEY, M.B., B.Chir., DANIEL G. REVELL, M.D., LUCIEN E. MORRIS, M.D.

THE REVELL circulator is a device designed for the purpose of eliminating or minimizing the mechanical dead space added by anesthesia apparatus, especially that space under the face mask. Although some form of circulator concept has been in use for approximately fourteen years,<sup>1</sup> the present modification has only recently been described;<sup>2</sup> it consists of a rotary pump, which propels the gases in an anesthesia circle system, with the motive power provided by an air turbine on the same shaft. A divided chimney piece provides a pipe into the mask and a pipe out of it so that the under mask space is included in the circulation of gases around the circle system and through the valves and absorber (fig. 1). Neither the bag nor the patient are included in this circulation, so the tidal exchange of gases between patient and bag are substantially unaffected; that is to say the bag moves normally—reflecting the tidal excursion moved by the patient. Thus the patient is able to breathe from under a mask fresh gases which do not contain recently exhaled carbon dioxide.

This paper reports an evaluation of the usefulness of this device, firstly from its performance as a pump, secondly from its efficiency in removing dead space and in preventing the accumulation of carbon dioxide in an analogue of the human infant, and finally from the improvement in ventilation in anesthetized patients.

### PERFORMANCE AS A PUMP

The circulator accomplishes its purpose of changing the under mask dead space at flows of approximately 15 l./minute. When set at

this rate flow will cease with 0.5 cm. of water back pressure. Even when set to deliver an extremely high flow rate of 100 l./minute it is impossible to generate a pressure greater than 3.5 cm. of water. The performance is illustrated by the flow-pressure graph (fig. 2). The air turbine which drives the circulator pump can be powered by either air pressure or by suction. In the studies graphed in figure 2, the motive power was compressed air which was measured by a flowmeter. Each curve was drawn at a constant power input, specified on the graph by the flow in liters/minute through the turbine. As can be seen by the steep slope of these curves, the flow produced drops rapidly to zero at a critical back pressure.

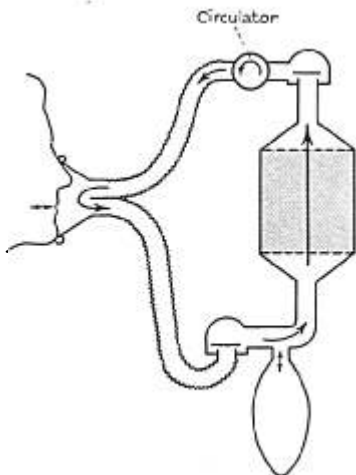


FIG. 1. Diagram of directional flows produced by circulator in anesthesia absorption system. The bag reflects patient respiratory excursion in the normal manner.

Received from the Division of Anesthesiology, University of Washington, and accepted for publication April 21, 1961. Dr. Revell's address is St. Joseph's Hospital, Victoria, B. C., Canada. Dr. Roffey and Dr. Morris are in the Anesthesia Research Laboratories, Providence Hospital, Seattle, Washington.

The actual flows produced in circle absorbers, full of soda lime and with the divided chimney and mask in place, were next measured. A pneumotachograph was constructed by packing together fifty polyethylene tubes, 5 cm. long and 0.7 mm. (inside diameter) inside a tube of 1 inch (inside diameter). The pressure across this was measured with a 0.05 p.s.i.d. Statham strain gauge. This device was calibrated against an Emerson dry gas meter and a stop watch. The flows measured by these means, in four commonly available American circle absorbers, both with the valve leaves in place and with them removed, at various flows of compressed air energizing the turbine of the circulator, are shown in figure 3. It can be seen that rates of flow which exceed the usual resting peak inspiratory flow rates of either a child or adult were readily produced, except in the case of the old model 9-B Heidbrink with the standard combined rubber and metal valve leaves which is represented by the lowest tracing in the illustration. When these heavy valves were replaced with light plastic valve discs the flows were almost the same as those obtained without valve leaves (top tracing). All these measurements were taken with

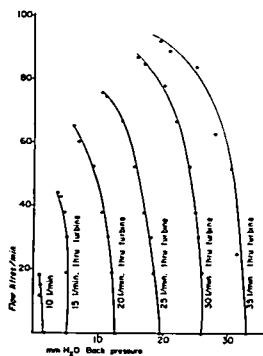


FIG. 2. Graph showing the decrease in flow produced by the circulator (ordinate) as it works against increasing pressure (abscissa) for various power inputs to the turbine that drives it (input flow values written along each curve).

