Influence of fresh-gas flow on humidity in respiratory and hose systems and selecting a ventilation filter

Urban Staubli

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Publisher:
Drägerwerk AG & Co. KGaA
Moislinger Allee 53–55
23558 Lübeck, Germany

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Medical knowledge is subject to constant change due to research and clinical experience. The author of this booklet has taken great care to ensure that the views, opinions and assumptions presented here, in particular those relating to applications and effects, correspond with the current state of knowledge. However, this does not relieve the reader of their responsibility for clinical measures.

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For a long time, it was usual to work with high fresh-gas flows in anaesthesia. However, modern anaesthesia devices (e.g. Dräger Primus IE, Perseus, Zeus) make it possible to control anaesthesia with a very low fresh-gas flow, resulting in significantly lower amounts of anaesthesia gases being used. We differentiate between low-flow, minimal-flow and metabolic-flow anaesthesia.

With low-flow anaesthesia, the fresh-gas flow is reduced to 1.0 l/min. This procedure was first described by Foldes et al. in 1952[1]. With minimal-flow anaesthesia, first described by Virtue in 1974, fresh-gas flow is reduced even further, to 0.5 l/min[2].

With a fresh-gas flow of 2 litres, it is essential to use a system that counteracts the drying of the airways. This is done with a filter/HME. This filter comprises two components. HME stands for Heat Moisture Exchanger, which is positioned on the patient side. This medium is able to heat and humidify the inhaled air. The humidity reserve is 34 - 39 mg H_2O/ l air, depending on the size and type of filter. The second component consists of bipolar charged plastic fibres, which work on the basis of electrostatics. The filter/HME both counteracts the drying of the airways and prevents contamination of the breathing circuit.

Low-flow and minimal-flow anaesthesia change two parameters in the overall breathing loop: temperature and relative breathing gas humidity. Both of the following graphics[3] show that temperature and relative breathing gas humidity are both much higher after just 30 minutes. At a fresh-gas flow of 2 l/min, the relative humidity remains very steady.

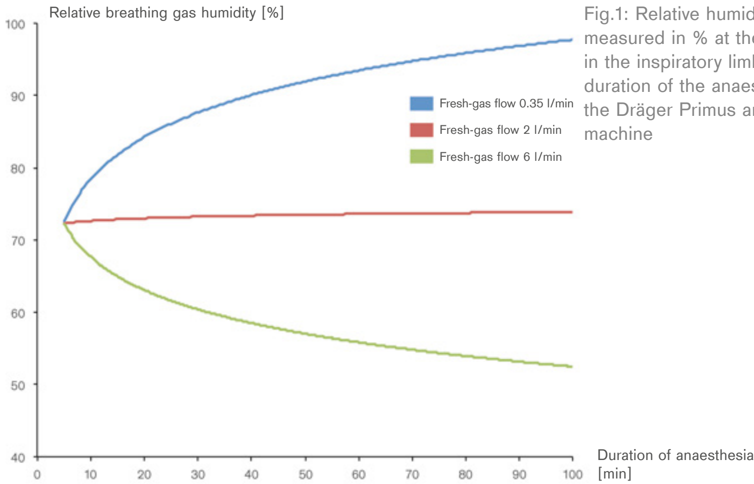

Fig.1: Relative humidity measured in % at the Y-piece in the inspiratory limb over the duration of the anaesthesia with the Dräger Primus anaesthesia machine

Anaesthesia machine: Dräger Primus
Hose system: Dräger breathing hose, silicone, reusable, 1.5 m, not heated

