

Technology Insights

Paediatric Ventilation

Ventilation of paediatric patients during general anaesthesia poses major requirements to anaesthesia workstations. Dräger works closely with clinicians and nursing staff around the world to understand the precise needs and requirements for protective ventilation in the OR. Below we describe the latest ventilation technologies in our anaesthesia workstations supporting protective ventilation in children.

Technology
for Life

Neonatal and paediatric patients run a much higher risk of suffering from severe anaesthesia-related complications compared to adults, respiratory complications playing a major role. This was impressively demonstrated by a large, trans-European study recently published in the *Lancet Respiratory Medicine* in May 2017¹. One reason for this lies in distinct differences in physiology and pre-existing diseases in paediatric patients, especially in newborns. Dr. Thomas Fischer, Chief Anesthesiologist of the department of paediatric anaesthesia and intensive care of the Municipal Hospital of Kassel, Germany, has elaborated further on this particular topic in the clinical whitepaper available on the Dräger Website for Protective Ventilation in the OR ([Link](#)). Anaesthesia workstations need to meet the child's demand during anaesthesia especially with respect to ventilation. The following chapters will provide background information on technological requirements for paediatric ventilation and how Dräger technology can support.

PRECISE TIDAL VOLUMES

When ventilating children during general anaesthesia, the accuracy of tidal volumes applied is very important. Especially in small children, an apparently small deviation from the set tidal volume can be a big deviation for the small child. In the case of a 5kg baby the targeted tidal volume may be 40ml (8ml/kg). An additional 20ml tidal volume means a 50% deviation for the baby resulting in a 12ml/kg tidal volume – a quite dramatic deviation which would not be regarded as being protective. For more details, please see the clinical whitepaper by Dr. Thomas Fischer on the ventilation of paediatric patients during general anaesthesia ([Link](#)). Dräger anaesthesia devices provide high tidal volume accuracy. The following technologies are of specific relevance.

Flow-Sensor Technology

Flow-Sensors measure gas flows in the breathing system which are used to calculate gas volumes delivered to the patient and/or being expired by the patient. Thus, a highly precise flow-measurement is crucial for exact tidal volume delivery, especially looking at small tidal volumes in paediatric ventilation.

Dräger deploys a very precise flow sensor technology called heated wire anemometry. This technology uses a metal wire that is being heated to a defined temperature while at the same time measuring the electrical impedance. Gas flowing through the sensor cools down the wire influencing the measured impedance. The change in impedance directly correlates with a change in flow. This technology has proven to be very reliable and precise and produces solid signals even with low flow rates (and thus low tidal volumes). Other technologies on the market have significant difficulties producing reliable measurements, especially at low flow rates which are important in paediatric anaesthesia.

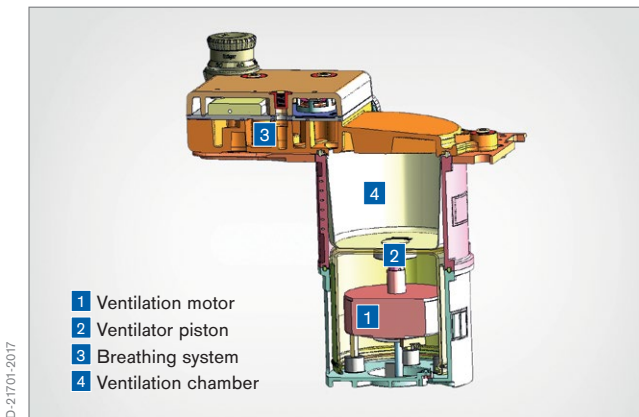
Depending on the technology used, flow sensors can also be sensitive to condensation potentially jeopardising precise measurement. Condensate water droplets can occlude the sensors and thus lead to measurement issues or even complete failure. Ventilators depending on this measurement will not be able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

Due to the heated wire anemometry technology used by Dräger, this sensor is very resistant to humidity and condensation. Thus Dräger sensors are very robust compared to many other sensors.