Anesthesiology  
July-Aug. 1951

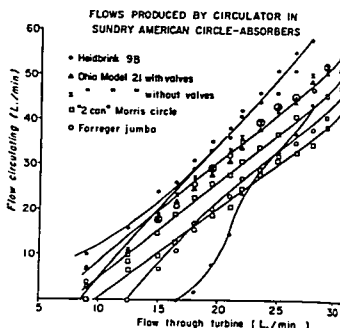


FIG. 3. Graph of the flows around various circle absorbers (ordinate) with increasing power to the driving turbine (abscissa). The measurements for the lower line on each circle absorber were made with the valve leaves in place and those for the upper line with the valve leaves removed. The top tracing is a composite consisting of the flows in a 9-B Heidbrink both with light valves and without valves. At lower flow through the turbine the tracing is bifurcated since with valves in place the circulating flow falls off more sharply.

the valve leaves dry to avoid any chance that water might reach the pneumotachograph which could not be effectively heated. When the valves were wet, as in clinical practice the circulator power required to open them initially was greater than when they were dry. Once open, however, wet valves tended to stay open almost as long as dry ones as the circulator power was reduced again. It seems probable, therefore, that in clinical practice the flows produced would be virtually those shown in the illustration if the circulator power were properly adjusted so that the valves were floating open at all times. This would ensure that circulating flow exceeds the inspiratory flow.

#### EFFICIENCY OF THE CIRCULATOR IN REMOVING DEAD SPACE

Attempts to show changes in the blood gases related to the use of the circulator in spontaneously breathing anesthetized patients were unsatisfactory mainly due to the efficient compensation in response to alterations



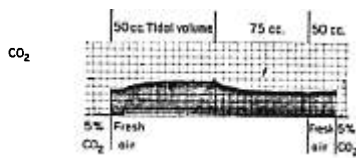


FIG. 7. Bloomquist pediatric circle connected to the analogue as though intubated. The experiment is similar to those in figures 5 and 6.

(1) To a Bloomquist pediatric circle absorber and mask, the glass pipe of the analogue being pushed through a hole in a rubber dam over the mask. The volume of the mask, which is supplied with the circle, was 43 ml. (fig. 5).

(2) To an Ohio pediatric circle absorber and mask, of volume 12 ml. when occluded with a rubber dam (fig. 6).

(3) To a Bloomquist pediatric circle absorber connected to the analogue as though the analogue had been intubated, the rubber pipe "trachea" being connected directly to an endotracheal tube connector which was inserted in the Y-piece of the circle (fig. 7).

(4) To an adult circle, incorporating two vertically stacked Waters' canisters (Morris), plus a Revell circulator. The mask used had a volume of 22 ml. to the rubber dam. The

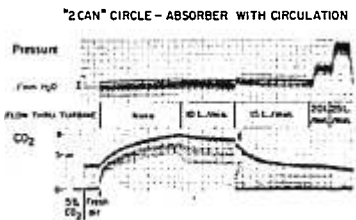


FIG. 8. Adult circle and circulator connected to the analogue. This experiment is similar to those shown in figures 5, 6 and 7 but differs in that the tidal volume was kept constant at 50 ml. and the power to the circulator varied in steps from 0 to 25 liters per minute of air blown through the turbine. In addition the under-mask pressure was monitored simultaneously to give a measure of the changes in resistance which were occurring.

TABLE 1  
RESULTS WITH ANALOGUE ATTACHED TO  
PEDIATRIC CIRCLE ABSORBERS

	Bloomquist Circle and Mask	Ohio Circle and Mask	Bloomquist Circle Intubated
Max. CO <sub>2</sub> conc. at 50 ml. tidal volume	8%	5.6%	4.9%
Tidal volume needed to return CO <sub>2</sub> to control conc.	125 ml.	85 ml.	75 ml.

power for the circulator turbine was provided by metered amounts of compressed air (fig. 8).

The results obtained with the analogue attached to pediatric circle absorbers are summarized in table 1.

It can be seen that quite marked carbon dioxide retention tended to occur and considerable increases in respiration were needed to prevent this.

