

Low Flow Anaesthesia

with Dräger Machines



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Because you care

Author

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Low Flow Anaesthesia with Dräger Machines

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1 Introduction to low flow anaesthesia

1. How much gas does the patient take up during anaesthesia?

Total gas uptake: The sum of the uptakes of anaesthetic agents, nitrous oxide, and oxygen (Fig. 1.1).

Oxygen is continuously taken up from the system by the patient at a rate which corresponds to his basal metabolic rate. During anaesthesia oxygen consumption can be regarded as virtually constant. It takes place at a rate which can be calculated using the simplified Brody formula :

$$\dot{V}_{O_2} = 10 \times KG [kg]^{3/4} [mL/min]$$

The uptake of nitrous oxide, which is not metabolised, is determined solely by the alveolar-arterial partial pressure difference. This is high at the beginning of anaesthesia but it becomes less in the course of time with the increased saturation of the tissue with gas. Nitrous oxide uptake can be calculated approximately for an adult patient of average weight using Severinghaus's formula:

$$\dot{V}_{N_2O} = 1000 \times t^{1/2} [mL/min]$$

Subject to the composition of the gas in the anaesthetic system remaining constant, the uptake of anaesthetic inhalation agent is decreasing during the course of Anaesthesia (Fig. 1.2), following a power function. Its behaviour is in proportion to the desired concentration and solubility of the anaesthetic agent and to the cardiac output, according to H. Lowe's formula:

$$\dot{V}_{AN} = f \times MAC \times \lambda_{B/G} \times \dot{Q} \times t^{1/2} [mL/min]$$

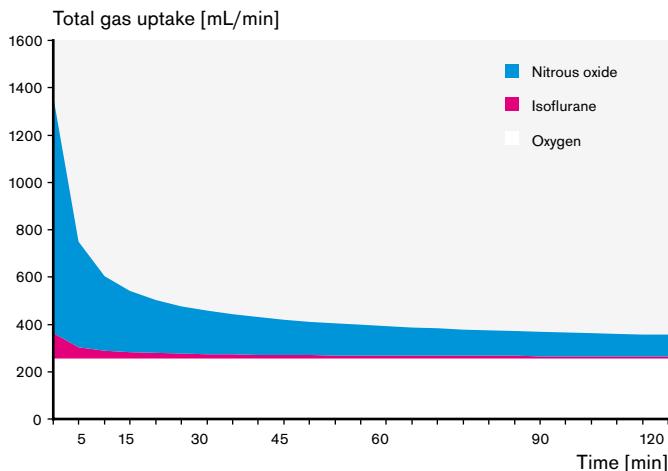


Fig. 1.1
Total gas uptake, carrier gas:
oxygen / nitrous oxide
(adult patient, 75 kg).

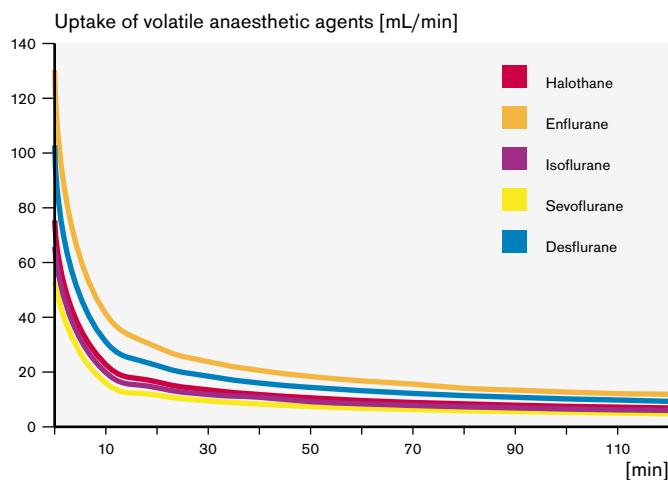


Fig. 1.2
Uptake of volatile anaesthetic
agents, nominal expired conc.: 0.8 x MAC.

2. What does the term low flow anaesthesia mean?

Low flow anaesthesia is carried out with a fresh gas flow rate which is significantly lower than the minute volume. When such low fresh gas flows are used, the anaesthetic gases must be conducted to the patient via semi closed or even closed rebreathing systems. The rebreathing fraction increases with the reduction of the fresh gas flow whereas the volume of excess gas decreases.

Low flow anaesthesia is defined to be an inhalation anaesthetic technique via a rebreathing system in which the rebreathing fraction at least amounts to 50 %, i.e. 50 % of the exhaled gas volume is led back to the patient after carbon dioxide absorption in the next inspiration. Using modern anaesthetic machines this will be gained at a fresh gas flow rate between 2 to 1 L/min.

Although the fresh gas supply into a gas tight rebreathing system can, of course, be reduced steplessly down to that gas volume which is just taken up by the patient at the respective time, a distinction is made in the literature between the following low flow anaesthetic techniques (Fig. 2.1):

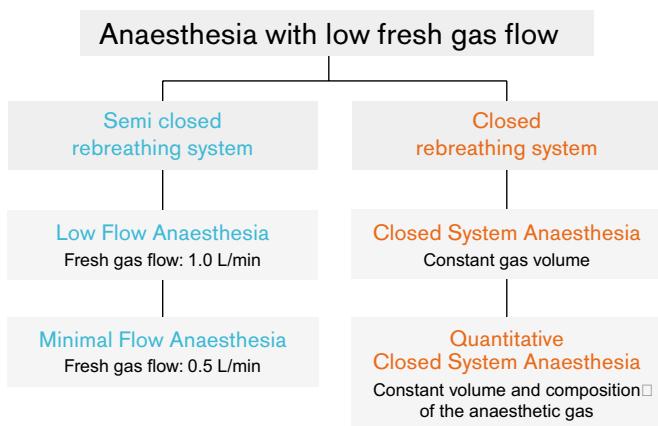


Fig. 2.1
Different methods of low flow anaesthesia.

In Low Flow Anaesthesia (Foldes, 1954) the fresh gas flow rate is reduced to 1 L/min, and in Minimal Flow Anaesthesia (Virtue, 1974) to 0.5 L/min.

In Closed System Anaesthesia , the fresh gas flow just meets the gas volume taken up by the patient, which can be only achieved by frequent adjustments of the gas flow controls. Both, the pressure within the breathing system and the circulating gas volume are maintained, and the ventilation pattern remains completely unchanged.

In Quantitative Closed System Anaesthesia not only the volume but also the composition of the fresh gas supplied into the breathing system corresponds exactly to just that volumes of oxygen, nitrous oxide and inhalation anaesthetic which are taken up by the patient at any given time. Thus, not only the gas volume circulating within the breathing system and the ventilation pattern but also the composition of the anaesthetic gas delivered to the patient remains constant during the whole course of anaesthesia.

With the different low flow anaesthetic techniques the fresh gas flow rate is adapted to the individual total gas uptake with increasing precision (Fig. 2.2).

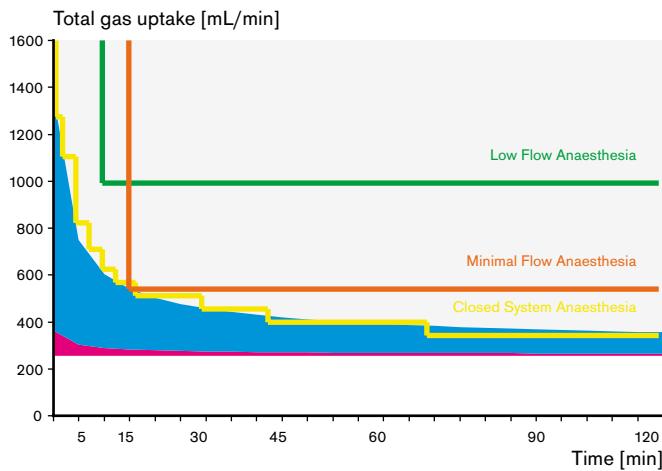


Fig. 2.2
Different methods of low flow anaesthesia: different grades of precision to adapting the fresh gas flow to the uptake.

2 How to perform low flow anaesthesia with an oxygen / nitrous oxide carrier gas mixture

3. How to induce low flow anaesthesia?

Premedication can take place in accordance with every routinely used scheme.

Induction by anaesthetic gas inhalation or intravenous administration of hypnotics and opioids can also take place in accordance with the usual procedures and as is appropriate for each individual case. The patient is connected to the breathing system after intubation or insertion of a laryngeal mask. There are no procedure specific requirements with respect to premedication or induction.

During an initial phase, lasting 10 to 20 minutes, a comparatively high fresh gas flow of about 4 L/min is set at the anaesthetic machine (for example 1.4 L/min O₂ and 3.0 L/min N₂O) (Fig. 3.1). During that time the desired anaesthetic gas composition is established within the breathing system. Set the vaporiser - adjusted to suit individual reactions and surgical requirements - to following standard concentrations respectively:

Halothane to 1.0 - 1.5 vol%,
Enflurane to 2.0 - 2.5 vol%,
Isoflurane to 1.0 - 1.5 vol%,
Sevoflurane to 2.0 - 2.5 vol%, and
Desflurane to 4.0 - 6.0 vol%.

In the specified time an expiratory concentration will be achieved corresponding to about 0.8 x MAC of the respective anaesthetic agent. Individual differences to the desired nominal value will be greater the higher are the solubility and the metabolism of the chosen anaesthetic (Fig. 3.2).

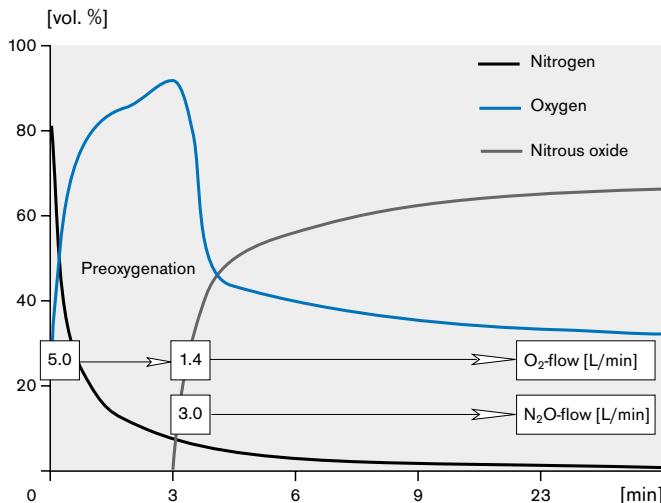
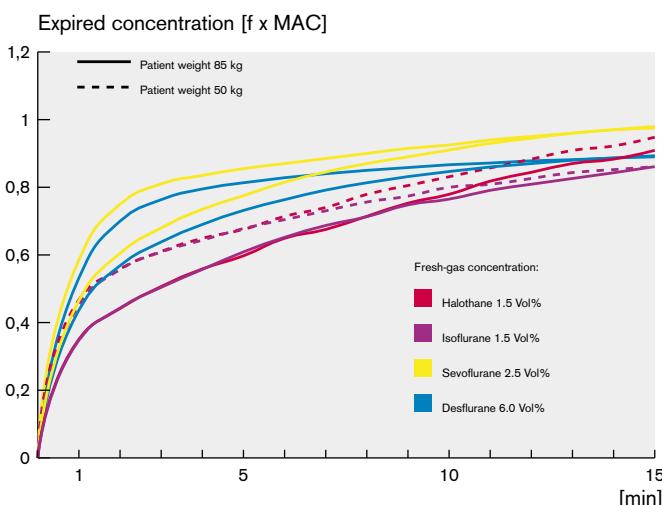


Fig. 3.1
Wash-in of desired anaesthetic
gas composition, insp.
concentrations.



3.2
Wash-in of different
anaesthetic agents.

4. What are the main pharmacokinetic and pharmacodynamic differences of the various anaesthetic agents with respect to low flow anaesthesia?

With respect to low flow anaesthesia following properties of inhalation anaesthetics are the most relevant ones (Fig. 4.1): solubility, metabolism, and anaesthetic potency. Solubility and metabolism determine the amount of anaesthetic vapour needed to establish and maintain a desired concentration. The anaesthetic potency, described by the MAC, determines the nominal concentration needed for sufficient depth of anaesthesia. The lower the solubility and the metabolism, and the higher the anaesthetic potency, the lower is the individual uptake and the less anaesthetic has to be supplied into the breathing system.

The maximum amount of anaesthetic vapour which can be delivered into the breathing system, using vaporisers outside the circuit under low flow conditions, is related to the anaesthetic potency of the agent, as the maximum concentration which can be dialled is limited to 3 to 5 times of its MAC. Thus, at a flow of 500 mL/min not more than about 25 mL/min isoflurane vapour but up to 110 mL/min vapour when using desflurane can be delivered into the breathing system. Low anaesthetic potency and low solubility essentially improve the controllability during performance of low flow techniques.

When using nitrous oxide as carrier gas, an expiratory agent's concentration being 0.7-0.8 times the MAC of the respective anaesthetic together with 60% N₂O (0.6 MAC N₂O) will result in an additive MAC of 1.3-1.4, equalling the AD95. This is the anaesthetic concentration guaranteeing that 95% of all patients tolerate the initial skin incision without any reflex movement. When omitting the use of nitrous oxide an anaesthetic concentration of 1-1.1 MAC, together with supplemental doses of opioids, has to be used to substitute for the missing effect of nitrous oxide.

