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A Compact, Well-humidified Breathing Circuit for the Circle System

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One of the disadvantages of conventional circle absorber breathing circuits is that twisting between the inspiratory and expiratory limbs sometimes occurs. In situations where access to the patient’s airway is limited, such as during neurosurgical and head and neck operations, this disadvantage may lead to accidental disconnection or extubation. Another is that the temperature and humidity of inspired gas are usually less than desirable, predisposing to heat loss, and drying of tracheal mucosa. We have constructed a circuit that houses the inspiratory limb entirely within the lumen of a slightly larger expiratory limb. This makes it easy to handle and allows heat exchange between the cold inspired and warm expired streams. Heat of condensation liberated by condensation of water on the outer surface of the inspiratory limb enhances vaporization of water droplets normally deposited on the inner surface of that limb, thereby increasing inspired humidity.

METHODOLOGY

A polyvinylchloride corrugated tube, 90 cm long and 2 cm in diameter, was introduced into

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Fig. 1. Patient placed on the unilimb circle system. FG1 = fresh gas inflow, IDV = inspiratory dome valve, ULCS = unilimb circle system, EDV = expiratory dome valve, LG = soda-lime granules in absorber canister.

A second corrugated tube of equal length but 2.8 cm in diameter (fig. 1), tapered at one end to adapt to the canister expiratory inlet. The inner tube was pulled through the wall of the outer tube at the tapered end, and connected to the inspiratory outlet of a Foregger canister. The other end of the inner tube was placed 2.5 cm short of an endotracheal-tube-mask mount inserted at the patient end of the outer tube and securely anchored by means of a plastic stay. Two other stays ensured concentricity. All connections were made airtight with acrylic cement. A unilimb circle system (ULCS) was thus created, with the inner tube as inspiratory limb and the outer one as expiratory limb. Unidirectional flow was ensured by the dome valves of the canister.
Fig. 2. Laboratory model patient and unilimb circle system. IDV = inspiratory dome valve and EDV = expiratory dome valve. ULCS = unilimb circle system, CC = cylindrical chamber, CCV = Columbia circle valve, B = bag receiving CO₂ from calibrated metered source, CH = Cascade humidifier, HS, WST, and UDV = hygrosensor, water-separating tampon, and unidirectional valve in gas shunting line, MCTT = multichannel telethermometer, T1, T2, and T3 = thermistor probes in inspiratory tube, cylindrical chamber and ambient air, EHI = electric hygrometer indicator. An Airshields Ventimeter (not shown) ensures ventilation.

The system was studied on a model and on ten anesthetized subjects.

Laboratory Study. The model (fig. 2) was composed of a small unidirectional circle, created by connecting the inspiratory limb of a Columbia circle valve to a Foregger circle Y piece and interposing a Cascade humidifier between the Columbia Valve exhaled limb and the other Y piece limb using two short lengths of corrugated tubing. A 5-liter bag was connected to the patient end of the Y piece. Carbon dioxide was introduced into the bag tail from a calibrated metered source. This model was attached to the ULCS by means of an interposed cylindrical chamber, 5 cm long and 2 cm in diameter. A gas shunt, to measure humidity in the ULCS inspiratory limb, was made by inserting one end of a 4-mm plastic tube 5 cm into the inspiratory limb of the ULCS, and the other end into the inspiratory limb of the Columbia valve. In this shunt a hygrosensor connected to a Hydrodynamics Electric Hygrometer Indicator was placed in series with a water-separating tampon and a unidirectional valve. Thermistor probes connected to a Yellow Springs Multichannel Telethermometer were placed: 1) within the ULCS inspiratory limb 5 cm beyond the patient end, 2) in the cylindrical chamber connecting the ULCS to the model, and 3) in ambient air. After stabilization, the thermistor probe was advanced in the inspiratory limb by 5-cm increments and temperatures recorded. The Cascade humidifier thermostat was adjusted to maintain cylindrical chamber gas temperature at 32 ± 0.6°C (the mean temperature of gas measured in the endotracheal tube of ten anesthetized patients at the level of the incisor teeth). Ventilation was provided by an Airshields Ventimeter ventilator using a fresh gas inflow of 5 l/min, a tidal volume of 500 ml, a respiratory rate of 12/min, and a CO₂ inflow of 200 ml/min. Temperature and humidity were recorded at ten-minute intervals until the system stabilized. A similar study was done with a standard Circlex disposable nonconductive circuit (SCC). The gas shunt tube and thermistor probe were inserted 5 cm into the inspiratory limb, measured from the Y piece bifurcation. All experiments were repeated five times, using fresh dry systems in each instance. Results were expressed as the mean ± 1 SD of each five readings.