The results obtained with the analogue attached to an adult circle absorber and the circulator, at 50 ml. tidal volume, are summarized in table 2. At 10 l./minute power the dome valve leaves in the circle were still seated. At 15 l./minute power the valves were open and just failed to seat during the respiratory cycle. This indicates that circulation must have been continuing through respiration and is a good

TABLE 2  
RESULTS WITH ANALOGUE ATTACHED TO ADULT  
CIRCLE ABSORBER. CIRCULATOR AT 50 ML.  
TIDAL VOLUME

Power to the turbine in l./minute of air flow	0	10	15	20	25
End-expiratory CO <sub>2</sub> conc. (Control value 3.6%)	8%	7.4%	3.6%	3.4%	3.2%
Min. CO <sub>2</sub> conc. in inspired gases	5%	3.4%	0	0	0

clinical guide to the minimum rate at which the circulator should be run to provide adequate clearance as is shown in figure 8. The concentration of carbon dioxide in the inspired gas can be seen to drop substantially to zero within a breath and soon thereafter the end-expiratory concentration drops to the control level so that with regard to carbon dioxide the analogue might be breathing fresh air. Higher circulation flows reduce carbon dioxide level to slightly below the control value.

The pressure under the mask was monitored, to provide a measure of the resistance to breathing, at the same time as the carbon dioxide concentration in this last experiment and is shown in the upper tracing (fig. 8). It can be seen that the resistance, as measured by the difference between the inspiratory and expiratory pressures, decreases at first as the circulator runs faster and then with faster circulation increases beyond the original value. The initial drop in resistance is due to the valves being opened by the circulation since it does not occur when the valve leaves are removed. The rise in resistance is probably due to the increased turbulence caused by the circulating flow. It can be seen, also, that the mean under mask pressure rises with increasing circulation. The amount of pressure change which occurs, and also whether it is a rise or a fall, depends on where the circulator is placed in the circle relative to the mask and relative to the bag. On this occasion the circulator was between the inspiratory valve and the corrugated hose so that the change in mask pressure was an increase. If the circulator were placed between the mask and the expiratory valve the under mask pressure would have been negative.

The greater the pressure change in the circle the more vulnerable it is to small gas leaks, especially between the mask and the face. Therefore, the circulator should be run no faster than required to clear the under mask space. From the standpoint of adequate elimination of carbon dioxide the circulator should be run, as indicated previously, at least as fast as the point where the valves just stay open throughout the respiratory cycle. Increasing the rate of circulation

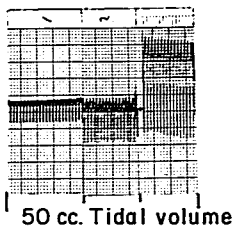


FIG. 9. Under mask pressure (resistance) at the same attenuation and tidal volume in the "two can" adult circle, and Ohio and Bloomquist pediatric circles.

beyond this point is of doubtful benefit. Finally the resistance to breathing is minimal when the valves are just open. For these reasons it seems desirable during clinical anesthesia to run the circulator at a moderate speed which will just float the valves.

The resistances of the three circles were compared by measuring the under mask pressure at 50 ml. tidal volume (fig. 9). The resistance of the Ohio pediatric circle was found to be twice that of the Morris circle plus Revell circulator, and the resistance of the Bloomquist pediatric circle at least twice that of the Ohio circle even eliminating the sharp peaks of pressure which occurred probably as a result of the reluctant opening of the small rubber valves.

With the high flows produced by a circulator it was thought that possibly some carbon dioxide might be swept through the canister without being absorbed. To assess this the analogue was set to deliver a tidal volume of

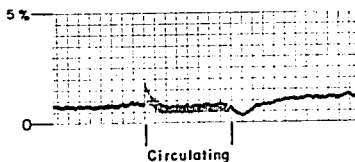


FIG. 10. Carbon dioxide through inefficient canister.

250 ml. and the carbon dioxide input was increased to 250 ml. The sample was withdrawn from the inspiratory hose of a Morris circle with only one canister and returned to the same hose nearer the Y-piece. No appreciable carbon dioxide could be detected with or without circulation. The canister was then made inefficient by filling it only half full. As can be seen in figure 10, the mean carbon dioxide concentration leaking through the canister was slightly less with circulation than without.

