Technology Insights

for low- and minimial-flow anaesthesia

Low-flow and minimal-flow anaesthesia can have significant advantages in protective the patients' lungs. In our whitepaper on the clinical benefits of this procedure, we have elaborated on this topic from a medical perspective (Link).
This paper will provide you with insights into the technical prerequisites for safe operation and supporting Dräger Technology.

Low-flow and minimal-flow anaesthesia can have significant advantages in protecting the patients' lungs by humidifying and warming the gas with which the patient is being ventilated. Mucociliary clearance is improved compared to ventilation with cold and dry gas; damage to the respiratory epithelium and release of inflammatory mediators is also reduced. We have summarized the clinical benefits of intraoperative humidification and warming of ventilation gas by means of low- and minimal-flow anaesthesia in our clinical whitepaper (Link).

Anaesthesia with low fresh-gas flows is a very safe procedure, beneficial to the patient and smart in financial and ecologic respects. However, the user needs to be aware of the dynamics of an anaesthesia system running on low fresh-gas flows and to know the technical prerequisites an anaesthesia system needs to fulfil for safe operation. This document is intended to provide insights into these technical prerequisites and to highlight how Dräger technology supports hospitals in utilizing low- and minimal-flow techniques so that the benefits materialize.

Definition of low-flow and minimal-flow

In many hospitals, anaesthesia machines are run with fresh gas flows of 2 l/min up to 6 l/min. Reducing this flow to 1 l/min is referred to as low-flow, a further reduction to 0.5 l/min is called minimal-flow. According to C. Hönemann and B. Mierke, the reduction of a fresh-gas flow to even 0.35 l/min is feasible and safe to operate (Link). They refer to this flow rate as metabolic flow because this flow rate is very close to the patient uptake of individual gases.

For further details see the booklet by C. Hönemann and B. Mierke "Low-flow, minimal-flow and metabolic-flow anaesthesia". The booklet can be downloaded at: (Link).

The high-flow technique utilizing fresh gas flows of 2-6 l/min ensures that a large quantity of fresh gas is available in the system at any time. As the patient takes up only a very small portion of that gas, a vast amount of the gas is exhausted into the anaesthetic gas scavenging system. On the one hand, this leads to a fairly quick achievement of changes in gas concentrations (O_2, volatile anaesthetic agent). On the other hand, the gas in the system remains cold and dry because the heat and humidity which is being emitted by the patient's lungs and the soda lime is being washed out. In addition to that, the quantity of wasted gas is immense.

Anaesthesia with low fresh-gas flows of 1 l/min and less means that a reduced amount of fresh-gas flows through the vaporizers into the breathing system. This can make the system react slower to changes in gas concentrations and needs to be taken into account by the user. A very easy and detailed guidance for users is provided by C. Hönemann and B. Mierke in their booklet on the use of low fresh-gas flows for general anaesthesia (Link).

Furthermore, the anaesthesia system needs to fulfil certain requirements to enable safe operation of low-flow anaesthesia. In the following, we will outline the most important requirements and will provide you with information on how Dräger anaesthesia systems support this important technique.

Which technical preconditions must be met by an anaesthesia device to perform low-flow anaesthesia?

1. Leak-tight breathing system and moisture handling
2. Robust and precise flow measurement and ventilator technology
3. Ability to sufficiently dose volatile anaesthetic agents
4. Impact of changes in fresh-gas settings on tidal volumes
5. Reliable gas measurement
6. Smart tools to support safe low-flow anaesthesia

1. LEAK-TIGHT BREATHING SYSTEM AND MOISTURE HANDLING

Using low fresh-gas flows reduces the quantity of surplus fresh gas flowing into the breathing system on top of the patient's uptake – which is specifically important for oxygen and volatile anaesthetic agents. This is why a leak-tight breathing system is a precondition for performing low- and minimal-flow anaesthesia (FG Flow = 0.5 - 1 l/min) – leakage is not compensated for by a high fresh-gas flow. Thus, leakage during low-flow anaesthesia has a much more direct impact on gas quantity and composition within the breathing system and could affect ventilation. In the worst case, this may potentially lead to an insufficient supply of oxygen and volatile anaesthetic agent to the patient. Various technical aspects have to be taken into account to enable safe operation during low-flow anaesthesia.

a. The breathing system needs to be as tight as possible to minimize the gas quantity lost via leakage. The fewer parts a breathing system has, the fewer the sources of leakage. Dräger breathing systems consist of only a few parts, thus reducing the number of connections, i.e. potential sources of leakage. This already applies to our Fabius, Primus and Zeus device families but is even more pronounced in our Perseus® A500 where the breathing system only has 11 parts.

