A CIRCLE SYSTEM WITH A ROTATING WICK VAPORIZER

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ABSTRACT

The humidity output of a circle system was raised to 28 mg H₂O/l by the use of a modified rotating wick vaporizer placed in the center of the soda lime canister and coaxial inspiratory and expiratory limbs. Both the fresh gas inflow and the expired gases passed through the lime and reached a compartment below it. The bag/ventilator connector, bearing a pressure relief valve, opened on the lateral wall of that compartment. Gases returning to the inspiratory valve passed: (1) through a tube in the canister connecting the inferior compartment to the vaporizer above water level, (2) through the upper portion of the vaporizer and around the rotating wick, and (3) through a tube emerging from the top of the vaporizer to reach the inspiratory valve. Thus inspired gases were humidified by the rotating wick constantly replenishing its water content warmed by the reaction of neutralization. The use of coaxial inspiratory and expiratory limbs reduced water condensation outside the canister.

KEY WORDS: EQUIPMENT, vaporizer, rotating wick.

WE HAVE PRODUCED several systems using the heat generated by the reaction of neutralization of soda- and barium-hydroxide lime by carbon dioxide to heat vaporizers inserted in the circuitry.¹⁻³ Our first prototype¹ delivered the fresh gas inflow (FGI) to the inspiratory valve of a Foregger circle system after humidification by passage through a water vaporizer placed in the center of the lime. Although this modification raised the humidity output of the semiclosed circuit from 12 mg H₂O/l⁴ to approximately 23 mg H₂O/l, the conservation of heat and moisture was less than ideal because humidified gases lost some of their water vapour content in the cool inspiratory limb. Modifications in the shape of the vaporizer and the addition of coaxial inspiratory and expiratory limbs² raised inspired humidity to 28 mg H₂O/l with a carbon dioxide output ($\dot{V}_{CO_2}$) of 300 ml/min and 24 mg H₂O/l with a $\dot{V}_{CO_2}$ of 200 ml/min. The new system incorporated previous modifications of the circle system which considerably raised its humidity output.³ This included: (1) the replacement of all external connections between the bottom of the canister and the inspiratory valve by a tube passing through

the center of the lime, (2) coaxial inspiratory and expiratory limbs, and (3) the introduction of the fresh gas inflow through the lime as recommended by Berry and Hughes-Davies.⁵ A vaporizer with a rotating wick, activated by a gas turbine, was placed in the center of the canister of a circle system. A tube emerging from the compartment below the lime introduced inhaled gases through the vaporizer and to the inspiratory valve which blew them into coaxial inspiratory and expiratory limbs. Performance variations, with changes in $\dot{V}_{CO_2}$ and constant FGI and $\dot{V}$, are described and discussed.

METHODOLOGY

A vaporizer containing a cylindrical wick was inserted in the center of a two piece soda lime canister (Figure 1). Both sections were joined by four flanges bolted together. Two rubber gaskets glued to the upper and lower halves were used to prevent gas leakage. The axis of the wick protruded through the vaporizer, running in a tube which connected the vaporizer to outside the canister through its junctional seam. Teflon bearings sealed the space between the axis of the wick and the tube which surrounded it after its protrusion through the canister. A pulley, 10 cm in diameter, was tightly secured to the axis of the wick. A gas turbine, with an axle bearing a second pulley 1 cm in diameter, was connected to the larger pulley of the vaporizer by an elastic band. The canister was divided into three compart-

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FIGURE 1 Diagram of the system used. CG = compressed gas entering the turbine which rotates the wick in the vaporizer, LFC = lime filling channel, IV and EV = inspiratory and expiratory valves, VAP = vaporizer in the lime, BL = barium hydroxide lime USP, H_2O = water in the vaporizer (100 ml), WFC = water filling channel, CL = flange clamping the upper and lower parts of the canister, PO = pressure release valve on connector joining the bottom compartment of the canister to the bag/ventilator attachment, B/V = bag or ventilator, FGI = fresh gas inflow port, PT = patient end of system.

ments by perforated plates placed above and below the lime. The compartment below the lime was connected to a bag/ventilator attachment, bearing a pressure relief valve. A breathing tube connected this compartment to the side of the ventilator above water level. The top of the ventilator was joined to an expiratory valve, placed between the inspiratory limb of the circuit and a short connecting tube. A coaxial expiratory limb returned exhaled gases to the top of the canister through an expiratory valve. The fresh gas inflow from the anaesthesia machine was introduced into the upper compartment of the canister. The top of the canister had a lime filling port closed off by a rubber cork. A water filling tube inserted at the top of the vaporizer protruded through the lateral wall of the canister and was also closed off by a plastic spigot. Thus expired gases and the fresh gas inflow (FGI) both reached the bottom of the canister after passing through the lime before entering the bag or ventilator connector. Gases returning from the bag or ventilator during inspiration passed around the top of the wick in the vaporizer (rotated by the turbine at a rate of 60 revolutions/min) and entered the inspiratory limb of the coaxial breathing tubes.