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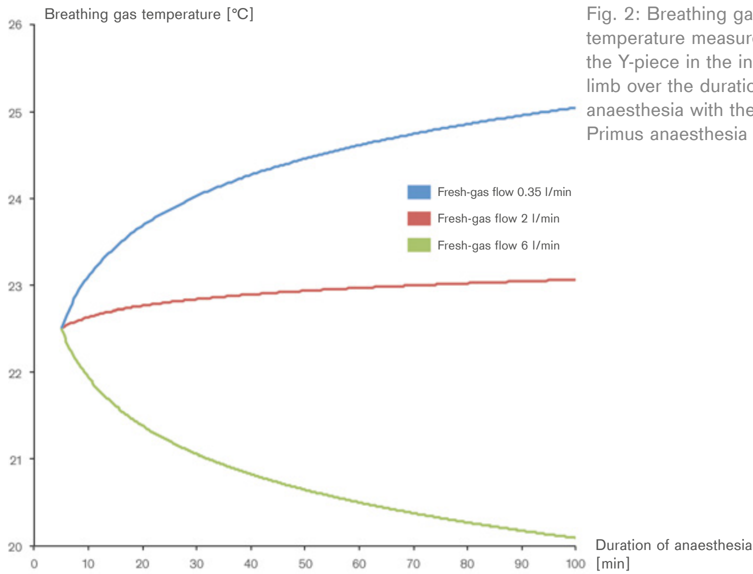

Fig. 2: Breathing gas temperature measured in °C at the Y-piece in the inspiratory limb over the duration of the anaesthesia with the Dräger Primus anaesthesia machine

Anaesthesia machine: Dräger Primus
Hose system: Dräger breathing hose, silicone, reusable, 1.5 m, not heated

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The importance of humidifying the breathing gas of anaesthetised patients has long been known. Today, the need to humidify breathing gas for intubated and tracheotomised patients in intensive care is undisputed. The overriding of the upper respiratory tract with a laryngeal mask or an endotracheal tube entirely prevents it from carrying out its physiological role (humidification and heating of breathing gas). Insufficient breathing gas humidification endangers the function of the respiratory ciliated epithelium and thus mucociliary clearance. Insufficient humidification of the breathing gas can cause morphological damage to the respiratory ciliated epithelium, potentially leading to a build-up of secretions, obstruction of the bronchioles and facilitation of microatelectasis. With longer-term anaesthesia, an absolute humidity of 17 to 30 mg H_2O/l, with an anaesthetic gas temperature of at least 28°C, must therefore be ensured. Minimal-flow anaesthesia meets these requirements: In clinical use, the desired absolute humidity is achieved after 15 minutes (see following comparative graphics) and the desired heating of the breathing gas after one to two hours[3].

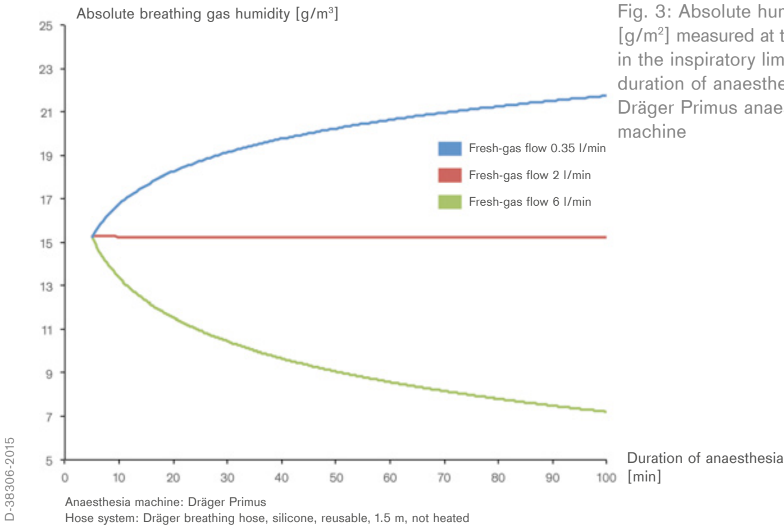

Fig. 3: Absolute humidity in [g/m²] measured at the Y-piece in the inspiratory limb over duration of anaesthesia with Dräger Primus anaesthesia machine