Unlike other anaesthesia systems, the breathing bag in Dräger devices is an integral part of the breathing system and acts as a fresh gas reservoir, thus being an additional indicator of insufficient fresh-gas flows. An empty breathing bag indicates a fresh gas deficit and that the fresh-gas flow needs to be increased.

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Breathing systems components of Perseus® A500

b. Due to the lower influx of fresh gas, the gas in the brathing system is humidified and warmed more quickly, which is the clinically desired effect. But the high humidity imposes the risk for condensation and subsequently of water within the breathing system potentially affecting the performance and the functionality of the system.

In order to reduce condensation to a minimum, Dräger offers active heating for its breathing systems, thus reducing the formation of condensate. An active breathing system heater is available for all Dräger breathing systems.

The Perseus® A500 comes with a software option to flush and dry the breathing system, e.g. at the end of operating list. To help dry up the least little bit of condensate appearing in the Perseus® A500 breathing system, the device can flush the system with a high flow for a defined time.

c. Hold on to your samples gas – especially during low-flow anaesthesia. In most devices, the sample gas extracted from the system for gas analysis at a rate of approx. 200 ml/min is not returned to the breathing system. This is a systematic leak of significant magnitude and is the reason why many devices are not able to run at flow rates of less than 600 or 500 ml/min. Dräger anaesthesia systems always return the sample gas back to the breathing system. Ventilator Technologies used by Dräger can ventilate with any fresh-gas flows.

d. To manage leaks, the anaesthesia system should be able to inform the user of leakage during preparation of the device for operation, i.e. during the system self-test, so that the user is aware of leaks and their magnitude. During the procedure, the anaesthesia system should also be able to inform the user of the sufficiency of the fresh-gas flow. To read more about smart software options covering this topic, please see chapter 6 "Smart tools".

e. The gas volume within the breathing system has a significant influence on the time constant of the device. This refers to the time required by the anaesthesia device running at low fresh-gas flows to apply a changed concentration of oxygen or volatile anaesthetic agent to the patient. The lower the fresh-gas flow, the longer the time constant. The same applies to higher breathing system volumes.

Dräger anaesthesia devices are designed for low breathing system volumes facilitating short time constants. Furthermore, our ventilator technology influences the time constant as well. The blower technology employed in the Zeus® and Perseus® device families provides a circular flow actively contributing to a shorter time constant. This is especially noticeable when small tidal volumes are used, e.g. in paediatric anaesthesia.

2. ROBUST AND PRECISE FLOW MEASUREMENT AND VENTILATOR TECHNOLOGY

Depending on the technology used, flow sensors can be sensitive to condensation potentially jeopardizing precise measurement. Condensate water droplets can occlude the sensors and thus lead to measurement issues or even complete failure. Ventilators depending on this measurement will not be able to continue accurate tidal volume delivery.

Dräger Flow sensors use heated wire anemometry technology. A wire within the sensor is heated to a defined temperature which results in a defined impedance measurement. The bypassed respiratory gas reduces the temperature of the wire resulting in a changed impedance measurement. The change of impedance is a precise measure for the respiratory gas flow rate. Due to the heated wire, this sensor is very resistant to humidity and condensation. Thus Dräger sensors are very robust compared to many other sensors.

If a flow sensor does fail, the Dräger piston ventilator utilised in the Primus and Fabius family devices is still able to continue accurate tidal volume delivery via the stepper motor moving the piston up and down; thanks to this technology, the ventilator always knows the position of the piston and is hence able to calculate the volume moved into the breathing system. This safety feature allows the piston ventilator to be independent of the flow measurement.