Tidal volume accuracy and the piston ventilator

Even though pressure controlled ventilation is the preferred mode of ventilation for paediatric patients, volume-controlled ventilation is also frequently used in order to make sure the sufficient tidal volume is being delivered to the child. The piston ventilator design is uniquely suited to deliver this tidal volume accurately. Since the surface area of the piston is fixed, the volume delivered by the piston is directly related to the linear movement of the piston (2). This makes the tidal volume delivery extremely accurate – and even in the unlikely event of a flow-sensor failure, ventilation with set volume delivery will still function. When the user sets a volume for ventilating the patient, the piston moves the distance necessary to deliver the required volume (4) into the breathing system (3). Furthermore, since the connection between piston and motor (1) is rigid, the position of the piston (2) is always identified and the volume delivered by the piston is, hence, always known.

For those who want to make sure, that the set tidal volume is being reliably delivered but are also worried about excessive pressures, Dräger offers an additional mode of ventilation: Volume Control Autoflow ensures the application of the set tidal volume at the lowest possible pressure and in a pressure controlled fashion.



Schematic of E-Vent ventilator Primus

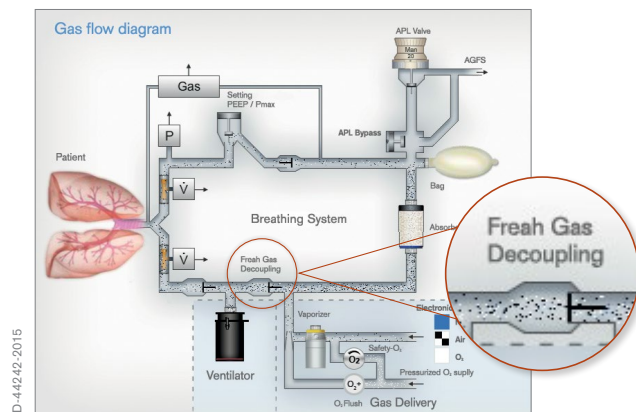
Compliance/Fresh Gas Compensation

Compliance refers to the fact, that parts of the system volume of an anesthesia device, including the hose system, can expand upon pressure causing them to “take up” volume which should actually be delivered to the patient. Without means of compensating for the effect of circuit compliance, the volume the patient receives will decrease as pressure in the circuit increases. Dräger ventilator units are able to compensate for the compliance of the breathing system by delivering sufficient additional volume with each breath to ensure that the patient receives the volume set to be delivered. Dräger ventilators measure the compliance of the system during the start-up self-test procedure. Once the compliance factor is determined, only a pressure sensor is required to calculate how much additional volume should be delivered with each breath to compensate for the loss due to the breathing system compliance. As a result, the set tidal volume is delivered to the patient's airway.

However, the compliant system volume is not the only influence on tidal volume that needs to be compensated. The set fresh gas flow can increase tidal volume significantly compromising tidal volume accuracy. This influence also needs to be eliminated. If fresh gas compensation is used in older types of machines, the disadvantage might be that the ventilator may deliver 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, the system latency causes the device to require a few seconds to adapt the tidal volume delivered by the ventilator. This may result in tidal volume and/or inspiratory pressure peaks. A much more direct and effective solution to this influence is to physically decouple fresh gas flow from tidal volume delivery.

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 from the Fabius and Primus families utilise a valve controlling the fresh gas influx into the breathing system. When closed during inspiration, this valve prevents the fresh-gas flow from influencing the tidal volume and the inspiratory pressure delivered. No peaks in tidal volume and inspiratory pressure occur. Furthermore, this technology reduces the potentially compliant volume of the breathing system.



Gas flow diagram Primus®

The Perseus® A500 utilises 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 also 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.

Dräger anaesthesia devices include both, fresh gas decoupling and compliance compensation to eliminate negative impact of system compliance and fresh gas flow, thus ensuring tidal volume accuracy.

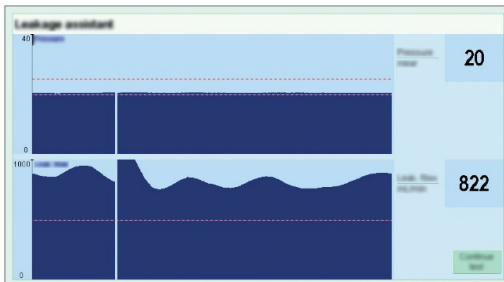
Leakages

System leakages lead to loss of ventilation volume. If not compensated for, they will lead to imprecise tidal volume application. Modern anaesthesia devices should minimise the risk of leakages and offer compensation mechanisms to enable precise tidal volume delivery.

