Heat and moisture retention in breathing gas during mechanical ventilation

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 by-passed 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°C during anesthesia. Cold and dry gas during ventilation is one of the mechanisms causing heat loss. If the breathing gas 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.

On the other hand, 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 of 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 GE 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.

Study scope and measurement methods

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 GE passive humidifiers HMEF 1000/S and Edith Flex.

The measurements were made with a low flow anesthesia simulation. An ISO 9630-1 patient model was used as a patient. A GE S/S 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.

Results

Warmer inspiration air for the patient - faster

Picture 1 shows the temperatures detected during the measurement described above. 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 3ºC warmer air than a typical GE dual limb breathing circuit. With the combination of the GE Uni-Circuit and HME (Edith Flex or HMEF 1000/S), the inspired gas temperature ranges from 4.5ºC to 8ºC warmer than with a dual limb circuit.

The full capacity of warming is reached remarkably faster when using an HME. The coaxial circuit and dual limb circuit by themselves require approximately 70 minutes to reach the maximum temperature. When an HME is added to either circuit, it reaches the maximum temperature within 5 minutes, still providing several degrees higher inspiration temperature.

If the inspired gas entering the patient's lungs is cooler than the temperature in the airways, the gas has to be heated by the patient. In this calculation, it has been assumed that the temperature in the airways is 37ºC and the tidal volume is 500 ml. With the Edith Flex and coaxial circuit combination, the inspired gas temperature was 33.5ºC. The energy required to heat the gas from 33.5ºC to 37ºC is 27 J/minute. With a dual limb circuit the required energy rate would have been up to 78 J/minute in the beginning and only slightly lower after longer use (67 J after 70 minutes of use). So the energy the patient uses to warm the inhaled air to body temperature is reduced by approximately 60% when using the coaxial circuit with HMEF, compared to the dual limb circuit. A coaxial circuit helps to prevent the heat loss, but the most favorable results are achieved when a coaxial circuit is used in conjunction with a passive humidifier.

![Temperature values in expiratory limb. HME on the patient side decreases the temperature steeply, after which the temperature is stable. In a dual limb circuit the temperature decreases continuously towards the ventilator, resulting in rainout.](image-url)
Water condensation on the ventilator side

Water vapor condenses in the tubing when the saturated air (relative humidity of 100%) 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 picture 2) allows a maximum condensation of 9.8 mg/m³ in a dual limb circuit while a coaxial circuit with HME 1000/S only condenses 2.0 mg/m³. The maximum water condensation in the tubing is therefore decreased by about 80%.

Conclusions

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 a GE HME maintained the temperature of inspired gas up to 8ºC warmer than a dual limb circuit by itself. Furthermore, the maximum heat retention and the highest inspiration temperature was reached in 92% 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 37ºC was at least 60% 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% 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.

References

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