#### IMPROVEMENT IN VENTILATION IN ANESTHETIZED PATIENTS

Using a Liston-Becker infrared  $\text{CO}_2$  analyzer studies were made of the carbon dioxide concentration in the under mask space. A typical result is presented (fig. 11). This tracing is from an adult patient under light halothane anesthesia using a semiclosed absorption circle system with a 5 l./minute flow of gases and a mask of 80 ml. dead space. It can be seen from the lower edge of the tracing that the minimum concentration of carbon dioxide in the inspired gas was 0.8 per cent with the standard mask and chimney piece. When the circulator was turned on during use of

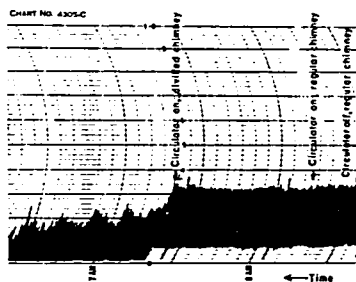


FIG. 11. Chart from Liston-Becker infrared carbon dioxide analyzer reading from right to left and giving a continuous record of the carbon dioxide concentration under the mask. The sampling rate was 90-100 ml./minute and the machine calibrated so that 5 per cent carbon dioxide gave a deflection to the center of the chart.

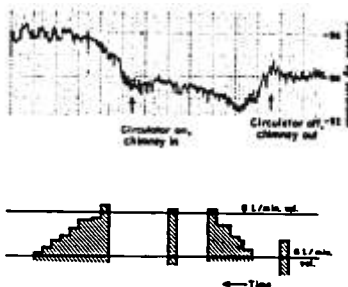


FIG. 12. The upper tracing is from an ear oximeter and reads from right to left. The stick-graphs below this were calculated from simultaneous observations of respiration rate and tidal volume as measured by a ventimeter.

the regular chimney piece only a very small effect was observed. Subsequently, when the divided chimney was introduced during circulation the minimum carbon dioxide concentration dropped rapidly to 0.05 per cent. The upper edge of the tracing representing the carbon dioxide concentration during expiration was also reduced by circulation due to the dilution of the expired gas in the mask during exhalation. The marked rhythmic fluctuations that can be noted in this tracing were due to changes in the negative pressure in the suction line that was being used to drive the circulator. Tidal volume was grossly measured with a Roswell Park Ventimeter. In the 20 minutes prior to the introduction of the divided chimney the respiratory minute volume was consistently 9 l./minute or more. In the 10 minutes following the introduction of the divided chimney respiratory minute volume fell to 8 l./minute or less.

In adult patients studies were done using an ear oximeter. The oxygen concentration in the inspired gases was maintained at 19 per cent as measured by an oxygen analyzer. The minute volume was recorded at the same time by counting the respiration rate and measuring the tidal volume with a ventimeter. One result is presented in figure 12. When the circulator was turned off there was a

small but definite decrease in saturation but within about 60 seconds the patient compensated for the adverse alteration in respired gases and the oxygen saturation returned to about the same level. Associated with this, and presumably mediated by a small rise in carbon dioxide tension, the minute volume showed a definite and sustained increase. The opposite occurred when the circulator was turned on. The results were frequently not as clear cut as this, particularly if the respiration rate varied so that the minute volume could not be observed accurately enough. However there was always a temporary decrease in oxygenation on turning off the circulator and a temporary increase on turning it on. Also the minute volume was always greater with the circulator off than with it on.

#### DISCUSSION

If the results obtained with the analogue of the human infant present a true picture of what happens during an actual anesthetic, and the results obtained by clinical studies in adults tend to confirm that they do, then an adult circle *with circulator* has definite advantages over a pediatric circle for pediatric patients. The Bloomquist circle is robust, practical and convenient but it does impose a greatly increased load on the child. About  $2\frac{1}{2}$  times the minute volume is necessary against a resistance that is four times as great which means that about ten times as much respiratory work must be done by a child breathing spontaneously through a Bloomquist mask and circle as against an adult circle *plus* circulator and mask with divided chimney. Intubation of the trachea greatly reduces the problem of dead space but does not eliminate it altogether and, if anything, increases the resistance. Manual ventilation solves the problem of increased work of inspiration but results in adverse effects such as a higher mean intrathoracic pressure.

The Ohio pediatric circle with its incorporated divided chimney and small mask is designed to give the minimum dead space that is possible by conventional means.

However, the resistance is twice that of an adult circle plus circulator and at least one and a half times the minute volume is necessary to keep the carbon dioxide normal, giving more than three times the work load.