The inspiratory gas stream of the ULCS was continuously analyzed for traces of carbon dioxide using a calibrated Goddard Capnometer. The under surface of the inspiratory dome valve leaflet was examined for water of condensation after each experiment. The inspiratory tube was then disconnected from the

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\[\text{\textsuperscript{\ddagger} Bennett Respiration Products, Inc., Santa Monica, California.}\]
\[\text{\textsuperscript{*} Electric Hygrometer-Indicator (model 15-3001), Hydrodynamics, Inc., Silver Springs, Maryland.}\]
\[\text{\textsuperscript{**} Yellow Springs Instrumental Co., Yellow Springs, Ohio (model 46).}\]

\[\text{\textsuperscript{11} Dupaco Inc., P.O. Box 98, San Marcos, California.}\]
\[\text{\textsuperscript{11} Instrumentation Associates, New York, New York.}\]
TABLE 1. Absolute Humidities (mg/l) in Inspiratory Limbs of ULCS and SCC at Onset of Experiment and One-hour Intervals (Mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Onset of Experiment</th>
<th>After One Hour</th>
<th>After Two Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unilimb circle circuit (ULCS) (n = 8)</td>
<td>7.9 ± 0.8</td>
<td>12.8 ± 0.1</td>
<td>14 ± 0.5</td>
</tr>
<tr>
<td>Standard circle circuit (SCC) (n = 8)</td>
<td>8 ± 0.5</td>
<td>10.2 ± 0.7</td>
<td>12 ± 0.8</td>
</tr>
<tr>
<td>ΔX</td>
<td>-0.1</td>
<td>2.6</td>
<td>2</td>
</tr>
<tr>
<td>Per cent increase</td>
<td>-1.2</td>
<td>25</td>
<td>17</td>
</tr>
</tbody>
</table>

A glass slide was put in the outwinding gas stream (with the ventilator functioning) and then examined macro- and microscopically for the presence of water droplets. At the end of all experiments with the SCC, the inspiratory tube was connected to a calibrated metered dry oxygen source, delivering 5 l/min. Temperature and humidity of the gases emerging from that tube were recorded at 1-minute intervals using a Telethermometer and Electric Hygrometer Indicator connected to a thermistor probe and a hygrosensor interposed between the patient end of the tube and a short extension tube. Absolute humidity was calculated and plotted against time to compute the weight of water deposited by integrating the curves obtained.

Clinical Study. Ten consenting patients, six women and four men, undergoing general endotracheal anesthesia were anesthetized and maintained on the ULCS. Surgical procedures performed included: 1 craniotomy, 2 vaginal hysterectomies, 4 abdominal hysterectomies, and 3 total hip replacements. Mean duration of operation was 180 ± 15 minutes. Arterial blood gases were continuously monitored.

Finally, the ULCS system was tested by each of us for subjective feeling of resistance of breathing.

RESULTS

Laboratory Study. At the start of each experiment the absolute humidities of gases emerging from the inspiratory limbs of the ULCS and SCC (table 1) were similar (7.9 ± 0.8 mg H₂O/l and 8 ± 0.5 mg H₂O/l, respectively) but mean inspired humidity rose faster and reached a higher level in the ULCS. At one hour, mean absolute inspired humidities were 12.8 ± 0.1 mg H₂O/l for the ULCS and 10.2 ± 0.7 mg H₂O/l for the SCC. At stabilization, two hours after the onset of the experiment, absolute inspired humidities were 14 ± 0.5 for the ULCS and 12 ± 0.8 for the SCC.

Advancing the thermistor probe into the inspiratory limbs of both systems showed that the temperature in the SCC remained close to room temperature throughout (±0.5°C). The temperature in the inhalational limb of the ULCS (fig. 3) was 3.5°C above room temperature 5 cm from the patient connection. This diminished gradually as distance increased, but remained 1°C above room temperature at 25 cm and throughout the rest of the tube.

No carbon dioxide was found in the inspiratory limb of the ULCS at any time.

The under surface of the inspiratory dome valve leaflet canister was soaked with water of condensation at the end of every (SCC and ULCS) experiment. Water droplets settled on the surface of a glass slide placed in the gas stream emerging from the valve.

When the inspiratory tubes of the SCC were dried with a 5 l/min flow of oxygen they were found to have contained 749 ± 89 mg H₂O. One can presume that a similar amount of water was deposited in the ULCS and that it was the warming of that water that increased the inspired humidity in that system.

Clinical Study. Arterial blood gases of all patients placed on the ULCS remained within normal limits (table 2). The circuit proved to be light, easy to handle, and offered no mechanical problem. Arterial carbon dioxide tension could be easily controlled by adjusting minute
volume, and none of the patients suffered any ill effect.

No subjective sensation of resistance to breathing was experienced when we tested the ULCS on ourselves.