The system was tested on a model patient (Figure 2). It was constructed by attaching a valved Y-piece to the patient end of the circuit (shown at the right of Figure 1). A hygrosensor joined to an electric hygrometer indicator and a thermistor probe attached to a multichannel telethermome-

FIGURE 2 Model patient used to test the humidity output of the system. A valved Y-piece is attached at the machine end of the circuit seen in Figure 1. HS = hygrosensor, EHI = electric hygrometer indicator, B = bag receiving carbon dioxide through its tail end. CH = Cascade humidifier, TI, TE, Tamb = thermistor probes attached to a multichannel telethermometer (MCTT).

ter, were placed in a breathing tube joined to the inspiratory side of the valved Y-piece and to a second Y-piece inserted in the neck of a five litre bag receiving carbon dioxide from a calibrated metered source through its tail end. The free end of the Y-piece in the bag was connected to a Cascade humidifier (Puritan-Bennett Respiratory Products, Inc., Santa Monica, California) by a second tube, while a third tube joined the expiratory port of the Cascade to the expiratory side of the valved Y-piece. A second thermistor probe was placed close to the expiratory valve of the Y-piece and a third in ambient air. Ventilation was accomplished by an Airshields Ventimeter Ventilator at a minute volume of six litres per minute. The thermostat of the Cascade was adjusted to maintain gases reaching the expiratory side of the valved Y-piece at 32°C (the temperature of gases in the tracheal tube of patients at teeth or gum level). Fresh gas inflow was maintained at five litres per minute.

Four sets of experiments were done using carbon dioxide inflows ($\dot{V}_{CO_2}$) of 150, 200, 250 and 300 ml/min, and the humidity output of the system and all temperatures were recorded every 15 minutes.

Circuit resistance was compared to that of a Foregger circle system. All experiments were repeated six times and results were expressed as mean value plus or minus one standard error of the mean.

The humidity output of the system was also measured twice on six awake volunteers, under basal conditions. They weighed from 54 to 81 kg. Their $\dot{V}_{CO_2}$ was first measured on a Collins

FIGURE 3 Humidity output of the system in relation to time. Top curve was obtained with a $\dot{V}_{CO_2}$ of 200–300 ml/min, and lower curve with a $\dot{V}_{CO_2}$ of 150 ml/min. Brackets indicate a standard error. They are only shown at hourly intervals since they vary little in the interval between.

spirometer and the results were corrected for temperature. They then breathed into the system through a sterile mouthpiece. Compressed air was used as the fresh gas inflow at a rate of five litres per minute. The vaporizer and all tubing were sterilized in ethylene dioxide between each trial.

Statistical significance was assessed by commonly used variance techniques (chi square, *t* test), at values of $P < 0.05$.

RESULTS

The humidity output of the system, using carbon dioxide outputs of 200 to 300 ml/min, was not significantly different. Their results were, therefore, combined (Figure 3) using the largest standard error obtained with 300, 250 or 200 ml/min of carbon dioxide. Initially, inspired humidity was oversaturated at ambient temperature (20.5 mg H₂O/l), reaching 24 mg H₂O/l. After three hours, inspired humidity approached 28 ± 1 mg H₂O/l. With $\dot{V}_{CO_2}$ of 150 ml/min, inspired humidity at the beginning of the experiment was similar but after three hours only attained 26 ± 0.6 mg H₂O/l. Mean ambient temperature was $23 \pm 0.5^\circ\text{C}$ and mean expired temperature at the valved Y-piece was $32 \pm 0.4^\circ\text{C}$. The resistance of the system was not statistically different from that of the regular Foregger circle circuit.

The $\dot{V}_{CO_2}$ of volunteers varied from 158 to 273 ml/min. The humidity output of the system during human experimentation was within ± 1.4 mg H₂O/l of values obtained on the model patient.