The presence of condensate in the breathing hoses shows the use of low-flow and minimal-flow anaesthesia. This condensate formation is caused by the mandatory carbon dioxide absorber in the anaesthesia circuit. This removes exhaled carbon dioxide from the breathing loop chemically and binds it. This elimination results in heat (ΔT) and humidity (H_2O), which contribute to the humidification of the breathing gas in the system. Soda lime is used to absorb the CO_2, and today mainly comprises calcium hydroxide ($Ca(OH)_2$). This absorption is an exothermic reaction, giving the end products calcium carbonate, water and heat: $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O + \Delta T$ (heat)[3]. Given this starting point, a special approach must be taken to the use of a breathing filter. The HME filter uses an electrostatic medium that causes microbes to stick to the filter. The increase in relative humidity means that there is a risk of condensate in the breathing loop as a whole, which could cause the filter to become wet and thus lose its efficacy, as the water causes the depolarisation of the textile. The first graphic shows that relative humidity of 90% is already achieved after approximately 30 minutes. A.R. Wilkes concludes that even with a transparent filter/HME, it can be difficult to identify the formation of condensate in the filter.[4]

It is therefore essential to use a filter that works in another way. This is a mechanical filter, made of densely woven ceramic-coated fibres. Filtration is based on 3 principles: sieve filtration, inertial filtration, diffusion filtration. Filters of this type are hydrophobic, i.e. water-repellent. According to the DGAI/DGKH, in terms of performance with regard to the retention of liquids, this hydrophobicity must withstand pressures of at least 60 hPa (=60 mbar) or 20 hPa above the selected maximum ventilation pressure in the anaesthetic system.[5] An electrostatic filter does not meet these criteria.

This hydrophobic nature of the mechanical filter causes more condensate to be retained in the ventilation system, as no water can cross the barrier. The choice of ventilation hose is therefore of the utmost importance. In paediatrics and neonatology, additional parameters must be taken into consideration when choosing the filter, as dead space and resistance also play a role here.

Both filters, mechanical and electrostatic, have the required filter performances in terms of bacterial and viral retention, if the filtration capacities of the electrostatic filter are not reduced/eliminated by humidity.

In 2011, A.R. Wilkes et al. described the use of breathing filters in anaesthesia in detail, coming to the following conclusion: "Circle breathing systems can contain condensation: this liquid can pass through low-density electrostatic filters under pressures typically encountered in anaesthesia, so the use of electrostatic filters with circle breathing systems cannot be recommended."[6]

The German Society for Anaesthesiology and Intensive Care Medicine (Deutsche Gesellschaft für Anästhesieologie und Intensivmedizin - DGAI), in collaboration with the German Society of Hospital Hygiene (Deutsche Gesellschaft für Krankenhaushygiene - DGKH)[5], and the French Society of Anesthesia & Intensive Care Medecine (Société Française d'Anésthesie et Réanimation - SARS)[7], recommend the use of a hydrophobic filter and/or a filter with the aforementioned hydrostatic capacities. English-speaking countries have also adopted this recommendation. There is a corresponding indication in the guidelines of the Association of Anaesthetists of Great Britain and Ireland (AAGBI).[8]

On the basis of these recommendations, we suggest that our customers use a hydrophobic, mechanical breathing system filter and hose systems with water traps, and place great emphasis on the reduction of nosocomial infections through the prevention of cross-contamination. With this holistic approach, paired with the standardisation of the preparation of anaesthesia workstations, we hope to contribute to hospital hygiene.

Author:

Urban Staubli
Product Manger
dipl. Intensive care expert NDS HF

Dräger Schweiz AG
Waldeggstrasse 30
CH-3097 Liebefeld, Switzerland

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REGION DACH
Drägerwerk AG & Co. KGaA
Moislinger Allee 53–55
23558 Lübeck, Germany
Tel +49 451 882 0
Fax +49 451 882 2080
info@draeger.com

REGION EUROPE
Drägerwerk AG & Co. KGaA
Moislinger Allee 53–55
23558 Lübeck, Germany
Tel +49 451 882 0
Fax +49 451 882 2080
info@draeger.com

REGION MIDDLE EAST, AFRICA
Drägerwerk AG & Co. KGaA
Branch Office
P.O. Box 505108
Dubai, United Arab Emirates
Tel +971 4 4294 600
Fax +971 4 4294 699
contactuae@draeger.com

REGION ASIA PACIFIC
Draeger Singapore Pte. Ltd.
61 Science Park Road
The Galen #04-01
Singapore 117525
Tel +65 6872 9288
Fax +65 6259 0398
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REGION NORTH AMERICA
Draeger, Inc.
3135 Quarry Road
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