	Halothane	Enflurane	Isoflurane	Sevoflurane	Desflurane	Nitrous oxide	Xenon
Solubility							
λ Blood/Gas	2.5	1.8	1.4	0.65	0.42	0.47	0.14
λ Fat/Gas	136	69	64	34	12	1.2	
λ Fat/Blood	51	36	45	48	27	2.3	
Metabolism							
Biotransformation [%]	20	2-4	< 1.0	3-5	< 0.1	0	0
Anaesthetic potency							
MAC [vol%]	0.8	1.7	1.2	2.0	6.0	105	55-70
MAC awake	0.3	0.6	0.4	0.7	2.0		
MAC 3-5 Jahre	0.9	2.4	1.6	2.5	8.6		
MAC ca. 30 Jahre	0.8	1.7	1.2	2.1	7.3		
MAC ca. 70 Jahre	0.6		1.1	1.5	5.2		

Fig. 4.1
Pharmacokinetic and
pharmacodynamic properties
of different inhalation
anaesthetics.

5. How long should the initial phase of low flow anaesthesia last?

The duration of the initial phase of low flow anaesthesia, in which a comparatively high flow of fresh gas has to be applied, must be adapted to the rate to which the flow is reduced, to the composition of the carrier gas, to the maximum output of the agent specific vaporiser, and to the individual gas uptake (Fig. 5.1).

During that time the desired anaesthetic gas composition must be established within the entire gas containing system, an adequate depth of anaesthesia must be reached, and denitrogenation must be completed.

Especially when nitrous oxide is used, only a considerable amount of excess gas guarantees sufficient gas filling of the breathing system. If in the initial phase, still characterized by high nitrous oxide uptake, the fresh gas flow rate is reduced too early, gas volume deficiency must occur: The fresh gas volume, delivered into the breathing system, does not meet the gas loss via uptake and leakages any more.

Thus, if one has to assume a comparatively high initial individual gas uptake, especially if nitrous oxide is used, in Low Flow Anaesthesia the initial phase should last about 10 minutes, in Minimal Flow Anaesthesia about 15 minutes, but for very strong patients it may be even as long as 20 minutes.

Initial High Flow Phase

Fig. 5.1

- Sufficient denitrogenation
- Rapid wash in of the desired gas composition into the breathing system
- Establishing of the desired anaesthetic concentration
- Avoiding gas volume deficiency

6. Can the duration of the initial phase be shortened?

If a nitrous oxide / oxygen mixture as carrier gas is used, an adult patient of average weight after 10 minutes still takes up about 570 mL/min of gas. At that time the fresh gas flow rate can be reduced to 1.0 L/min without any problems. If the flow rate, however, would be reduced to 0.5 L/min already at that time, then more gas would be extracted from the breathing system than being supplied to it (Fig. 6.1).

The resulting gas volume deficiency in the system would lead to changes in ventilation pattern. The tidal volume would decrease and alternating pressure ventilation would result, if conventional anaesthetic machines were being used with suspended bellows arrangement, whose expiratory filling is supported by an additional external force.

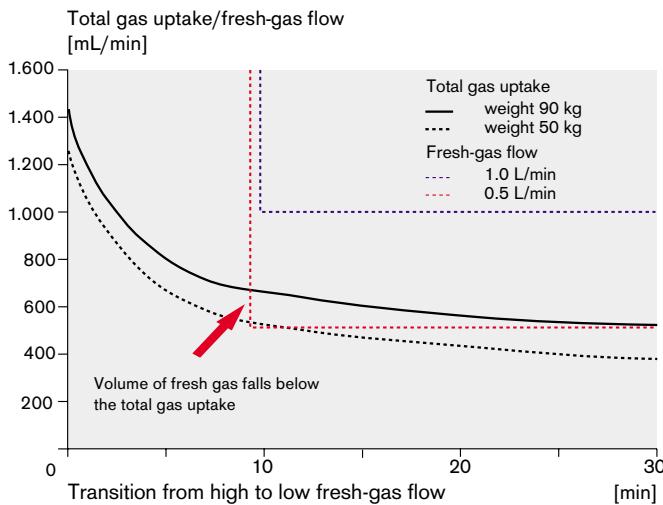


Fig. 6.1
Gas volume deficiency
resulting from inappropriate
early flow reduction.

Furthermore, it must be remembered that the output of the vaporisers is limited. Even when an isoflurane or an enflurane vaporiser, for instance, is fully opened, at a fresh gas flow rate of 0.5 L/min not more than 25 mL/min agent vapour can be supplied to the breathing system. When individual uptake is high this small amount of anaesthetic agent will not meet the needs to maintain an adequate depth of anaesthesia, particularly if a relatively high anaesthetic concentration is desired (Fig. 6.2).

Bearing these problems in mind, the initial phase could only be shortened in the following ways:

- Accelerating the denitrogenation and the wash-in phase by increasing the initial high fresh gas flow rate to 8-12 L/min.
- Selecting a suitable inhalation anaesthetic agent with low blood solubility and correspondingly low individual uptake like sevoflurane or desflurane. A desired expiratory concentration of about $0.8 \times \text{MAC}$ will be achieved rapidly in only 10 minutes. As denitrogenation, too, is completed at that time, the fresh gas flow may be reduced to even 0.5 L/min already after ten minutes. However, this is only advisable if the anaesthetic machine is equipped with an anaesthetic gas reservoir balancing short lasting gas volume deficiency, which may result from still high nitrous oxide uptake.
- Accelerating the approach of the desired anaesthetic depth by increasing the amount of anaesthetic agent taken up through initially setting a high fresh gas concentration of the respective agent (e.g., isoflurane 4-5 vol.%).
- Stepwise reducing the fresh gas flow rate, e.g. reducing the flow to 2 L/min after the initial 5 minutes, to 1 L/min after 10 minutes and, finally, to 0.5 L/min after 15 minutes.

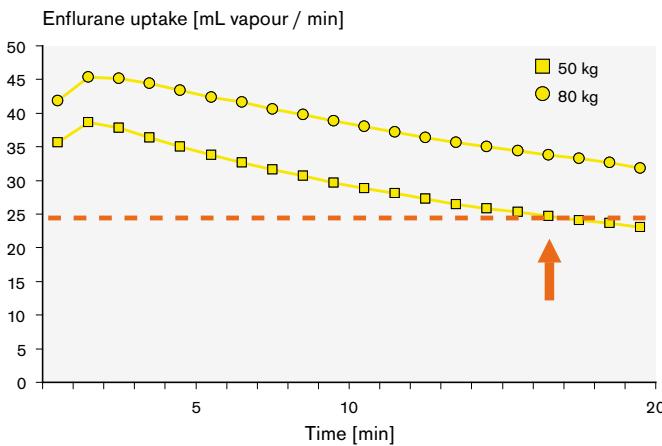


Fig. 6.2
Limitation of the enflurane vaporiser's output does not allow early reduction of the flow to 0.5 L/min: The amount of agent delivered (red line) initially would be far less than the amount needed to meet the uptake (red arrow).

7. Why must the concentration of oxygen in the fresh gas be increased when the flow is reduced?

With fresh gas flow reduction the rebreathing fraction increases, and with it the volume of oxygen depleted expired gas which is supplied to the patient again during the next inspiration. The proportion of oxygen in the fresh gas must therefore be increased as flow is reduced. During Low Flow Anaesthesia (1.0 L/min), the oxygen concentration shall be increased to 50 vol.%, but at least to 40 vol %, and during Minimal Flow Anaesthesia (0.5 L/min) to 60 vol.%, but at least to 50 vol%. For most of all patients this setting will guarantee an inspiratory oxygen concentration of at least 30 vol.%.

In the first 30 to 45 minutes after flow reduction the inspiratory oxygen concentration increases but then falls back slowly but continuously during the following course of anaesthesia (Fig. 7.1).

The continuous change in inspiratory oxygen concentration during the course of anaesthesia is due to the continuous decrease of the nitrous oxide uptake. The phenomenon is all the more striking the lower the fresh-gas flow rate and the higher the individual oxygen consumption (Fig. 7.2).

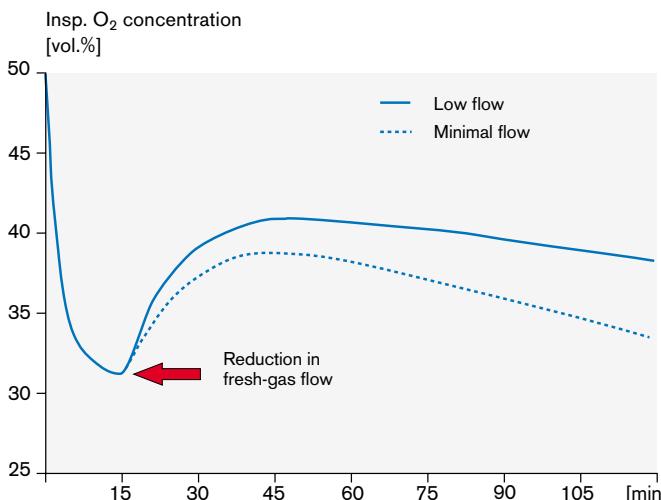


Fig. 7.1
Insp. oxygen concentration
during the course of Low- and
Minimal Flow Anaesthesia,
patient weight 75 kg.

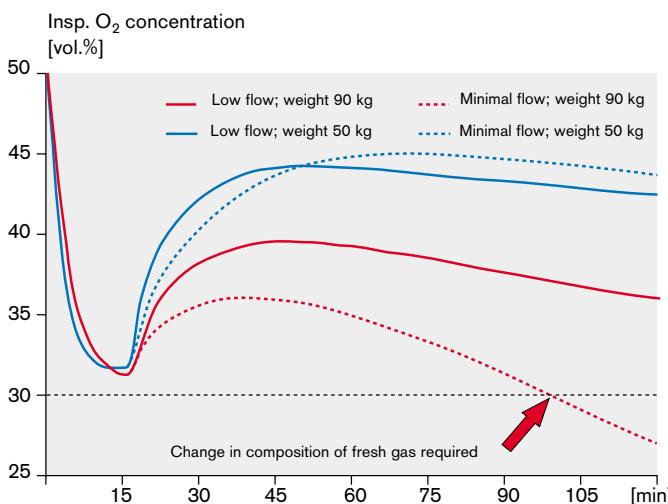


Fig. 7.2
Insp. oxygen concentration
during the course of Low- and
Minimal Flow Anaesthesia,
patients with different oxygen
uptake.

8. Which setting at the gas flow controls will guarantee a safe inspiratory oxygen concentration?

In inhalational anaesthesia conducted with high fresh gas flow rates the inspiratory oxygen concentration is roughly equal to that of the fresh gas. It hardly changes during the course of anaesthesia. In low flow anaesthesia, however, the difference between the inspiratory oxygen concentration and that of the fresh gas increases with the extend of the fresh gas flow reduction. In addition, due to the increasing rebreathing fraction, the inspiratory oxygen concentration is increasingly influenced by the individual oxygen consumption and by the nitrous oxide uptake, at an extend which is clinically relevant. Thus, the inspiratory oxygen concentration changes continuously during the course of anaesthesia.

Thus, steps must be taken to cope with these specific characteristics of low flow anaesthesia:

- The oxygen concentration of the fresh gas must be adequately increased when the flow rate is reduced (Low Flow Anaesthesia: 40-50 vol.% O₂, Minimal Flow Anaesthesia: 50-60 vol.% O₂).
- The inspiratory oxygen concentration must be monitored continuously, and the lower alarm limit set to the nominal inspiratory value. In the author's own department, this nominal value is 30 vol.%, in accordance with the recommendations of Barton and Nunn.
- If the inspiratory O₂-concentration falls below 30 vol %, the O₂-flow must be increased by 10% of the total gas flow, and the N₂O-flow be reduced by the same value. Thus, during Low Flow Anaesthesia the O₂-flow must be increased by 100 mL/min (Fig. 8.1), and by 50 mL/min during Minimal Flow Anaesthesia (Fig. 8.2) each time that the alarm limit is reached. The nitrous oxide flow must be reduced accordingly.

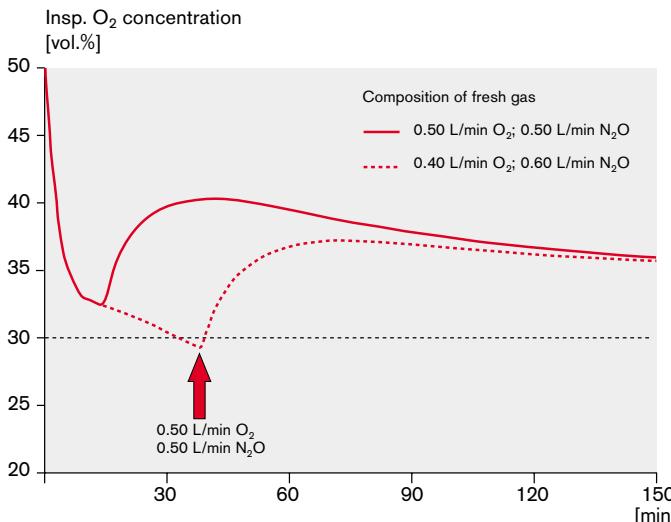


Fig. 8.1
Insp. oxygen concentration during the course of Low Flow Anaesthesia, different oxygen concentrations of the fresh gas.