The nonrebreathing technique, although not investigated in this study, may be expected to impose a load about as great as a Bloomquist circle, since the usual nonrebreathing valves are small and of similar design. The dead space, which extends back to the valve farthest from the patient, is usually as great as that between the valves in the Bloomquist Y-piece.

The T-piece technique, alone, has none of these disadvantages but must be used with high flows which tends to preclude the use of such expensive agents as cyclopropane and halothane. The circle plus circulator allows the use of these agents, and incorporates the use of an anesthetic bag so the respirations can be more readily seen and the pulmonary compliance more readily felt.

There are two disadvantages in the use of the circulator. Firstly, it needs an ancillary source of power either from suction or from compressed air or gas, which increases the complexity of the anesthetic apparatus. Secondly, the increased and decreased pressures generated by the circulator magnify the effects of small leaks, which either empty the bag or dilute the anesthetic mixture with air. This does not, however, seem to be much of a problem in practice.

#### SUMMARY

The Revell circulator, a device for moving the gases around an anesthetic circle and sweeping the under mask space free of carbon dioxide, has been found to be an efficient pump capable of causing flows of up to 50 l./minute in adult anesthetic circles.

Studies with an analogue of the human infant indicate that the use of the circulator with an adult circle absorber has very definite advantages over other presently used pediatric anesthetic apparatus in that it effectively eliminates dead space, and reduces resistance.

Studies in anesthetized adult patients tend

to confirm that the analogue presents a true picture.

This work was supported (in part) by Training Grant 2 G-104, United States Public Health Service. The data from this paper were presented by Dr. Revell at the Second World Congress of Anaesthesiologists, Toronto, Canada, September, 1960.

## REFERENCES

1. Revell, D. G.: Circulator to eliminate mechanical dead space in circle absorption systems, *Canad. Anaesth. Soc. J.* 6: 98, 1959.
2. Revell, D. G.: Improved circulator for closed circle anaesthesia, *Canad. Anaesth. Soc. J.* 6: 104, 1959.

**MYOCARDIAL INFARCTION** Twelve of 496 unselected patients who had a pre- and postoperative electrocardiogram had a myocardial infarction postoperatively. All of the patients with infarction were over 50 years of age. Six of the 12 patients were asymptomatic in reference to myocardial infarction postoperatively and the diagnosis was made on the basis of the electrocardiogram. The occurrence of the infarction did not appear to be related to the operative procedure, the anesthetic agent, duration of surgery, or incidence of hypotension during surgery. The over-all incidence of myocardial infarction was 2.4 per cent while in patients 50 years of age or over it was 4.5 per cent. In this older age group the incidence of postoperative myocardial infarction rose to 7.2 per cent when only patients with pre-existing known heart disease, hypertension, diabetes, peripheral vascular disease, or abnormal electrocardiogram were studied. (*Driscoll, A. C., and others: Clinically Unrecognized Myocardial Infarction Following Surgery, New Engl. J. Med.* 264: 633 (Mar. 30) 1961.)

**BRAIN INJURY** Treatment of brain injury resulting from trauma is basically divided into two major categories, medical and surgical. Conservative treatment that is in reality inactive treatment will result in an exceedingly high mortality. The brain reacts to

trauma by swelling. Brain swelling assumes lethal significance because the rigid cranium limits expansion and eventually forces brain displacement to unnatural exits. Maintenance of a free airway is extremely important and will prevent an increased intrathoracic pressure with resultant increased venous pressure and elevated intracranial pressure. There is some question as to the value of urea in the treatment of brain injuries since it may disguise the progression of an initial clinically insignificant subdural or extradural hemorrhage. Hypothermia is recommended because it lowers the brain's need for oxygen by decreasing cerebral metabolism and also reduces brain volume and intracranial pressure. The duration and degree of hypothermia has not been clearly established. (*Spatz, E. L.: Treatment of Craniocerebral Injuries, New Engl. J. Med.* 264: 286 (Feb. 9) 1961.)

**ANISOCORIA** In 52 cases of ether anesthesia dilatation and elliptic deformation of the pupil of one eye were the first signs of third plane of third stage anesthesia. They occurred before changes of respiration or circulation were observed. Bilateral pupillary dilatation will follow unless the ether concentration is reduced. (*Jordanoff, J. G.: Anisocoria and Deformation as Clinical Signs of Depth of Anesthesia, Der Anaesthetist* 10: 33 (Feb.) 1961.)