3. ABILITY TO SUFFICIENTLY DOSE VOLATILE ANAESTHETIC AGENTS

During anaesthesia with low fresh-gas flows, the supply of volatile anaesthetic agents is reduced if not compensated by higher vaporizer settings. To achieve or to maintain the targeted concentrations, especially when reducing the fresh-gas flow at the beginning of the procedure, the vaporizer needs to deliver a much higher concentration compared to what users would normally set during high-flow anaesthesia. For example, Sevoflurane vapour should have a maximum concentration of up to 7%, Isoflurane up to 6% and Desflurane up to 14%.
Detailed information can also be taken from the booklet "Low-flow, minimal-flow and metabolic-flow anaesthesia" by C. Hönemann and B. Mierke (download here: Link).

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Dräger Vapor 3000 / D-Vapor 3000

4. IMPACT OF CHANGES IN FRESH-GAS SETTINGS ON TIDAL VOLUMES

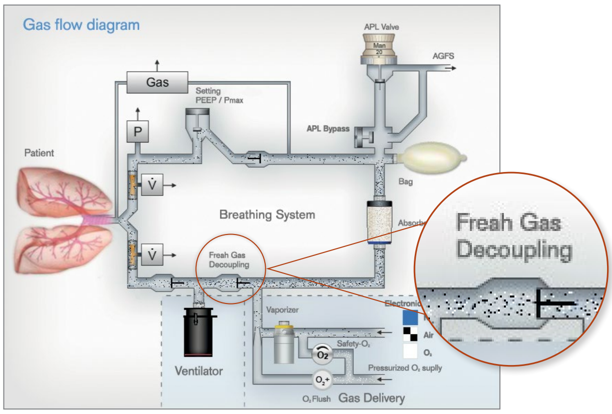
If the user needs to wash in a higher dosage of oxygen or anaesthetic agent or wash out anaesthetic gas quickly at the end of surgery, he will need to turn up the flow rate setting rapidly. Depending on the technology employed, a rapid increase in flow rate carries the risk of peaks in inspiratory pressure and tidal volume being delivered directly to the patient. There are 2 technologies on the market to mitigate this risk:

a. Fresh gas compensation

Fresh gas compensation is based on software monitoring the tidal volume delivered to the patient by using the signal of the inspiratory flow sensor and adjusting the volume delivered from the ventilator to compensate for changes in fresh gas flow. This can result in the ventilator delivering a tidal volume that is higher or lower than the one set by the user. The set tidal volume is achieved together with the fresh-gas flow. However, if rapid changes in fresh-gas flow settings are made, this technology needs a few seconds to adapt the tidal volume delivered by the ventilator. This latency may result in inspiratory pressure and/or tidal volume peaks.

b. Fresh gas decoupling

Fresh gas decoupling refers to the ability of an anaesthesia device to separate fresh gas flow from inspiration to avoid undesirable influence on ventilation. Dräger anaesthesia devices of the Fabius and Primus families utilise a valve controlling the fresh gas influx into the breathing system. Being closed during inspiration, this valve prevents the fresh-gas flow from influencing the inspiratory pressure and/or the tidal volume. No peaks in inspiratory pressure and tidal volume occur.



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Gas flow diagram Primus®

The Perseus® A500 utilizes a slightly different technology to achieve the same target of avoiding influence of fresh gas flow on ventilation. The blower ventilator of the Perseus® A500 actively uses the fresh gas flow during the inspiratory flow phase in order to further reduce breathing systems' time constant, but physically decouples the fresh gas flow during the rest of the inspiratory phase by a specifically designed inspiratory valve. Therefore an undesirable influence of fresh gas flow on ventilation is avoided.

5. RELIABLE GAS MEASUREMENT

Anesthetic gas measurement

During low- and minimal-flow anaesthesia, precise gas measurement is of utmost importance because vaporizer settings can differ significantly from the measured values delivered to the patient. The low influx of fresh gas consequently leads to a lower quantity of volatile anaesthetic agent being flushed into the system. To achieve the target MAC values, vaporizer settings need to be significantly higher than those used in high-flow anaesthesia. The high humidity achieved during low- and minimal-flow anaesthesia may lead to condensation potentially damaging the gas analyser, i.e. causing unreliable measurements or even gas measurement failure.