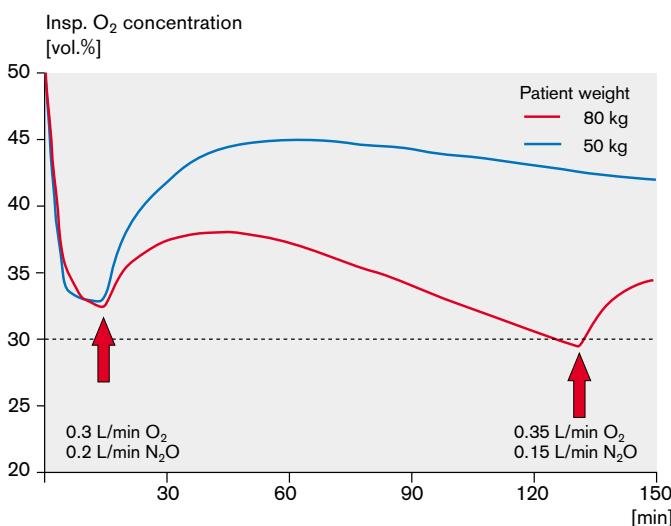


Fig. 8.2
Insp. oxygen concentration during the course of Minimal Flow Anaesthesia, increase of the fresh gas oxygen content when the insp. oxygen concentration reaches the lower limit of 30 vol% .

The frequency to adapting the oxygen concentration of the fresh gas increases:

- When the individual oxygen consumption is comparatively high (Fig. 8.2 and 8.3).
- When, at the time when flow is reduced, a comparatively low fresh gas oxygen concentration has been set at the gas flow controls (Fig. 8.3).

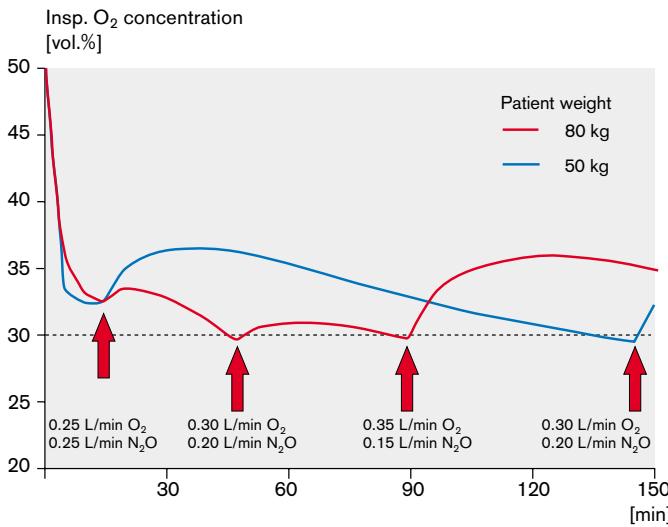


Fig. 8.3
Insp. oxygen concentration
during the course of Minimal
Flow Anaesthesia, more
frequent alterations of the
fresh gas oxygen concentration
in case of high oxygen uptake.

9. What should the vaporiser setting be when the fresh gas flow is reduced?

The difference between the concentration of the anaesthetic agent in the fresh gas and that in the anaesthetic system increases with the extend of the fresh gas flow reduction.

When the flow is being reduced the setting on the vaporiser must be increased. This is the only way that the desired concentration of anaesthetic agent can be maintained in the breathing system after flow reduction. When taking over clinically-proven standard settings it is important to bear in mind that, as the rebreathing fraction increases, the concentration of anaesthetic agent is influenced to a considerable extent by the individual's anaesthetic uptake. This does not apply in anaesthetics performed with high fresh gas flow rates, where the agent concentration within the breathing system mainly equals the vaporiser setting. If, when maintaining low flow rates during low flow anaesthesia, the concentration of the volatile anaesthetic agent shall be increased or reduced, the concentration set on the vaporiser must considerably exceed - or fall below - the desired nominal value.

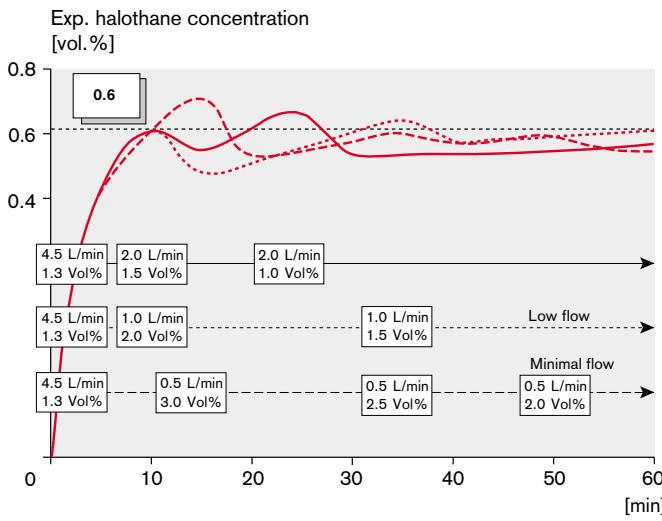
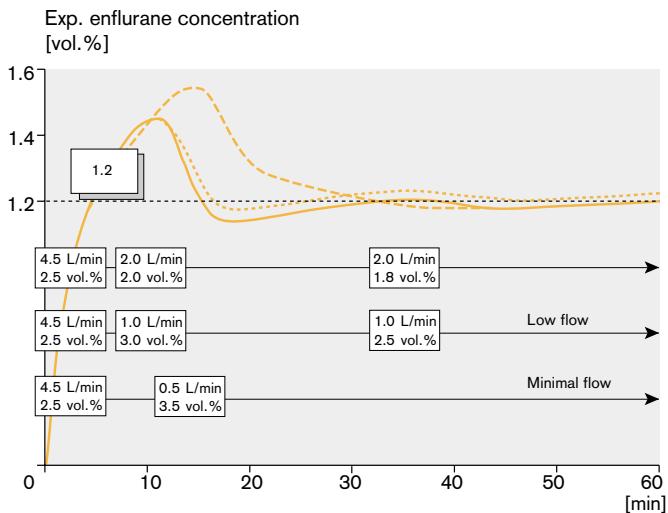


Figure 9.1
Expiratory halothane concentration (nominal value, 0.6 vol.% \approx 0.8 MAC, patient 75 kg) and vaporiser settings required for the different fresh-gas flows.

After an initial phase with high fresh gas flow of 4.5 L/min and a vaporiser setting of 1.3 vol% halothane, lasting for 10 or 15 minutes respectively, the flow is reduced to 2.0, 1.0 or 0.5 L/min. The lower the fresh gas flow, the higher the concentration to be dialled at the vaporiser to maintain a desired expiratory halothane concentration of about 0.6 vol% during the remaining course of anaesthesia.

Figure 9.2
Expiratory enflurane concentration (nominal value, 1.2 vol.% \approx 0.7 MAC, patient 75 kg) and vaporiser settings required for the different fresh-gas flows.

After an initial phase with high fresh gas flow of 4.5 L/min and a vaporiser setting of 2.5 vol% enflurane, lasting for 10 or 15 minutes respectively, the flow is reduced to 2.0, 1.0 or 0.5 L/min. The lower the fresh gas flow, the higher the concentration to be dialled at the vaporiser to maintain a desired expiratory enflurane concentration of about 1.2 vol% during the remaining course of anaesthesia.



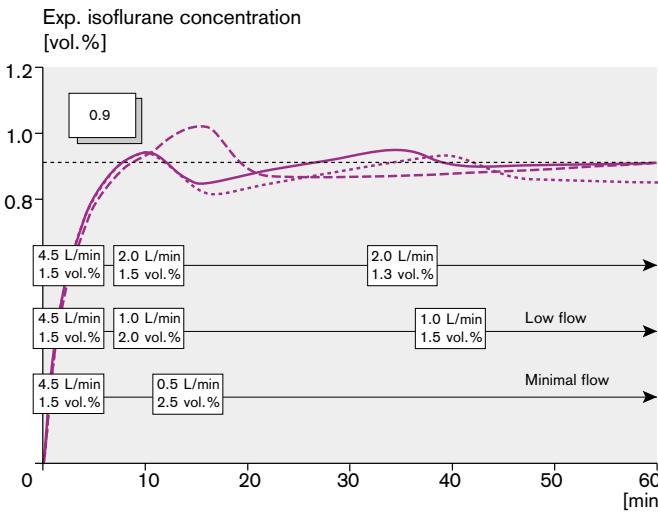


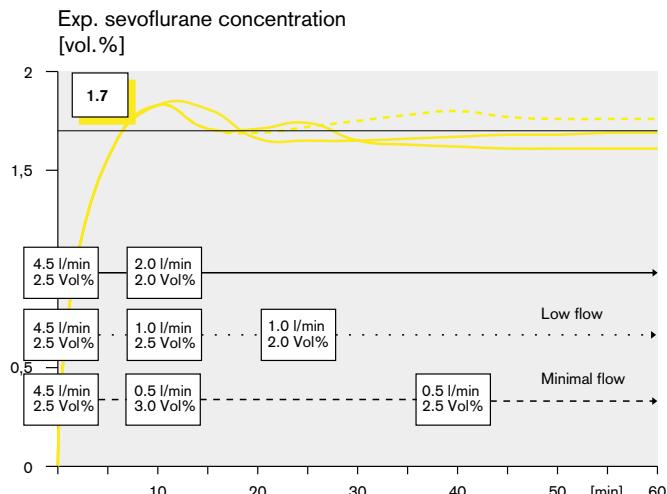
Figure 9.3
Expiratory isoflurane concentration (nominal value, 0.9 vol.% \approx 0.8 MAC, patient 75 kg) and vaporiser settings required for the different fresh gas flows.

After an initial phase with high fresh gas flow of 4.5 L/min and a vaporiser setting of 1.5 vol% isoflurane, lasting for 10 or 15 minutes respectively, the flow is reduced to 2.0, 1.0 or 0.5 L/min. The lower the fresh gas flow, the higher the concentration to be dialled at the vaporiser to maintain a desired expiratory isoflurane concentration of about 0.9 vol% during the remaining course of anaesthesia.

Figure 9.4
Expiratory sevoflurane concentration (nominal value, 1.7 vol% ≈ 0.8 MAC, patient 75 kg) and vaporiser settings required for the different fresh-gas flows.

After an initial phase with high fresh gas flow of 4.5 L/min and a vaporiser setting of 2.5 vol% sevoflurane, lasting for 10 or 15 minutes respectively, the flow is reduced to 2.0, 1.0 or 0.5 L/min. The lower the fresh gas flow, the higher the concentration to be dialled at the vaporiser to maintain a desired expiratory sevoflurane concentration of about 1.7 vol% during the remaining course of anaesthesia.

Actually the American FDA and the manufacturer likewise still recommend not to use sevoflurane with fresh gas flows lower than 1.0 L/min, and in low flow technique the sevoflurane load shall not exceed 2 MAC. According to recently published data, any restriction with respect to the fresh gas flow used in sevoflurane anaesthesia seems not to be justified any more.



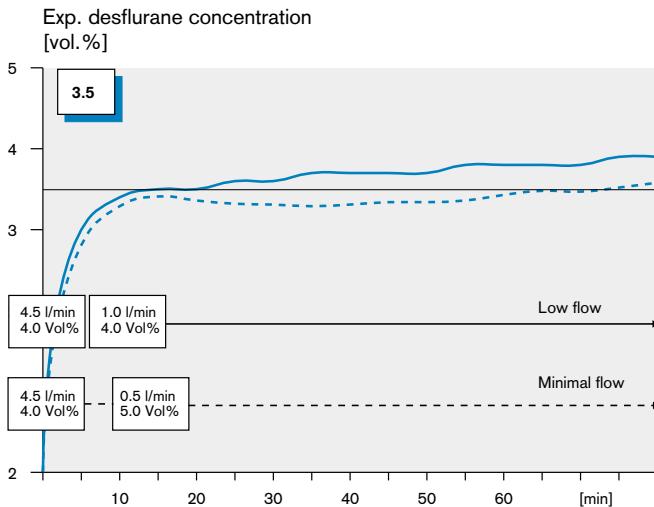


Figure 9.5
Expiratory desflurane concentration (nominal value 3.5%, patient 75 kg) and vaporiser settings required at different fresh gas flows.

When desflurane is used in Low Flow Anaesthesia the flow can be reduced from 4.5 to 1.0 L/min already 10 minutes after induction without any alteration of the vaporiser setting. In Minimal Flow Anaesthesia the nominal expired concentration will be maintained if, after the 10 to 15 minutes lasting initial phase, the fresh gas desflurane concentration is increased by 1.0 vol% when the flow is reduced to 0.5 L/min.

The difference between fresh gas and inspiratory anaesthetic agent concentration is the less, the less soluble is the anaesthetic agent.

10. What is the time constant of a breathing system?

The time constant is a measure for the time required for changes in the composition of the fresh gas to lead to corresponding changes in the composition of the gas in the anaesthetic system.