Leakage Assistant

To manage leaks, the anaesthesia system should be able to inform the user of identified leakages 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.

If pre-tests fail, the Perseus® A500 offers a convenient tool to identify leakages. Upon start of this application, the ventilator creates a continuous flow and visualises the missing volume by displaying the leakage value of the system. This tool runs without alarming the user in between. When closing the leakage the user gets direct visual feedback (numerical and graphical) so that it is obvious to the user if the machine is functioning correctly.



Leak-tight Breathing System

Although system leakages can be compensated for, they should be minimised to reduce the need for compensation. This requires the breathing system to be as tight as possible to minimise 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.



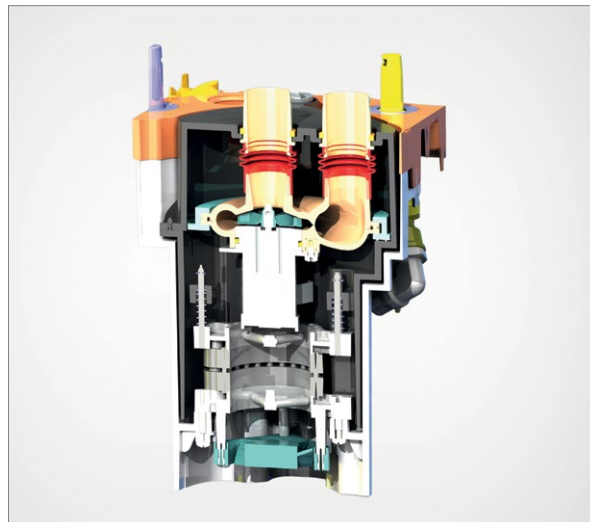
Breathing systems components of Perseus® A500

PRECISE PRESSURES

In order to protect the patient's lungs, especially in children, precise application of ventilation pressures is of vital importance, as excessive pressure may harm the lung by overdistension and loss of PEEP may facilitate the formation of atelectasis. As pointed out in the clinical whitepaper by Dr. Thomas Fischer ([Link](#)), the mean airway pressure (MAP) should be limited to 10cmH₂O and a PEEP of 3-5 should be regularly used in healthy children, and up to 8-10cmH₂O in children with sick lungs. To precisely deliver these pressures, the anaesthesia device ventilator needs to be specifically suited to do so.

Ventilator Technology

Built in the anaesthesia devices Perseus® A500 and Zeus® IE, the TurboVent blower ventilator technology is specifically suited to deliver precise pressures. To understand the operating principle, one can think of a hair dryer. It draws in ambient air, heats it up and accelerates it in one direction. The TurboVent ventilator works in a very similar way, just without heating. Through the one-directional rotation of an impeller (1), a gas mixture is drawn in from the reservoir bag in the breathing system (through 2), gets compressed (1 and 3), and it is then emitted towards the patient (4). Thus, the TurboVent ventilator is a pressure source and is specifically suited for all pressure focused modes of ventilation. Also, the rotation speed of the impeller can be changed extremely quickly facilitating quick changes in pressures, e.g. with high respiratory rates in children.



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Schematic of TurboVent ventilator

Also the Dräger piston ventilator (E-Vent and E-Vent plus) offers precise delivery of ventilation pressures. Due to the direct drive via an electronic motor, the Pistion ventilator achieves pressures quickly and precisely. This is also specifically important in ventilating paediatric patients as the respiratory rates are high and pressure targets have to be achieved very quickly.

Active PEEP

Leakages can have a significant influence on ventilation. To apply precise tidal volumes, the system leakage identified during the leakage test is being compensated by correspondingly increasing the tidal volume. However, this does not prevent the PEEP in between expiration and inspiration from falling or even diminishing. Dräger anaesthesia devices actively hold the PEEP at the set level. The blower ventilator TurboVent (Perseus® A500 and Zeus® IE) is by nature capable of delivering continuous pressure and thus compensating leakages by keeping up the rotation of the impeller and moving additional volume towards the patient. The Dräger piston ventilator E-Vent plus (Primus family) actively holds PEEP levels by continuously moving the piston upwards during PEEP and thus compensating for lost volume via leakages.

