Heat and moisture retention in breathing gas during mechanical ventilation

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Introduction
Dry gas flowing from the ventilator may cause problems when delivered to a patient’s lungs during anesthesia. The warm, moist climate in the nose and mouth are bypassed by the ET tube and the gas is still dry and cool when it reaches the lower airways. Dry breathing gas dries respiratory mucosa, resulting in impaired surfactant activity, higher risk of injury on mucosa and increased risk of obstruction and infection. The likelihood of this damage is increased by the length of exposure to the dry gas.

The human body is not capable of maintaining its temperature at a nominal 37 ºC during anesthesia. Cold and dry gas during ventilation is one of the mechanisms causing heat loss. If the breathing is moisturized, it transfers heat to the patient and thereby supports thermal balance in the lungs and the body. These factors have driven the development of several methods for moisturizing and warming the breathing gas.

However, humidification of the patient causes problems on the machine side. Water can act as an obstruction in a flow sensor, leading to inaccurate volume readings. It may also block a pressure sensing line and cause alarms or possibly ventilation stoppage. This need for humidifying the patient, coupled with the disadvantage of moisturizing the machine side, has created a problem. This problem can be addressed by choosing the correct accessories.

Effect of the choice of accessories
In order to optimize the thermal economy and ergonomics in the breathing system, many clinicians have chosen to use coaxial patient circuits. A coaxial patient circuit has two lumens within each other. Inspiratory gas flows through the inner limb and is warmed by the expiratory gas flowing through the outer limb. This helps to maintain the heat in the patient, but has no affect on moisture loss.

Active humidifiers have been used to add heat and moisture in intensive care. However, this method is not often used in the operating room as it creates additional humidity in the breathing circuit, which causes the disadvantages described earlier. Humid conditions in the breathing tube create problems on the machine side and are also a favorable breeding ground for bacteria.

Passive humidification is a suitable option for the operating room. A passive humidifier does not add heat to the patient, but retains the heat and moisture released by the patient in the expired gas. Therefore, there is no threat of overheating or over moisturizing. Also, the moisture remains on the patient side of the HME element and decreases the humidity in the tubing and machine.

Together the GE coaxial Uni-circuit and AirLife® HME provide warm and moist inspiratory gas, while keeping the tubing and machine end dry and cool. The target of this study is to determine how the temperature changes in the different points of the breathing circuit with various combinations of accessories.
The scope of this study was to determine the thermal economy differences with different breathing circuits. The scope includes the GE coaxial Uni-Circuit and the GE dual limb circuit. Also, the comparison includes the influence of AiLife passive humidifiers HMEF 1000/S and Edith Flex.

The measurements were made with a low flow anesthesia simulation. An ISO 9631-1 patient model was used as a patient. A GE S/5 Anesthesia Delivery Unit was used for the ventilation and GE Compact Absorber for CO₂ absorption. The patient model was ventilated with the following settings: Tidal volume 500 mL, I:E ratio 1:2, fresh gas flow 500 mL/min, respiration rate 12 bpm.

### Warmer inspiration air for the patient-faster

Chart 1 shows the temperatures detected during the measurement described. The blue curves refer to the coaxial (lighter blue) and dual limb (darker blue) circuits. The pink and yellow lines show the temperature behavior in a coaxial circuit combined with an HME. The coaxial circuit provides approximately 3 ºC warmer air than a typical GE dual limb breathing circuit. With the combination of the AiLife HME (Edith Flex or HMEF 1000/S), the inspired gas temperature ranges from 4.5 ºC to 8 ºC warmer than with a dual limb circuit.

### Water condensation on the ventilator side

Water vapor condenses in the tubing when the saturated air (relative humidity of 100 percent) loses heat. Air temperature inside the tubing decreases as the gas flows toward the ventilator. If the temperature of the saturated gas decreases, some of the water vapor condenses in the tubing. An HME combined with a coaxial patient circuit captures most of the heat and moisture released by the patient during expiration. Therefore, the temperature in the tubing remains stable, unlike in a dual limb circuit with no HME. The absolute moisture content in the gas depends on the temperature of the gas. The temperature difference in the tubing (shown in chart 2) allows a maximum condensation of 9.8 mg/m³ in a dual limb circuit while a coaxial circuit with HMEF 1000/S only condenses 2.0 mg/m³. The maximum water condensation in the tubing is therefore decreased by about 80 percent.

### Conclusion

The combination of a coaxial circuit and an HME provides advantages from several different points of view. The advantages can be seen both for the patient and for the ventilator.

In this test the combination of a GE coaxial circuit and an AiLife HME maintained the temperature of inspired gas up to 8 ºC warmer than a dual limb circuit by itself. Furthermore, the maximum heat retention and the highest inspiration temperature was reached in 92 percent shorter time with the combination of coaxial circuit and HME compared to a regular dual limb circuit. The energy required for warming the inspiratory gas to 37 ºC was at least 60 percent less with a coaxial circuit with HME than with a dual limb circuit without HME. This helps to prevent continuous heat loss during mechanical ventilation.

On the ventilator side, condensed water causes problems. The temperature drop in the expired gas as it flows from the patient causes water to condense in the expiratory limb. When using the combination of a coaxial circuit and HME, the temperature drop was only 20 percent that of the dual limb circuit temperature drop. These results clearly show that moisturizing and warming can be influenced by the right choice of accessories when the function of the combination is well known. The advantages can be seen both on the patient side in the form of minimizing the heat loss, and on the machine side by decreasing the amount of water condensation.

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**Study scope and measurement methods**

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