Based on the calculation formula given by Conway

$$T = V_S / (\dot{V}_D - \dot{V}_U)$$

the time constant T is proportional to the volume of the system (ventilator and lung volume) V_S and inversely proportional to the difference between the amount of anaesthetic agent delivered into the breathing system \dot{V}_D and the individual uptake \dot{V}_U at the same time. As, if the vaporiser is switched into the fresh gas line, \dot{V}_D is directly proportional to the fresh gas flow, the time constant is inversely proportional to the flow rate. The higher is the fresh gas flow rate, the shorter is the time constant, the lower is the flow rate, the longer is the time constant of a breathing system (Fig. 10.1 and 10.2).

As a numerical value, the time constant describes the speed of the wash-in and wash-out processes. At the end of $1 \times T$ time the concentration of the anaesthetic agent or gas in the system will have reached 63%. After $2 \times T$ it will have reached 86.5%, and after $3 \times T$ about 95% of the alteration in the agent's fresh gas concentration will have taken place.

In low flow anaesthesia alterations of the fresh gas composition will lead only with a considerable time delay to corresponding alterations of the anaesthetic gas composition within the breathing system. The prolonged time constants must be taken into account whenever the anaesthetic concentration shall be changed during low flow anaesthesia. The time constant, additionally, will be the more prolonged the higher is the individual anaesthetic uptake, which on its side is related to the solubility of the anaesthetic agent.

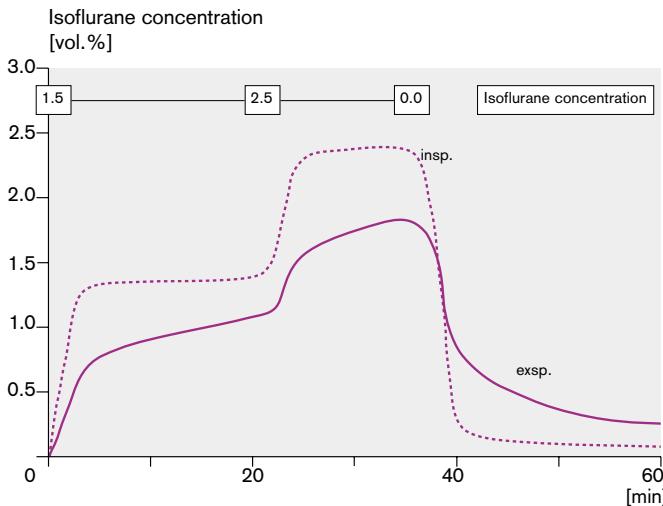


Fig. 10.1
Short time constant in high flow anaesthesia: Rapid alteration of isoflurane concentration within the breathing system after alteration of the fresh gas composition.

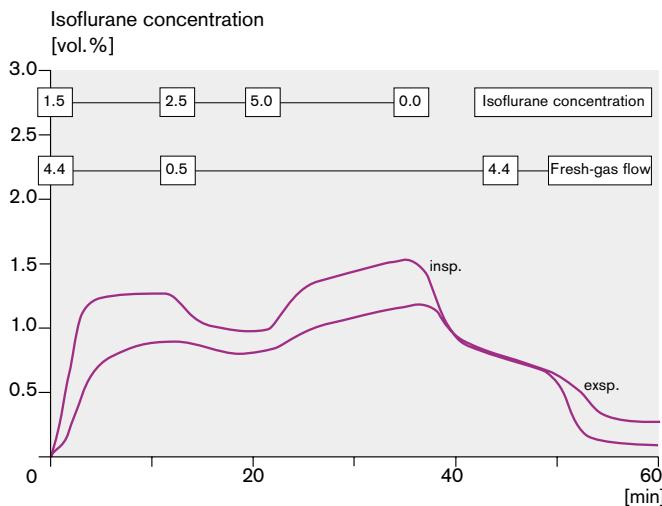


Fig. 10.2
Long time constant in Minimal Flow Anaesthesia: Delayed and slow alteration of isoflurane concentration within the breathing system after alteration of the fresh gas composition.

11. How can anaesthetic depth be changed rapidly during low flow inhalation anaesthesia?

When the low fresh gas flow rate is maintained (anaesthesia with a long time constant) the anaesthetic depth can be increased rapidly by supplemental administration of intravenous analgesics or hypnotics. If, however, anaesthetic depth shall be raised quickly by an appropriate increase of the concentration of the anaesthetic agent, the flow must be increased for a short time and the concentration of the anaesthetic agent in the fresh gas be adapted to the desired nominal value. By this manoeuvre the desired higher agent concentration can be established rapidly within the breathing system (anaesthesia with short time constant) (Fig. 11.1). Contrarily, short-term reduction of the anaesthetic depth during low flow anaesthesia only can be achieved by switching to a high fresh gas flow rate to rapidly wash-out the anaesthetic agent and establish the lower desired anaesthetic concentration within the breathing system (anaesthesia with a short time-constant). If the fresh gas flow rate is increased to 4 L/min to rapidly wash-in a new - higher or lower - anaesthetic agent concentration, the time of 5 minutes will be sufficient to achieve the desired change in the composition of the anaesthetic gas within the breathing system. After this, the fresh gas flow rate can be reduced again, but one has to keep in mind, that the fresh gas composition has to be adapted again to the low flow conditions. On the other hand the anaesthetist also can make use of the long time constant if, preferably, any alteration of the anaesthetic concentration should become effective somewhat delayed. In this case the low fresh gas flow is maintained and a concentration dialled at the vaporiser significantly exceeding the newly desired nominal concentration. This „coasting“ towards another anaesthetic concentration - performance of inhalation anaesthesia with long time constants - may be advantageous for instance in geriatric patients or during emergence (Fig. 11.2).

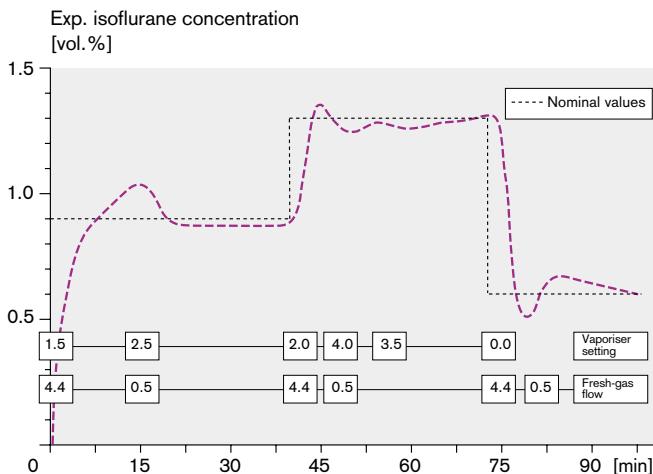


Fig. 11.1
Changing from long to short time constant by varying not only vaporiser setting but also fresh gas flow during performance of Minimal Flow Anaesthesia to quickly alter the depth of anaesthesia.

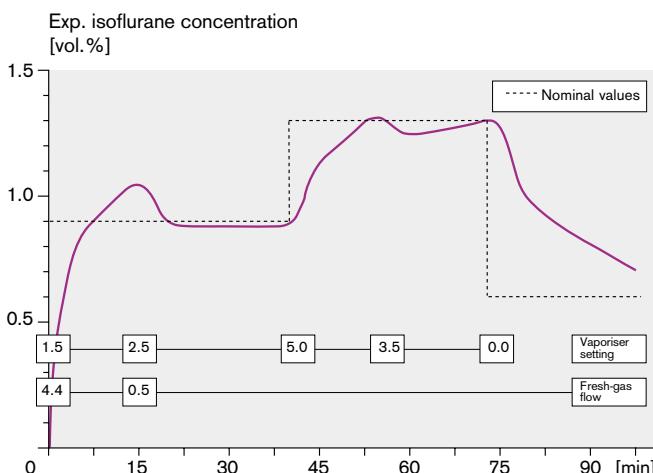


Fig. 11.2
Maintaining long time constant during performance of Minimal Flow Anaesthesia: slow alteration of the depth of anaesthesia only by alteration of the vaporiser setting.

12. Does the use of sevoflurane or desflurane improve the control of anaesthetic concentration in low flow anaesthesia?

Both inhalation anaesthetics are characterised by low solubility, correspondingly low individual uptake, and comparatively low anaesthetic potency.

Due to the latter property, the maximum output of both of the vaporisers is limited to a fairly high concentration, 8.0 vol% for sevoflurane, and 18.0 vol% for desflurane. Thus, even if the flow is kept as low as 0.5 L/min, the amount of vapour delivered into the system reaches 43.5 mL/min with sevoflurane or even 110 mL/min with desflurane at its maximum. According to Conway's formula, low individual uptake together with high amount of agent delivered into the breathing system results in a marked decrease of the time constant.

Thus, even if the flow is kept unchanged at a very low flow rate, a comparatively rapid increase of the agent's concentration can be gained when use is made of the maximum output of the vaporiser (Fig. 12.1). The use of desflurane will result in an even more pronounced decrease of the time constant than the use of sevoflurane (Fig. 12.2).

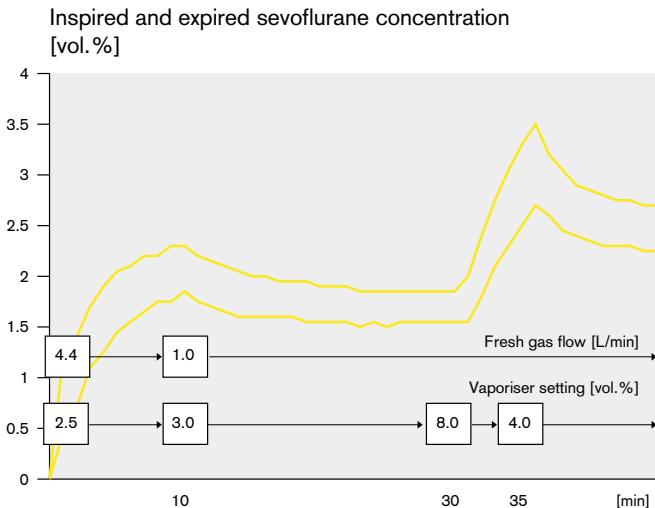


Fig 12.1
Even if the flow is maintained at 1.0 L/min the sevoflurane concentration can be increased rapidly when use is made from the wide dialling range of the vaporiser.

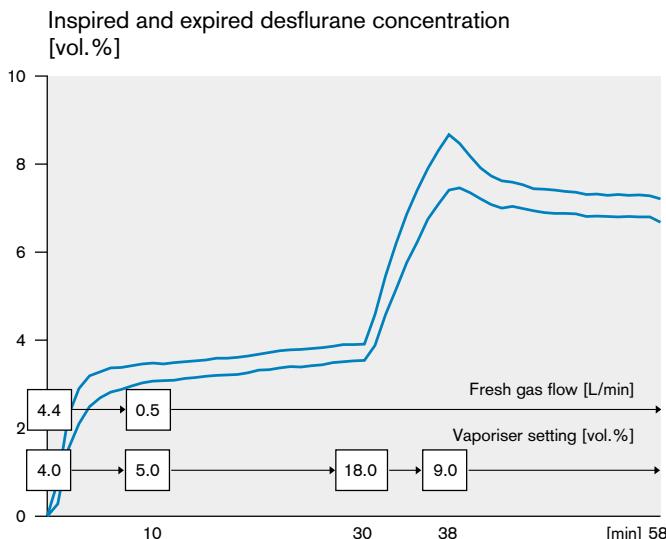


Fig 12.2
Even if the flow is maintained at 0.5 L/min the desflurane concentration can be increased rapidly when use is made from the wide dialling range of the vaporiser.

13. How to carry out the emergence phase in low flow anaesthesia?

Due to the long time constants, the vaporiser can be closed distinctly prior to the definite end of the surgical procedure. If the low fresh gas flow is kept unchanged, the time required for the wash-out process increases with the extent of flow rate reduction (Fig. 13.1) and the total duration of the anaesthetic. The decline of the concentration of the respective anaesthetic, given in vol%, seems to be faster if the less soluble agents like sevoflurane or desflurane are compared with isoflurane. Due to its low solubility the wash-out of desflurane from the patient's tissues into the breathing system also is more rapid than that of isoflurane. If, however, the decline of the anaesthetic concentration is related to the respective MAC value, the wash-out curves of the different agents are nearly identical if a very low fresh gas flow is maintained. The more rapid wash-out from the patient is buffered by the still low wash-out from the breathing system (Fig. 13.2). The differences resulting from the different solubility of the anaesthetics only will become effective if the wash-out from the breathing system itself is improved by increasing the fresh gas flow.

During Minimal Flow Anaesthesia the vaporiser can be closed about 10 minutes before the end of surgery -or about 20 minutes before in prolonged anaesthesia. In the time that follows the patient is weaned on to spontaneous breathing via manually-assisted ventilation whilst maintaining low flow. If the anaesthetic machine features a SIMV or even ASB ventilation mode this can be used to prevent accidental hypoxaemia caused by hypoventilation during this phase. Not earlier than about 5 to 10 minutes before the definitive extubation the nitrous oxide supply is ceased and the oxygen flow increased to about 5 L/min to wash out the anaesthetic gases. The immediate post-operative patient care follows the customary scheme.