Fresh gas decoupling

The influx of fresh gas and how this is managed can influence ventilation pressures. Mechanisms like fresh gas decoupling and fresh gas compensation are intended to counteract this influence. Please refer to the chapter "Precise Tidal Volumes" and "Fresh Gas Decoupling" for more details.

Pressure Precision in Man/Spont mode

When ventilating a child using the hand bag of the anaesthesia device, the APL valve is the pressure limiting part in the system. While the anaesthesiologist creates the pressure by pressing the ventilation bag, the APL valve limits the pressure in the system to the set value. Therefore, the precision of the APL valve in limiting the pressure in the system is of high importance. A recent study found significant differences in the pressure limit supposedly set by the user and the actually delivered pressure to the patient. One of the 2 APL valves compared in this study showed significant deviations from the set pressure limit, achieving much lower or much higher actual pressure. The APL valve should ideally produce a linear pressure profile, meaning that the pressure in the system should precisely correspond to the set value. Dräger APL valve was found to produce this linear pressure pattern and thus reliably prevents excessive pressures in manual ventilation.²

SUPPORT FOR SPONTANEOUS BREATHING

In case you intend to have the child breathe spontaneously, it is important that the anaesthesia device supports this measure instead of making it hard for the child to breathe. It is vital that the system recognises the smallest breathing attempt in order to provide support, e.g. pressure support. Keeping the low tidal volumes in mind, this requires a very sensitive flow trigger. Dräger anaesthesia devices provide highly sensitive flow triggers so that spontaneous breathing attempts are reliably detected. However, as already stated in the clinical whitepaper by Dr. Thomas Fischer ([Link](#)), resistance is an important topic, especially in small

children. In order to make it easier for children to breathe spontaneously, the resistance of the breathing system should be as low as possible.

Breathing system resistance

In blower-driven anaesthesia machines like in the Zeus® family and the Perseus® A500, a circle flow reduces the resistances of the breathing system, and this facilitates spontaneous breathing and reduces the work of breathing. The circle flow is a minimum flow continuously circulating in the system. The minimal pressure required to achieve this circle flow mitigates the breathing system resistance. With these systems, the patient can breathe spontaneously at any time, even during inspiratory phase and at the PEEP (CPAP) level. During expiration, the E-Vent and E-Vent plus piston-driven ventilators in the Fabius® and Primus® families synchronise the expiratory phase with the expiration flow, and actively support the patient's expiration by regulating the pistons' movement accordingly.

RELIABLE GAS COMPOSITION

Reliable Gas Measurement & Sample Gas Return

Gas measurement in anaesthesia machines includes the measurement of O₂, CO₂ and anaesthetic agents. In children, a reliable measurement of gases, especially oxygen is of vital importance as children can desaturate very quickly. For oxygen measurement different technologies are available on the market. Dräger deploys paramagnetic as well as electrochemical O₂ sensor technologies, both of which reliably measure oxygen not influencing the composition of the sample gas.

The sensor technology used in many other devices requires a so-called reference gas, e.g. ambient air, for correct measurement. This implies that ambient air is being mixed with the sample gas from the breathing system along the process. The composition of this mixture is then different to the gas mix in the breathing system. Oxygen and volatile anaesthetic agent concentrations will be lower, nitrogen – usually not present in breathing systems – is being added. In devices utilising this technology and returning the sample gas back into the breathing system, this can significantly alter the gas composition within the breathing system. Especially the influx of nitrogen and a missing, dedicated elimination mechanism, just like soda lime for carbon dioxide, may lead to undesirable nitrogen accumulation. However, many devices utilising this sensor technology may not return sample gas back into the breathing system, thus creating another relevant problem: leakage. In most devices, the sample gas is extracted from the system at a rate of approx. 200 ml/min. This is a systematic leak of significant magnitude and is the reason why these devices are not able to operate at flow rates of less than 600 or 500 ml/min. Furthermore, hypoxic gas mixtures may occur when combining oxygen measurement using a reference gas with samples gas return and low fresh gas flow rates.