To mitigate this risk, all Dräger gas analysers are equipped with a water trap to protect the respiratory gas module from moisture condensation and water. Breathing hoses with water traps are also available to prevent condensation in the breathing system.

Oxygen measurement

Depending on the technology used, oxygen sensor technology requires a reference gas for precise measurement. This technology implies, that the sample gas extracted from the breathing system is mixed with a reference gas, which has a different composition (room air, with lower oxygen and no anesthetic gas contents). In devices utilizing this technology and returning the sample gas to the breathing system, this may have an impact on the gas composition within the breathing system. Especially in low- and minimal-flow anaesthesia, the sample gas returned with a different composition may lower the portion of oxygen and anaesthetic agent and accumulate nitrogen (N_2) in the entire breathing system.

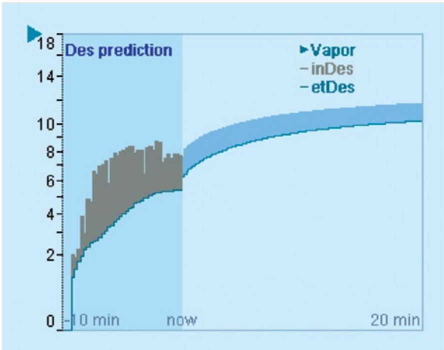
Dräger oxygen sensors do not require a reference gas and thus have no impact on gas composition in the breathing system.

6. SMART TOOLS TO SUPPORT SAFE LOW-FLOW ANAESTHESIA

As described above, leakages and time constants need to be taken into account when performing low- or minimal-flow anaesthesia. The dynamics of an anaesthesia system should be well understood by the user. But software-based tools can offer support by indicating a fresh-gas flow shortage, predicting concentration changes or even taking control of the gas dosing and delivery process.

a. The Dräger Econometer and the low-flow Wizard are tools monitoring the fresh-gas flow and visually indicating if the flow becomes insufficient. The tools also indicate if the fresh-gas flow is higher than required, helping the user achieve low and safe fresh-gas flows. In order to do this, the tools analyse data like patient uptake, breathing system leakage and the volume of CO_2 absorbed by the soda lime and comparing the sum of these values with the actual fresh-gas flow. (Link zu Perseus® Econometer & low-flow wizard broschure)

b. Dräger VaporView and O_2 Prediction are advanced software tools available for the Perseus® A500 anaesthesia system visualizing a forecast of the course of anaesthetic gas and oxygen concentrations over the next 20 minutes and a trend of the past 10 minutes. These tools provide an easy-to-understand, graphical visualization on how the concentration of the above mentioned gases will develop over the next 20 minutes providing the user with ample time to react to undesired changes in concentration or an indication of what effect a recently made change will have. The basis for these tools are calculations based on physiological and technological models and the ability of the device to read the volatile anaesthetic concentration set on the vaporizer (only available in Perseus® in conjunction with the Vapor 3000 / D-Vapor 3000).



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VaporView in the Perseus® A500

c. xMac calculation – in addition to the afore mentioned prediction tools, Dräger anaesthesia systems provide another method for controlling whether or not the anaesthesia system delivers a sufficient dosage of volatile anaesthetic agent. Apart from checking the expiratory volatile anaesthetic concentration, an age-adapted MAC (xMAC) is displayed to provide additional information for drug dosing. By these means, the user is well informed of the MAC value currently provided to the patient. However, it is important to enter the patient's age into the system to ensure the correct calculations.

d. The Auto-Control Function is the ability of the Zeus® IE to run the system in a completely closed circuit mode. This means that there is no constant fresh-gas flow, but an automatic injection of volatile anaesthetic agents and oxygen to compensate for patient uptake. The user sets target values for these gases and the Zeus IE will fully automate their dosage. This results in almost no waste of humidified and warmed gas maximum savings of volatile anaesthetic agents and oxygen.

What are the steps to be followed for a safe low-flow anaesthesia?

C. Hönemann and B. Mierke have published their booklet on low-flow, minimal-flow and metabolic-flow Anaesthesia and provide background knowledge and detailed instructions to safely apply anaesthesia with low fresh-gas flows from a clinical perspective. The booklet can be downloaded from the Dräger Website (Link). But users can also contact their local Dräger representative for a printed version.

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