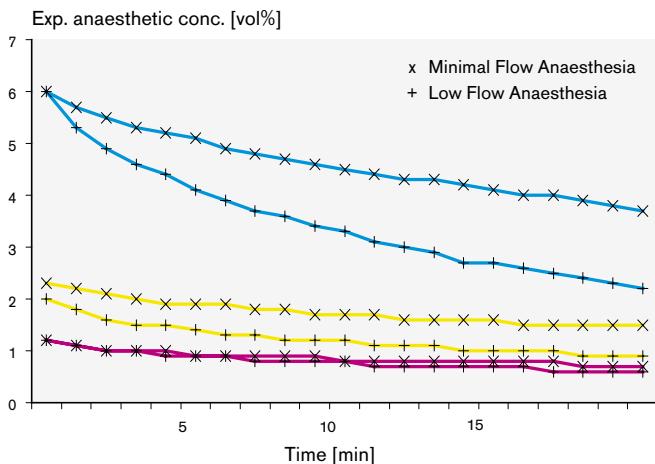


Fig. 13.1
Wash-out of anaesthetic agents: Vaporisers closed after 2 h lasting inhalation anaesthesia, flows remain unchanged at 1.0 or 0.5 L/min respectively. (Pat. 80 kg, 176 cm)

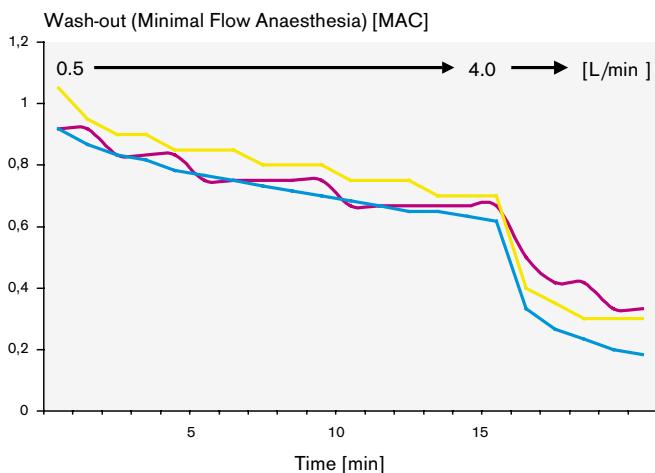


Fig. 13.2
Wash-out of anaesthetic agents related to the respective MAC: No significant difference unless the flow is increased to 4.0 L/min. (Vaporisers closed after 2 h of inhalation anaesthesia, flow remains unchanged at 0.5 L/min over a period of 15 minutes. Calculation base: Pat. 80 kg, 176 cm).

3 How to perform low flow anaesthesia without nitrous oxide

14. Is nitrous oxide indispensable in inhalation anaesthesia?

- Pros and Cons for the use of nitrous oxide -

For decades a mixture of oxygen and nitrous oxide has been used to deliver inhalational agents, with no thought given to its true value or disadvantages. The routine use of nitrous oxide as carrier gas in inhalational anaesthesia - especially if the newer anaesthetic agents are applied - is unanimously put into question in all the newer review articles on the actual role of this anaesthetic gas. Concurrent to the acknowledged and well known contraindications, which speak in favour to renounce the use of nitrous oxide, are still some arguments favouring its further use (Fig. 14.1). Low flow enthusiasts, furthermore, have to acknowledge that the development of the rebreathing systems is closely related to the use of this gas as an inhalation anaesthetic and the endeavour to reduce its consumption for economical reasons.

Arguments in Favour for Nitrous Oxide

- Reduction of supplementary opioids and anaesthetics
- Rapid wash-in and wash-out
- Shortens time required for mask induction
- Stabilizes cardiocirculatory function
- Prevents from intraoperative awareness
- Suppresses reflex movements

Fig. 14.1

Contraindications for Nitrous Oxide

Fig. 14.2

- Confinement of air in tissues or hollow spaces
- Bowels distended by gas, bowel obstruction
- Increased intracranial pressure
- Vitamin B₁₂ deficiency
- Immunodeficiency, bone marrow depression, severe marasm

Whether all the arguments given in favour for the use of nitrous oxide are still justified nowadays, especially when the newer generation of anaesthetics and opioids with their advantageous pharmacokinetics are used, remains the actual scientific question. However, besides the generally acknowledged contraindications (Fig. 14.2), additional arguments and facts speak well in favour to consistently renounce any further use of nitrous oxide (Fig. 14.3): It should not be used in case of severe cardiac insufficiency, in immunosupprimized patients and, due to its inhibitory effect on methioninsynthetase, during early pregnancy and in-vitro-fertilisation. Nitrous oxide seems to be one factor increasing the incidence of postoperative nausea and vomiting (PONV), it prolongs the reconvalaescence after longer lasting abdominal surgery. After prolonged exposition to nitrous oxide in animal studies teratogenic and embryotoxic effects were found. It remains a matter of scientific discussion whether chronic exposure of the theater personnel to subanaesthetic concentrations of nitrous oxide is harmful, nevertheless in most of the industrial countries a maximum workplace concentration for this gas between 25-100 ppm is bindingly defined. Emitted into the atmosphere it takes part in the ozone depletion and the green house effect, although it is generally accepted that the proportion of the total nitrous oxide emission coming from medical use hardly exceeds 1%.

Further arguments not to use nitrous oxide

Fig. 14.3

- Severe cardiac insufficiency
- Early pregnancy, in-vitro-fertilisation
- Immunosupprimized patients
- Severe postoperative nausea and vomiting in patient's history
- Long lasting abdominal surgery
- Reduction of the work place load with N₂O
- Ecological arguments: ozone destruction and green house effect

15. What are the advantages of low flow anaesthesia without nitrous oxide?

Omitting the use of nitrous oxide considerably simplifies the performance of low flow anaesthesia. Even at a fresh gas flow rate of 0.5 L/min the duration of the initial high flow phase can be kept at its minimum. It is only determined by the specific wash-in characteristic of the respective inhalation anaesthetic used. Neither denitrogenation or nitrous oxide wash-in, nor the initially high nitrous oxide uptake have to be considered as prolonging factors for this period any more. Thus, even in Minimal Flow Anaesthesia an initial high flow phase of only 10 minutes sufficiently meets the needs (Fig. 15.1). The gas volume circulating within the breathing system increases as only oxygen and a negligibly small amount of anaesthetic agent vapour are still taken up by the patient. At a given fresh gas flow rate, the total gas uptake is less and the excess gas volume higher than with the use of nitrous oxide, resulting in reduced risk of gas volume deficiency (Fig. 15.2).

The following general advantages also should be mentioned: A carrier gas mixture, containing only oxygen and nitrogen, is totally inert with respect to the environment, there are no contraindications at all, pressure and volume of any gas confinement within the body remain constant. Furthermore, the technical infrastructure for supplying with nitrous oxide becomes dispensable, as also the maintenance of the central nitrous oxide manifold, the distribution pipework, and the wall outlets, or the logistics with nitrous oxide and the measurement of work place contamination, which - at least in Germany - is a statutory requirement if there is any doubt whether the given limits might be exceeded during clinical practice.

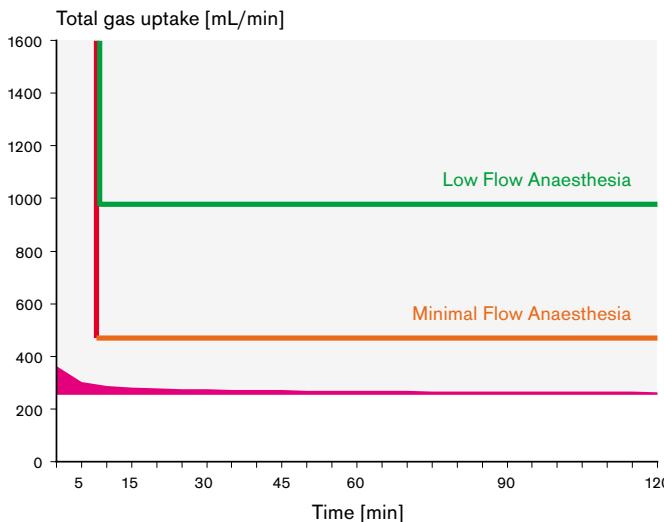


Fig. 15.1
Different methods of low flow anaesthesia: different grades of precision to adapting the fresh gas flow to the total gas uptake - here: carrier gas mixture: oxygen / nitrogen.

Advantages of low flow anaesthesia without nitrous oxide

- Performance of LFA simple and easy
- Initial phase short, increased excess gas volume, reduced risk for gas volume deficiency
- No contraindications for oxygen / air mixture
- Carrier gas ecologically safe
- Long lasting abdominal surgery
- Pressure within any air confinement remains constant

Fig. 15.2

16. How to perform Minimal Flow Anaesthesia without nitrous oxide?

Premedication and induction can be performed in the usual manner. However, to substitute for the missing analgesic effect of nitrous oxide routinely the additive intravenous injection of supplemental doses of opioids, i.e. 0.1-0.2 mg fentanyl or 0.5-1.0 mg alfentanil, is strongly recommended.

Initial high flow phase: After connecting the patient to the rebreathing system a flow of 4 L/min is set at the flow controls: 1 L/min O₂, 3 L/min air. A mean inspiratory oxygen concentration of about 35-40% will result (Fig. 16.1). Due to the fact that the gas uptake is less and the excess gas volume higher than with the use of nitrous oxide the flow can be reduced to 0.5 L/min early, already after 10 minutes. The limiting factor for further shortening of the initial high flow phase remains the need to initially deliver a suitable high amount of inhalation anaesthetic into the breathing system to establish a sufficient anaesthetic depth. To compensate for the missing anaesthetic effect the expiratory concentration of the volatile anaesthetics should be increased by 0.2-0.25 times the MAC of the respective inhalation anaesthetic. Thus, 1.2 vol% isoflurane, 2.2 vol% sevoflurane, and 5.0 vol% desflurane should be established as the expiratory nominal values. The vaporisers - adapted to suit individual reactions and surgical requirements - can be set to following standard concentrations:

isoflurane to 2.5 vol%,
sevoflurane to 3.5 vol%, and
desflurane to 6.0 vol%.

In the specified time an expiratory concentration of the respective anaesthetic will be achieved corresponding to about 1.0-1.1 x MAC (Fig. 16.2-16.4).

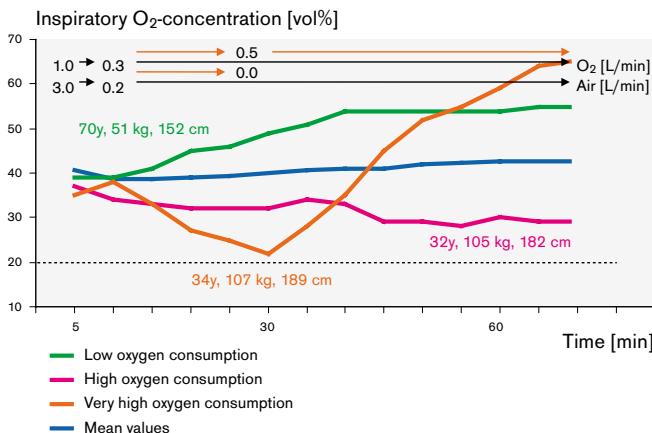


Fig. 16.1
Insp. oxygen concentration
during the course of Minimal
Flow Anaesthesia, carrier gas:
oxygen / air.

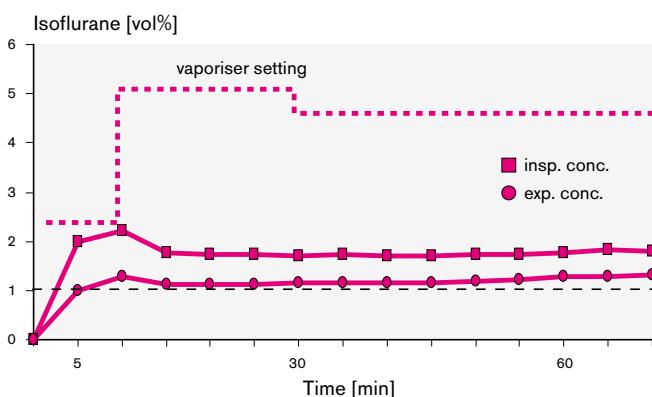


Fig. 16.2
Insp. and exp. isoflurane
concentration during the
course of Minimal Flow
Anaesthesia, nominal value
exp. conc.: 1.2 vol%,
standardized vaporiser settings
as given in the text.

Flow reduction to 0.5 L/min: with flow reduction the rebreathing fraction, containing less oxygen, increases demanding a considerable increase of the fresh gas oxygen content to about 68%. A mixture of 0.3 L/min O₂ and 0.2 L/min air is needed to maintain an inspiratory oxygen concentration of about 40 vol%. The oxygen concentration, however, is considerably influenced by the individual oxygen uptake (Fig. 16.1). The vaporisers should be set to following standard concentrations:

Isoflurane to 5.0 vol%,
Sevoflurane to 5.0 vol%, and
Desflurane to 8.0 vol%.

With these settings a desired expiratory anaesthetic concentration in the range of 1.0-1.1 MAC can be maintained (Fig. 16.2-16.4). The rules concerning maintenance and emergence generally are the same as given beforehand.