Therefore it is important that A) sample gas is returned into the system, and B) the composition of the sample gas is not altered. Note: For the above mentioned reasons, some countries do not permit sample gas return in systems using O₂ sensor technology requiring reference gas.

Dräger anaesthesia systems always return the sample gas back to the breathing system and do not alter the concentrations of the individual gases. Therefore, the gas composition in the system is not changed and no systemic leak needs to be compensated.

Time Constant of System

This refers to the time an anaesthesia device requires to effectively deliver a changed gas composition to the patient. If the anaesthesiologist intends to increase the FiO₂, the system will require up to a few minutes to actually achieve the targeted value in the entire system. Especially in children, a quick change in gas composition can be crucial, therefore the time constant should be as small as possible.

The gas volume within the breathing system has a significant influence on the time constant of the device. 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.

QUICK RESPONSE / SPEED OF THE SYSTEM:

High respiratory rates.

The smaller the child, the higher the frequency required for appropriate ventilation. This can result in very low inspiratory times. Especially if a minimum time for expiration of 0.4 seconds needs to be provided in order to avoid air trapping, inspiratory times can get very short. In order to provide the set tidal volume in this short inspiration time, anaesthesia ventilators need to provide high inspiratory flows to apply the set tidal volume in the short time given. All Dräger ventilators are capable of providing high inspiratory flows enabling high respiratory rates.

However, the TurboVent blower ventilator is by design specifically suited to provide maximum inspiratory flow very quickly as the rotation speed of the impeller can be change rapidly. Thus, this technology is able to move large volumes in very short time.

Time Constant

A quick change in gas composition can be necessary in children, e.g. an increase in FiO₂ to stop a fall in SaO₂ and to improve oxygenation. Therefore, the responsiveness of the system to changes in gas composition is very important. Dräger breathing systems are specifically designed for short time constants. For more details, please see the chapter on “Reliable Gas Composition”.

ADEQUATE PREPARATION

Patient categories & ventilation presets

Thorough preparation of the anaesthesia workplace is of utmost importance. Once the child has arrived for induction of anaesthesia, there will be very little time. Especially once anaesthesia is induced, the time for clinically relevant oxygen desaturation (apnea tolerance) can be as short as 90 seconds. Therefore a swift change to appropriate mechanical ventilation by the anaesthesia device is required. This can only be achieved when all preparation and settings have been made prior to induction. Dräger anaesthesia devices facilitate this process by offering customisable presetting for specific patient categories, incl. paediatric patients (paediatric & neonatal). Once the correct patient category is chosen, the relevant settings and alarm limits will adapt automatically. In most cases, only few manual adaptations to the specific patient need to be done.

Minimising system deadspace

The importance of deadspace reduction to a minimum is described in detail in the clinical whitepaper by Dr. Thomas Fischer ([Link](#)). The physiologic deadspace is already estimated to be approx. 1/3 of the tidal volume. Therefore, the system deadspace between the Y-piece and the patient plays an important role and should be optimised by selecting the right accessories and their position in the system. Filters, such as the HME filter, should be mounted proximal to the device. A position close to the patient should be avoided, especially in small children. However, if a position close to the patient is required, a filter with a small volume should be chosen. Dräger not only offers a wide range of paediatric and neonatal filters, but also offers more deadspace optimised accessories. Please click here to learn more about accessories for Dräger anaesthesia devices specifically suited for children.

References:

1. Habre W, Disma N, Virag K, Becke K, Hansen TG, Jöhr M, Leva B, Morton NS, Vermeulen PM, Zielinska M, Boda K, Veyckemans F; Incidence of severe critical events in paediatric anaesthesia (APRICOT): a prospective multicentre observational study in 261 hospitals in Europe; Lancet Respir Med. 2017 May;5(5):412-425. doi: 10.1016/S2213-2600(17)30116-9
2. Spinney S, Sprigge KA, Lawson T, Flow-pressure characteristics of an Intersurgical adjustable pressure-limiting valve; Anaesthesia, 2017 Apr;72(4):539-540. doi: 10.1111/anae.13846.

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