Water of condensation was visible throughout the expiratory tube in all clinical and laboratory settings.

**DISCUSSION**

Both temperature and humidity inspired gas were higher in the ULCS than in the SCC. Heat loss during surgery will be minimized if gases are delivered at higher temperature and humidity. Damage to tracheobronchial ciliated cells will also be reduced and the function of the mucociliary transport system improved. The heat in the inspiratory limb of the ULCS is derived both from the temperature gradient between inspired and expired gas streams and from the heat of condensation of surplus water in the expiratory limb. This phenomenon, facilitated by the countercurrent flow of the two gas streams, could be accentuated by using a better thermal insulator for the outer tube than for the inner tube. An apparent paradox was the increase in absolute humidity in the ULCS, caused by warming the inspiratory limb. It was by demonstrating that gases emerging from the inspiratory outlet of the canister carried water droplets that we were able to solve this enigma. The net cross-sectional areas of the inspiratory and expiratory tubes of the ULCS are equal. It is, therefore, possible to switch the inspiratory and expiratory connections at the canister. This would result in a slight lowering of inspired humidity due to heat loss through the outer surface of the ULCS (now the outer surface of the inspiratory limb).

The gas shunt was introduced in the laboratory model to sample the relative humidity of unsaturated inspired gases, the absolute humidity being computed at the temperature of the inspiratory limb. The water-separating tampon and unidirectional valve protected the hygrosensor from the moist warm gases circulating in the small circle during the expiratory pause.

The mechanical superiority of the ULCS was readily appreciated by the ease with which it could be handled and by elimination of the bulky Y or swivel connecting piece at the patient end. This double-lumen circuit adapts to all circle canisters and permits the elimination of carbon dioxide independently of fresh gas inflow.

**Table 2. Arterial Blood Gases of Ten Adult Patients Placed on the Unilimb Circle System under General Endotracheal Anesthesia**

<table>
<thead>
<tr>
<th></th>
<th>Immediately after Induction</th>
<th>One Hour after Induction</th>
<th>Two Hours after Induction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH</strong></td>
<td>7.43 ± 0.1</td>
<td>7.43 ± 0.1</td>
<td>7.44 ± 0.8</td>
</tr>
<tr>
<td><strong>FIO₂</strong></td>
<td>153 ± 18</td>
<td>145 ± 24</td>
<td>144 ± 17</td>
</tr>
<tr>
<td><strong>Paco₂</strong></td>
<td>29 ± 5</td>
<td>29 ± 8</td>
<td>28 ± 4</td>
</tr>
</tbody>
</table>

* In all instances FIO₂ was 0.33, V₁, 600 ml, and f 12/min. There were six women 30–48 years old and four men 33–78 years old. Results are expressed as mean ± SD.
REFERENCES

1. Berry FA Jr, Hughes-Davies DI: Methods of increasing the humidity and temperature of inspired gases in the infant circle system. Anesthesiology 37:456–461, 1972


Mean-blood-pressure Meter

JAMES H. PHILIP, M.E.E., M.D.*

Arterial blood pressure is one of the most useful variables that can be monitored in the anesthetized patient.1 Arterial cannulation is invaluable in assessing instantaneous blood pressure and for managing metabolic and respiratory derangements.2 Systems commonly used today consist of an intra-arterial cannula, pressure transducer, electronic pressure processor, and oscilloscope. Some systems include meter readouts for systolic, diastolic and mean pressure, although the display is usually not visible in more than one location. Large numerical digital displays of many physiologic variables are available but costly.

When cardiopulmonary bypass is employed during operation, knowledge of mean arterial blood pressure is needed by the pump-oxygenator technician. It is difficult to read non-pulsatile pressure from the large-screen arterial pressure waveform.

Therefore, I have designed and constructed a simple electronic instrument allowing remote monitoring of mean arterial blood pressure. The device is designed to connect to the analog waveform output of a Hewlett-Packard 7809 pressure processor or any other similar instrument with sensitivity 1 volt/100 torr.

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![Fig. 1. Mean-blood-pressure meter.](image-url)

The blood-pressure meter consists of a 16 x 9.5 x 5 cm Bakelite box with a meter on the front panel (fig. 1). One hundred- or 200-torr full scale is selected by a front panel switch. Mean blood pressure is continuously displayed, or fluctuations can be observed by depressing the "instantaneous" button on the front panel. This button also serves for rapid calibration.

Diodes D1 through D5 protect meter M1 from overvoltage (fig. 2). Resistor R1 and capacitor C1 determine the 1.6-second time constant for low pass filtering of the input to obtain mean input voltage. Depressing front panel switch SW2 disconnects C1 and eliminates input filtering. With switch SW1 in the "100-torr full scale" position, the series combination of R1, R2, VR1 and the internal meter...