However, when the maximum output of the isoflurane vaporiser is limited to 5 vol%, it becomes impossible to further increase the isoflurane concentration within the rebreathing system without increasing the fresh gas flow. Due to their even higher solubility, enflurane and halothane are not suitable for Minimal Flow Anaesthesia without nitrous oxide at all.

If the use of nitrous oxide is omitted the hypnotic state during emergence phase mainly is maintained by the inhalation anaesthetic. Therefore, to prevent early awakening of the patient, even if the low flow rate is maintained the delivery of anaesthetic agent may not be stopped earlier than 5-10 minutes prior to the definite end of the surgical procedure.

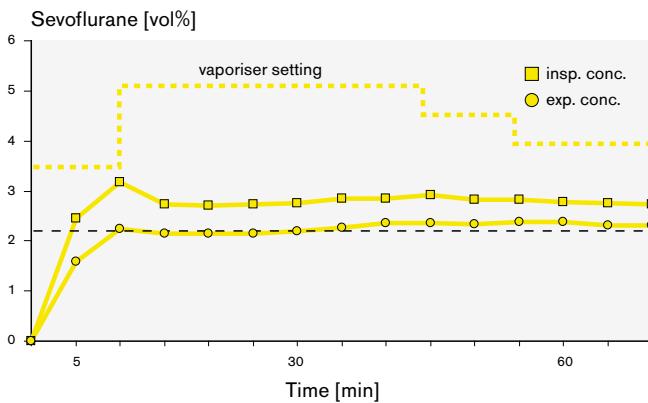


Fig. 16.3
Insp. and exp. sevoflurane concentration during the course of Minimal Flow Anaesthesia, nominal value exp. conc.: 2.2 vol%, standardized vaporiser settings as given in the text.

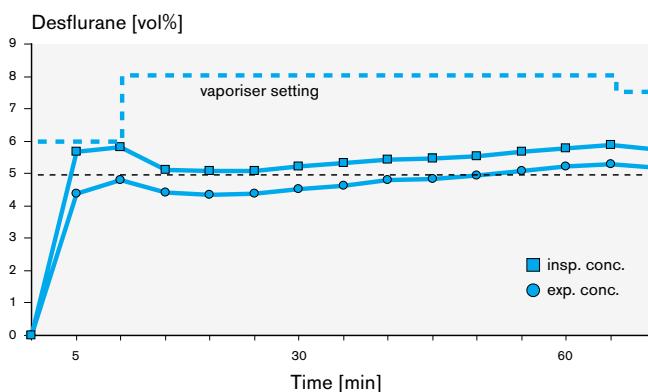


Fig. 16.4
Insp. and exp. desflurane concentration during the course of Minimal Flow Anaesthesia, nominal value exp. conc.: 5.0 vol%, standardized vaporiser settings as given in the text.

17. How to perform Closed System Anaesthesia with conventional anaesthetic machines?

Consistent renunciation of nitrous oxide is an indispensable precondition for the performance of Closed System Anaesthesia with conventional anaesthetic machines in routine clinical practice. When the initial high flow phase is finished the total gas uptake can be assumed to remain nearly constant during the following course of anaesthesia, thus, the flow can be reduced to just that amount of oxygen taken up by the individual patient, which can be calculated by applying Brody's formula (Fig. 17.1). Generally, the anaesthetic vapour being delivered into the breathing system is supplied by a vaporiser outside the circuit. At such low flows, however, this technique to supply the anaesthetic agent reaches its limits, as the maximum output of the vaporisers does not exceed $3.5 \times \text{MAC}$ of the respective agent. For instance, at a fresh gas flow rate of 250 mL/min not more than 12.5 mL/min vapourized isoflurane, but at least 20 mL/min sevoflurane or even 45 mL/min desflurane vapour can be delivered into the breathing system. These amounts of sevoflurane and, especially, desflurane vapour sufficiently cope with the needs to maintain the desired expiratory agent concentrations (Fig. 17.2 and 17.3). With isoflurane - and that would be the more striking with enflurane or halothane - the individual uptake of an adult patient exceeds the amount of agent which maximally can be supplied into the breathing system (Fig. 17.4). Actually, Closed System Anaesthesia with conventional anaesthetic machines only can be realized with isoflurane, sevoflurane or desflurane. Especially suitable are sevoflurane and desflurane, characterized by low solubility and low anaesthetic potency, the latter resulting in comparatively high maximum output of the agent specific vaporisers. These agents meet well the pharmacokinetic and pharmacodynamic preconditions to be used in closed system anaesthesia in clinical routine practice.

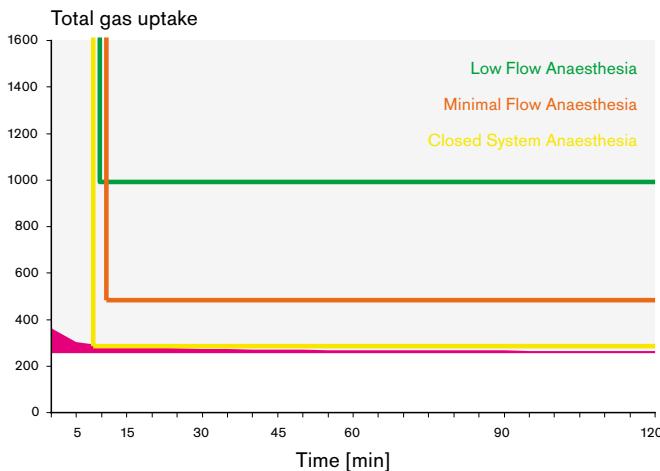


Fig. 17.1
Different methods of low flow anaesthesia: different grades of precision to adapting the fresh gas flow to the total gas uptake - here: carrier gas mixture: oxygen / nitrogen.

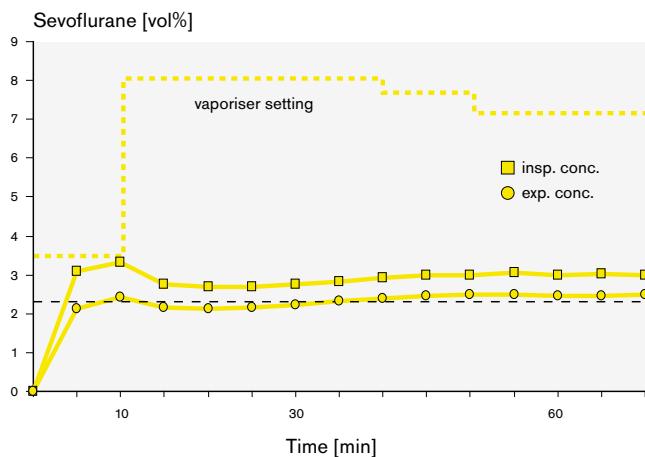


Fig. 17.2
Insp. and exp. sevoflurane concentration during the course of Closed System Anaesthesia, nominal value exp. conc.: 2.2 vol%, standardized vaporiser settings as given in the text.

Following settings at the gas flow controls and the vaporisers are recommended:

Initial high flow phase:

1.0 L/min O ₂ ,	3.0 L/min air,
isoflurane	2.5 vol%,
sevoflurane	3.5 vol%,
desflurane	6.0 vol%.

Flow reduction:

0.3-0.2 L/min O ₂ ,	
isoflurane	5.0 vol%,
sevoflurane	8.0 vol%,
desflurane	10.0 vol%.

In general, when using these standardized settings, the expiratory desflurane and sevoflurane concentrations are maintained at about 5.0 vol% and 2.0-2.2 vol% (Fig. 17.2 and 17.3). The expiratory isoflurane concentration, however, at a flow of 0.3-0.2 L/min will decrease to 0.9-0.8 vol% although using the maximum output of the vaporiser (Fig. 17.4). According to own experiences this concentration together with small supplemental doses of opioids results in a sufficient anaesthetic depth in most of all surgical procedures.

As the maximum output of the isoflurane and sevoflurane vaporisers are limited to 5 vol% or 8 vol%, it becomes impossible to further increase the isoflurane or sevoflurane concentration within the rebreathing system without increasing the fresh gas flow.

To prevent early awakening of the patient, even if the low flow rate is maintained at 0.3-0.2 L/min, the delivery of anaesthetic agent may not be stopped earlier than 5-10 minutes prior to the definite end of the surgical procedure.

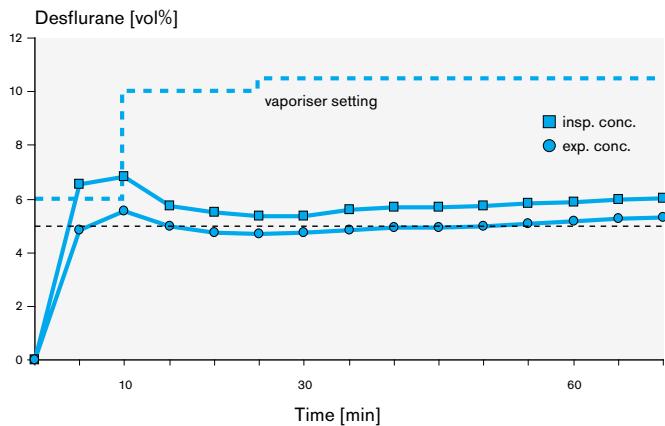


Fig. 17.3
Insp. and exp. desflurane concentration during the course of Closed System Anaesthesia, nominal value exp. conc.: 5.0 vol%, standardized vaporiser setting as given in the text.

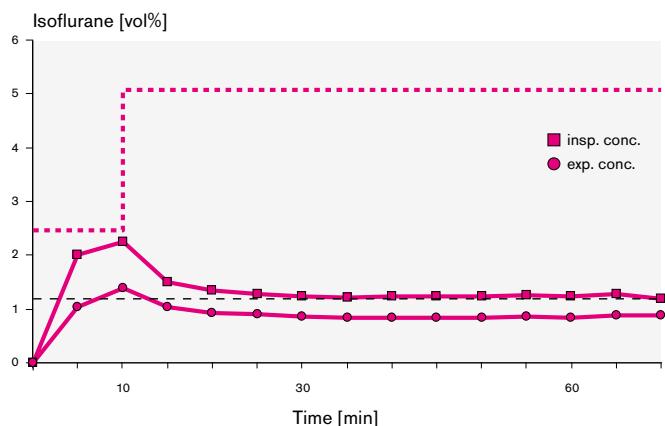


Fig. 17.4
Insp. and exp. isoflurane concentration during the course of Closed System Anaesthesia, nominal value exp. conc.: 1.2 vol%, standardized vaporiser setting as given in the text. With a flow of 0.25 L/min the nominal value can not be maintained, even not by dialling the vaporiser's maximum output.

18. Are there limitations for the performance of nitrous oxide-free low flow anaesthesia?

When isoflurane is used as the anaesthetic agent and the fresh gas flow is reduced to extremely low values, it may become impossible to maintain the expiratory agent concentration at the nominal value of 1.2 vol%. Due to the agent specific limitation of the maximum output of the vaporisers and their position in the fresh gas line (VOC) a sufficient amount of anaesthetic vapour, coping with the individual uptake, cannot be supplied into the breathing system. Due to their higher solubility, this especially holds also for enflurane and halothane. When, contrarily, inhalational anaesthetics with lower solubility and correspondingly lower uptake are used, whose vaporisers, furthermore, feature higher maximum output, the desired expiratory concentrations can not only be established in a short period of time but even maintained with extremely low fresh gas flow rates.

With older type conventional anaesthetic machines the flow control system for medical air may not be graduated and calibrated in the low flow range, or an air flow control system may even be missed. These apparatus, thus, do not cope with the basic technical requirements for low flow anaesthesia with an oxygen / air mixture.

Even when renouncing the use of nitrous oxide, the accidental development of hypoxic gas mixtures within the breathing system is not excluded at all by the use of a carrier gas consisting only of oxygen and nitrogen (Fig. 16.1). Continuous monitoring of the inspired oxygen concentration remains an indispensable precondition for safe performance of low flow anaesthesia without nitrous oxide. Only if pure oxygen is used as carrier gas the development of hypoxic gas mixtures within the breathing system becomes nearly impossible, proper function of the anaesthetic machine provided.

19. Can pure oxygen be used as carrier gas in nitrous oxide-free low flow anaesthesia?

The use of pure oxygen as fresh gas can be the alternative for the use of an oxygen / air (nitrogen) carrier gas mixture. The advantages are obvious (Fig. 19.1): Significantly reduced risk for the development of hypoxic gas mixtures, thus, enhanced safety for the patient. Low flow anaesthesia becomes even more easy, simple gas flow controls could be developed as anti hypoxic devices would become dispensable. Furthermore, the use of high oxygen concentrations seem even to be beneficial for the patients: In recently published investigations the authors succeeded to prove that the small increase in microatelectases, resulting from the perioperative application of high oxygen concentrations, does not impair the postoperative function of the lung , but significantly decreases the incidence of postoperative nausea and vomiting and of postoperative wound infections. The application of high inspiratory oxygen concentrations during general anaesthesia over a period of 8-12 hours seems not to be harmful for the patients, at least if routinely measures are taken to improve ventilatory recruitment of the alveoles, like PEEP or intermittend forced ventilation of the lung. There are also contraindications: premature neonates, chronic broncho-pulmonal disease with increased bronchial secretion, patients undergoing chemotherapy, and surgical procedures with the aid of laser beams. The scientific discussion on this topic, however, isn 't finished yet, although from the viewpoints of a practitioner all arguments speak in favour to using pure oxygen as fresh gas.