DISCUSSION

The humidity output of the system at the onset of anaesthesia (24 mg H₂O/l) is far above that of all other circle systems. The regular circle system used with the same FGI and ventilatory settings only delivers 6 mg H₂O/l and 9 mg H₂O/l if the FGI is reduced to 500 ml/min.⁴ If a vaporizer is introduced into the canister and delivers the fresh gas inflow to the inspiratory valve of a circuit without coaxial respiratory limbs,¹ original humidity output is in the range of 15 to 17 mg H₂O/l. Improving the system by introducing all external connections through the lime and using coaxial breathing tubes,² raises initial humidity still further but only to approximately 20 mg H₂O/l. Modifying the circle without introducing a vaporizer by using coaxial breathing tubes, and placing all external connections through the lime canister,³ only produces an initial humidity of 12–15 mg H₂O/l. At stabilization, the humidity delivered by our system reaches 28 ± 0.5 mg H₂O/l, with carbon dioxide inflows of 200–300 ml/min. If the $\dot{V}_{CO_2}$ is reduced to 150 ml/min, stabilized humidity falls to 26 ± 0.3 mg H₂O/l. This compared favourably with all other circle systems: (1) 12 and 19 mg H₂O/l for the regular semiclosed and closed circle, (2) 23 mg H₂O/l for the original vaporizer in the lime, (3) 27 ± 3 mg H₂O/l for the improved vaporizer with coaxial respiratory tubes at a $\dot{V}_{CO_2}$ of 300 ml/min, but only 23 ± 1.5 mg H₂O/l when the $\dot{V}_{CO_2}$ is reduced to 200 ml/min, and (4) 28 ± 2 mg H₂O/l in the modified circle without vaporizer in the lime. Our initial and final humidity figures compare favourably with those of all other systems mentioned. We have shown that postoperative pulmonary complication rates were reduced to a minimum when inspired humidity was close to 32 mg H₂O/l.⁶ Our initial and final figures are the highest at the beginning of the experiment and compare favourably with that of all other systems at stabilization. An initially high inspired humidity is important since it will prevent approximately 12 per cent of the damage sustained by the ciliated epithelial cells of the tracheobronchial tree by dryness of anaesthetic gases during the first two hours of anaesthesia⁷ seen with regular circle systems which only deliver 6–12 mg H₂O/l.²

We constructed three additional vaporizers which enabled us to conduct uninterrupted tests on human volunteers, because they allowed the experiments to continue during the sterilization of previously used apparatus.

FIGURE 4 Suggested commercial model of the system shown in Figure 1. EDV and IDV = expiratory and inspiratory dome valves, FGI = fresh gas inflow port, CT = coaxial inspiratory and expiratory tubes, PT = patient end, C = connection between the tube emerging from the top of the vaporizer and that leading to the inspiratory dome valve which is made air tight when the metal framework (MF) is clamped, BHV = bracket supporting the vaporizer, B = anaesthesia bag or ventilator, GT = geared gas turbine activated by compressed gas or suction, RW = rotating wick VAP = vaporizer in lime, H₂O = water in vaporizer, PO = pressure release valve.

If the system goes into commercial production it should be more compact and include separable components (Figure 4). The compartment of the

cylinder containing the vaporizer should be removable, because it is difficult to sterilize in situ. It should fit snugly into a metal framework replacing the upper and lower compartments. When the framework is clamped tightly around the cylinder, the tube emerging from the vaporizer should make an airtight connection with that leading to the inspiratory dome valve. A geared turbine activated by compressed gas or suction should be attached to the protruding axle of the wick as a nonsterilizable item. All breathing tubes should be sterilized routinely.

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RÉSUMÉ

Le débit de vapeur d'eau du système en cercle fut élevé à 28 mg H₂O/l par l'emploi d'un vaporisateur à mèche rotative placé au centre du contenant de chaux sodée, et avec tuyaux respiratoires coaxiaux. Les gaz frais provenant de la machine d'anesthésie et les gaz expirés furent dirigés à travers la chaux et atteignirent un compartiment au-dessous d'elle. Le tuyau d'attachement du ballon d'anesthésie (ou du respirateur automatique), sur lequel fut monté un clapet d'échappement, fut placé sur la surface latérale de ce compartiment. Les gaz arrivant à la valve inspiratoire passèrent: (1) par un tuyau joignant le compartiment inférieur du contenant de chaux sodée à la surface latérale du vaporisateur au-dessus du niveau d'eau, (2) à travers la partie supérieure du vaporisateur et autour la mèche rotative, et (3) par un tuyau émergeant du sommet du vaporisateur et atteignant la valve. Les gaz inspirés furent donc humidifiés par la mèche rotative, continuellement mouillée d'eau chauffée par la réaction de neutralisation de la chaux par le gaz carbonique. L'usage de tuyaux respiratoires coaxiaux permit de réduire la condensation de vapeur d'eau entre la valve inspiratoire et le malade.