Pure oxygen as carrier gas – advantages

Fig. 19.1

- Less postoperative wound infections
- Less PONV
- Decreased risk of hypoxaemia
- Simple gas supply

Following settings at the gas flow controls and the vaporisers are recommended if pure oxygen is used as carrier gas:

Initial high flow phase:

4.0 L/min O ₂ ,
isoflurane 2.5 vol%,
sevoflurane 3.5 vol%,
desflurane 6.0 vol%.

Flow reduction:

0.3-0.2 L/min O ₂ ,
isoflurane 5.0 vol%,
sevoflurane 8.0 vol%,
desflurane 10.0 vol%.

With these setting in general an inspiratory oxygen concentration of about 85 vol% will be achieved after a certain time (Fig. 19.2). The rules governing the performance of closed system anaesthesia with pure oxygen are the same as given beforehand.

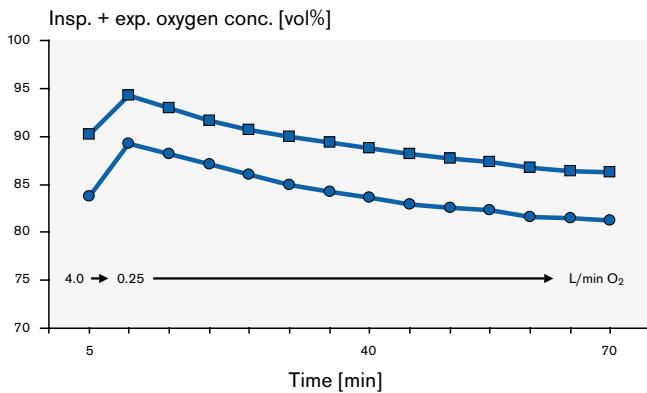


Fig. 19.2
Insp. and exp. oxygen concentration during the course of Closed System Anaesthesia, carrier gas: pure oxygen.

4 Technical preconditions for safe performance of low flow anaesthesia

20. What should be the features of the anaesthetic machine with respect to the fresh gas controls, the vaporisers, and the rebreathing systems?

The fresh gas controls should work precisely, and the flow meter tubes should be calibrated and graduated in the low flow range. Low and high flow rotameter tubes in tandem-arrangement are advantageous. Newer anaesthetic machines may be also equipped with electronic fresh gas flow displays, allowing the setting of very low flows.

The vaporisers should feature pressure-, temperature-, and flow compensation, a demand being met by all modern vaporisers. Using conventional anaesthetic machines with vaporisers outside the circuit, the limitation of the maximum output of the vaporisers at a concentration equalling 3-5 times the respective MAC makes it impossible to use anaesthetic agents with comparatively high solubility like halothane or enflurane in closed system anaesthesia.

The leakage rate of the rebreathing systems must not exceed 100 mL/min at an internal system pressure of 20 mbar to meet the demands on gas tightness for performance of all different techniques of low flow anaesthesia. By correct technical maintenance this gas tightness can be achieved in everyday clinical routine even with conventional circle systems (Fig. 20.1 and 20.2). Some of the newer generation anaesthetic machines are equipped with highly gas tight compact rebreathing systems and automatically run the check for gas tightness.

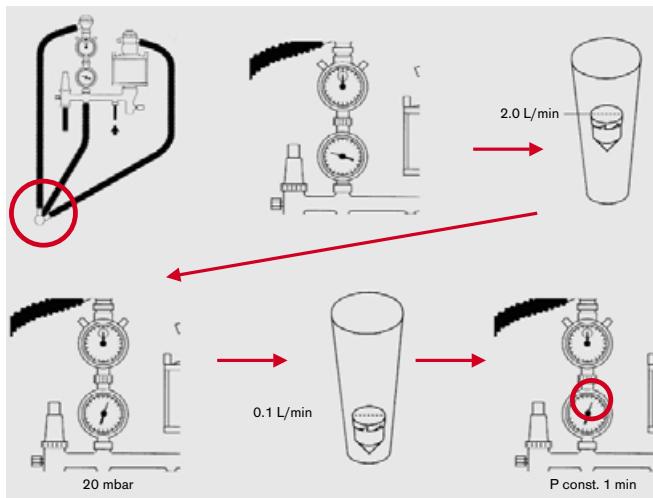


Fig. 20.1
Leak-test with conventional rebreathing systems: Connect manual-bag hose to Y-piece, close overflow valve, fill up breathing system by an oxygen flow of about 2.0 L/min to a pressure of 20 mbar, reduce oxygen flow to 0.1 L/min, pressure must then remain constant over a period of 1 min.

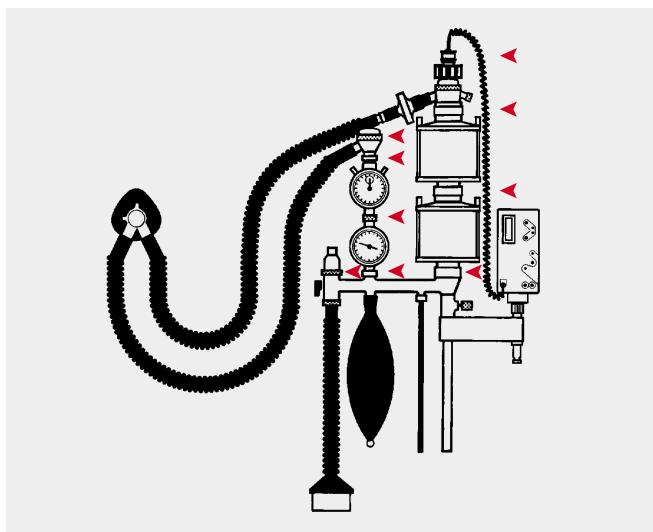


Fig 20.2
Likely points for leakages: All screwed or plug-in connectors as well as valve and absorber seals.

21. What is the fresh gas flow compensation of an anaesthetic ventilator?

In older type conventional anaesthetic machines the tidal volume, supplied to the patient with each ventilation stroke, is made up of the gas volume delivered by the ventilator plus the additional fresh gas volume delivered into the breathing system during the inspiratory phase. Thus, any reduction in the fresh gas flow results in a corresponding reduction in the tidal volume. The decrease of the tidal volume is proportional to the extend of fresh gas flow reduction.

Newer generation anaesthetic machines feature fresh gas flow compensation: the preset tidal volume is being delivered to the patient independently of the fresh gas flow rate or its variation (Fig. 21.1).

Technically, fresh gas flow compensation is realized in three different ways in Dräger machines:

- Fresh gas decoupling valve: Controlled by the function of a valve, in the inspiratory phase the continuous stream of fresh gas is not supplied directly into the breathing system, but it is stored intermittently in the manual bag serving as a gas reservoir (Fig. 21.2). Only during the expiratory phase this valve opens giving free the connection between the fresh gas supply, the gas reservoir and the breathing system. Thus, fresh gas flow compensation is realized by the function of a fresh gas decoupling valve effecting a discontinuous delivery of the fresh gas into the breathing system only in the expiratory phase. This concept of fresh gas flow compensation can be found in the Dräger Cato, Cicero, Fabius, Primus and Sulla 909 anaesthetic machines.

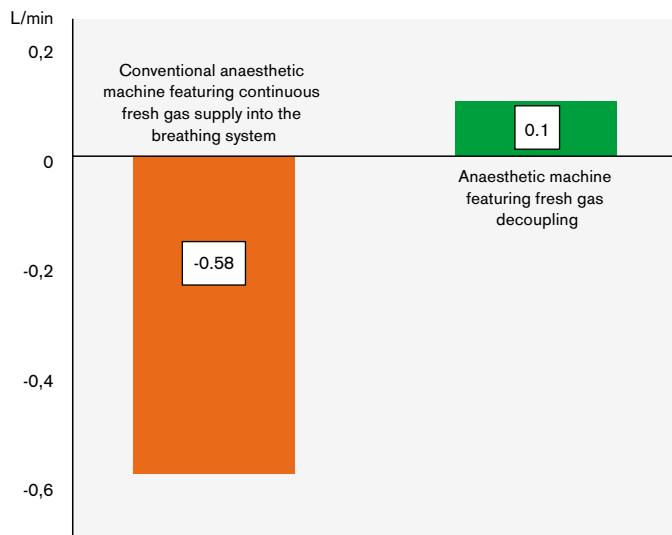


Fig. 21.1
Alteration of minute volume (MV) whilst flow is reduced from 4.4 to 0.5 L/min.

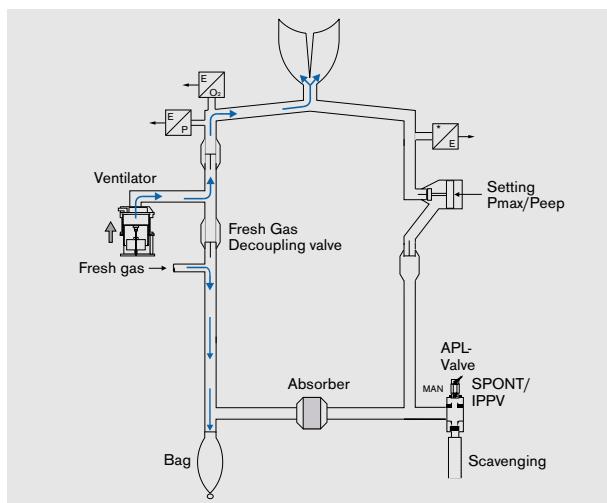


Fig. 21.2
Fabius anaesthetic machine: fresh gas decoupling

- Electronically controlled discontinuous fresh gas supply into the breathing system: Fresh gas flow compensation can also be gained by electronically controlled discontinuous delivery of the fresh gas into the breathing system only during the expiratory phase. This technical feature is realized in the Dräger Julian anaesthetic machine (Fig. 21.3). The fresh gas is mixed and supplied to the breathing system by the aid of an electronically controlled delivery system. The preset fresh gas volume is delivered into the system in distinct quanta, adapted to the preset ventilation patterns.
- Closed loop feedback control of the ventilator performance to the delivered tidal volume: The tidal volume delivered to the patient is measured electronically and, once the preset gas volume is supplied, the ventilator stops the delivery of any further volume. Thus, by closed loop feedback control the ventilator delivers just the preset tidal volume, absolutely independent from the fresh gas flow. This kind of fresh gas flow compensation is realized in the Zeus anaesthesia workstation.

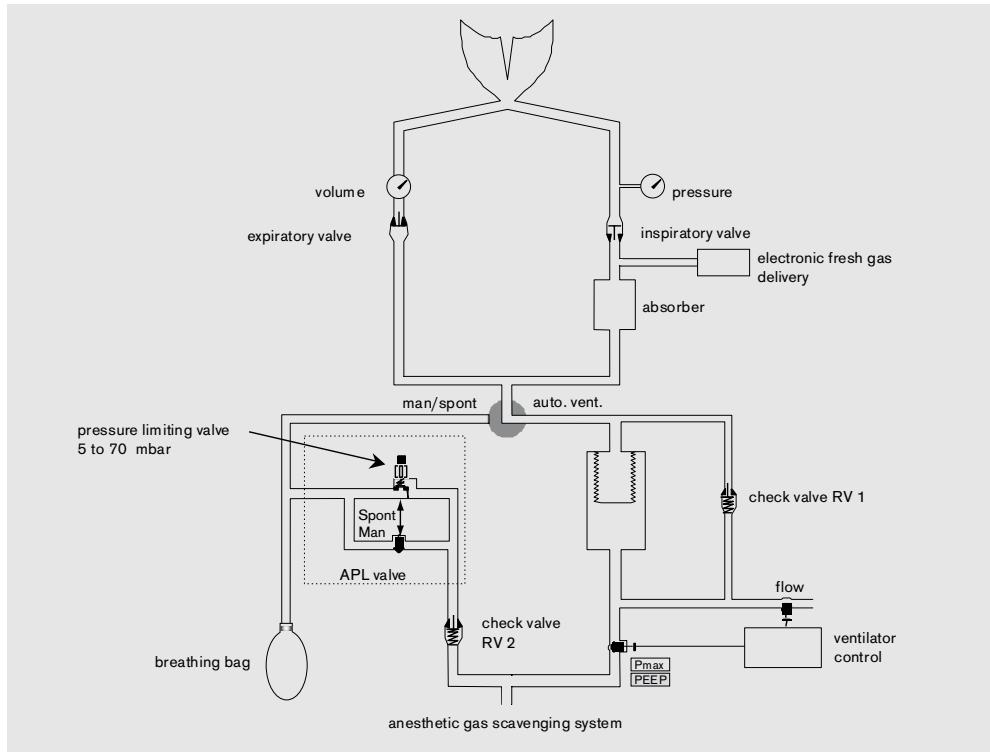


Fig. 21.3
Julian anaesthetic machine:
flow compensation by
electronically controlled
intermittent delivery of the
fresh gas into the circuit.

22. How does an anaesthetic gas reservoir facilitate the performance of low flow anaesthesia?

Any case of gas volume deficiency directly will result in insufficient expiratory filling of the anaesthetic ventilator and corresponding decrease of the tidal volume and the inspiratory peak and plateau pressure.

If anaesthetic ventilators are used in which the bellows' expiratory expansion is supported by an additional external force, for instance the older type Dräger ventilators with hanging bellows arrangement and a weight fixed to the bottom of the bellows, a change from intermittend positive pressure ventilation to alternating pressure ventilation will furthermore be observed (Fig. 22.1).

In the anaesthetic machines Cato and Cicero, equipped with a piston pump ventilator (Fig. 22.2), the expiratory retraction of the piston is stopped immediately whenever a negative pressure develops within the breathing system and a clear text alarm message "Gas Volume Deficiency" will be displayed.

In other ventilators, featuring mechanical support of the expiratory filling of the bellows, the entry of ambient air via an emergency air intake valve prevents an accidental change of the ventilatory pattern in case of gas volume deficiency. Thus, any development of a negative pressure within the breathing system is impossible. This technical feature is realized in the Julian Primus and Fabius anaesthetic machines.

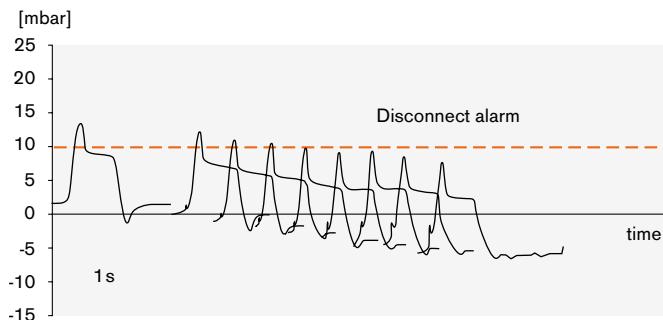


Fig. 22.1
Decrease of the peak and plateau pressure resulting from gas volume deficiency : Early detection by correctly set disconnect alarm.

Alternating pressure ventilation when there is a gas shortage.
(Sulla 808)

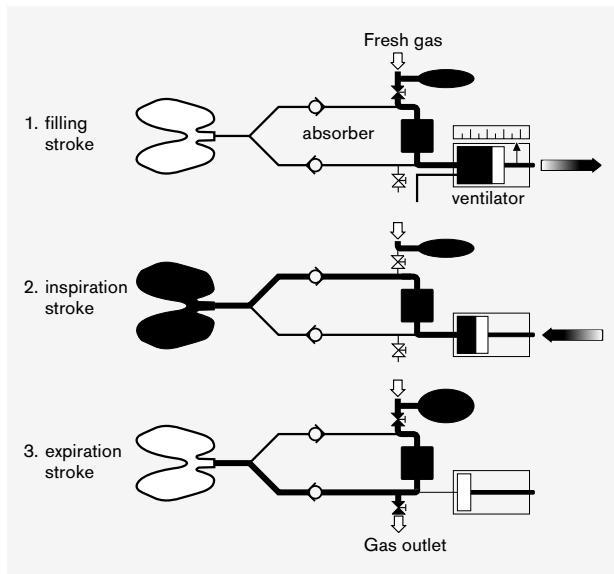


Fig. 22.2
Piston pump ventilator of the Cato or Cicero anaesthetic machines: retraction of the piston is stopped in any case of gas volume deficiency.

An anaesthetic gas reservoir (Fig. 22.3) essentially facilitates the routine performance of low flow anaesthetic techniques, as short lasting volume imbalances can be compensated by changing filling of the reservoir. Only when the reservoir is completely emptied gas volume deficiency will become effective.

In machines featuring a fresh gas decoupling valve, Cato, Cicero, Fabius, Primus and Sulla 909 the manual bag serves as the anaesthetic gas reservoir. In anaesthetic ventilators with floating bellows arrangement, like the Julian anaesthetic machine, the bellows itself serves as the reservoir. The capacity of the bellows exceeds the tidal volume, and the gas, endinspiratorily still contained in the bellows, serves as the reservoir volume.

The latter technical principle is also realized in all the anaesthetic ventilators with standing floating bellows arrangement, as one can find it in the Datex-Engström and Ohmeda anaesthetic machines. In all the classical „Bag-in-Bottle“ ventilators, the capacity of the reservoir bag by far exceeds the tidal volume and the gas, still endinspiratorily contained in the bag, is the reservoir gas volume.

Anaesthetic Gas Reservoir**Fig. 22.3**

- Manual bag (fresh gas decoupling valve)
- Floating bellows (bellows-in-box ventilators)
- Reservoir bag (bag-in-bottle ventilators)

23. Which monitoring is indispensable for safe performance of low flow anaesthesia?

The following specific features of low flow anaesthesia have a particular bearing on patient safety (Fig. 23.1):

- The excess gas volume is reduced: If the volume supplied into the breathing system is less than that which is taken up by the individual patient or lost by leakages, the result is a change in ventilation, with a drop in peak and plateau pressure, and minute volume, and, possibly also a change in the ventilation patterns.
- The difference between the oxygen concentration in the fresh gas and that in the anaesthetic system increases with the extent of flow reduction. In contrast to anaesthesia with a high fresh gas flow rate, the O₂-concentration continues to change during the course of anaesthesia and is essentially influenced by an individual's oxygen consumption. Even if renouncing any use of nitrous oxide the development of hypoxic gas mixtures within the breathing system remains possible!
- The difference between anaesthetic agent concentration in the fresh gas and that in the anaesthetic system increases with the extent of flow reduction in the same way as does the time-constant. For very low fresh gas flow rates (< 1.0 L/min) much higher settings of anaesthetic agent concentration are required on the vaporiser than for high flow. If, accidentally, the vaporiser setting is not reduced when flow is increased, there is a danger of overdosing.

Characteristics of Low Flow Anaesthesia

- Increased rebreathing volume
- Less excess gas
- Difference of gas composition – Fresh gas versus gas in the circuit
- Long time constants

Fig. 23.1

Concerns about Safety in Low Flow Anaesthesia

- Hypoxia
- Gas volume deficiency
- Misdosage of volatiles
- Reduced controllability
- Exhaustion of the absorbent

Fig. 23.2

- The load of the carbon dioxide absorbent with carbon dioxide increases with the extent of fresh gas flow reduction. A sufficient carbon dioxide absorption has to be safely guaranteed under this condition. Insufficient carbon dioxide absorption, being negligible in high flow anaesthesia because of the small rebreathing fraction, in low flow anaesthesia might result in a fast increase of the carbon dioxide partial pressure of the breathing gas.

Resulting from the concerns about safety in low flow anaesthesia (Fig. 23.2) following monitoring - continuous measurement with set and activated alarm limits - becomes essential for safe performance of low flow anaesthesia: airway pressure and/or minute volume, inspiratory oxygen concentration, concentration of anaesthetic agent within the breathing system, and expiratory carbon dioxide concentration (Fig. 23.3).

The monitoring being essential for safe performance of low flow anaesthesia completely has become the obligatory safety standard for all anaesthetic workstations in the countries of the European Union, as required by the European technical norm EN 740. Except the measurement of the agent's concentration in the breathing system this monitoring also is required in the United States of America by the ASA-Monitoring Standards.

Monitoring for Safe Performance of Low Flow Anaesthesia

Fig. 23.3

- Inspiratory oxygen concentration
- Airway pressure and/or minute volume
- Anaesthetic agent concentration in the circuit
- Expiratory CO₂-concentration

24. How to detect early and reliably any gas volume deficiency?

If the fresh gas flow is too low to meet the individual gas uptake and the gas loss via leakages, the resulting gas volume deficiency will lead to a reduction of the tidal and minute volume and a corresponding decrease in peak and plateau pressure.

If the disconnect alarm is set close to the peak pressure (5 mbar lower than the actual peak pressure) in any case of gas volume deficiency the alarm is triggered at an early stage (Fig. 22.1). When the minute volume is being monitored electronically, any deficiency of gas volume is signalled equally quickly if the lower MV-alarm limit is set close to the desired minute volume, i.e. 0.5 L/min lower than the desired value.

In the newer generation anaesthetic machines, like Cato, Cicero and Primus, any occurrence of gas volume deficiency triggers the display of a clear text alarm message “Gas Volume Deficiency”.

25. How much carbon dioxide absorbent is consumed in low flow anaesthesia?

The rebreathing fraction, the proportion of exhaled gas volume being supplied back to the patient in the following inspiration after carbon dioxide absorption, increases as flow is reduced (Fig. 25.1). At a flow of 0.5 L/min about 80% of the exhaled carbon dioxide passes through the absorber and is bound there by the soda lime, instead of only about 20% at a flow of 4.0 L/min.

The time between the re-filling and exhaustion of an absorber canister containing soda lime, the utilisation time, decreases with decreasing fresh gas flow rate. If the fresh gas flow is consistently reduced to 0.5 L/min during all anaesthetics - whenever possible - the utilisation time of the absorbers drops to about 25% compared with the life time at a flow of 4.4 L/min (Fig. 25.2).

Consistent performance of Minimal Flow Anaesthesia with a fresh gas flow of 0.5 L/min, therefore, increases the consumption of soda lime about fourfold. The cost of soda lime can be assumed to be 0,14 Euro (Drägersorb 800 plus) - 0,36 Euro (Drägersorb free) per hour of high flow anaesthesia with a flow of 4.4 L/min, if the absorbent is used until complete exhaustion. Thus, consistently reducing the flow to 0.5 L/min means that the cost resulting from the increased consumption of soda lime rises fourfold to 0,56-1,46 Euro per anaesthesia hour.

If double or jumbo absorber canisters filled with pelleted soda lime are used, the absorption capacity of the lime will safely guarantee sufficient CO₂ absorption, even if flow is reduced to the extreme, for at least an entire working day.

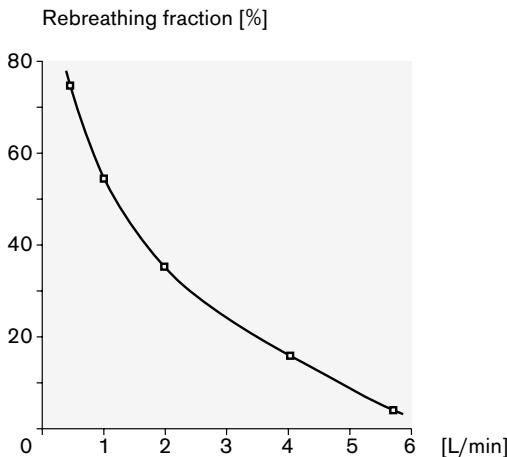


Fig. 25.1
Rebreathing fraction: percentage of exhaled air really passing the absorber and being led back to the patient during the next inspiration. Measurement on an ISO Circle System 8, Pat. 72 kg, 182 cm, MV 5.7 L/min.

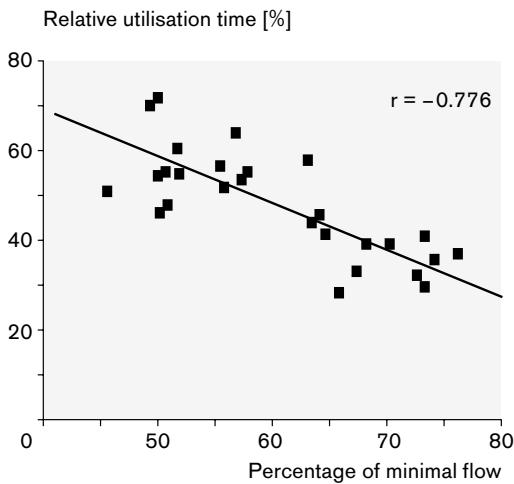


Fig. 25.2
Utilisation time of soda lime (depicted as percentage of utilisation time, using a flow of 4.4 L/min), as a function of the percentage of time during which anaesthesia was actually performed with a flow of 0.5 L/min.

Only when the continuous monitoring of inspiratory and expiratory CO₂-concentration can be guaranteed it becomes possible to dispense with the use of double or jumbo canisters and the daily replacement of the soda lime filling for low flow anaesthesia.

New less reactive absorbents were introduced into clinical practice: absorbents containing neither potassium- nor sodium hydroxide, referred to as calcium hydroxide lime or non-caustic lime, in vitro and in vivo investigations proved to be significantly less reactive than conventional - or potassium free soda lime, likewise in dehydrated and normally hydrated condition. The following mean utilisation times (UT) were determined for different brands of absorbents: Amsorb™: UT 18 hrs; LoFloSorb™: UT 18.6 hrs; Superia™: UT 21.7 hrs; Drägersorb Free™: UT 27.8 hrs; Sofnolime™: UT 29.2 h; Drägersorb 800 plus™: UT 33.1 h; Spherisorb™: UT 33.4 h (Fig. 25.3). Thus, the utilisation time of calcium hydroxide lime and non-caustic lime under comparable clinical conditions was found to be about 55-65 %, and the life time of Drägersorb Free, still containing a small amount of sodium hydroxide but inert with respect to compound A or carbon monoxide generation, to be about 80-90 % of the utilisation time of potassium-free soda lime.

In low flow anaesthesia the costs resulting from increased consumption of carbon dioxide absorbents by far are balanced by the savings resulting from decreased consumption of anaesthetic agents.

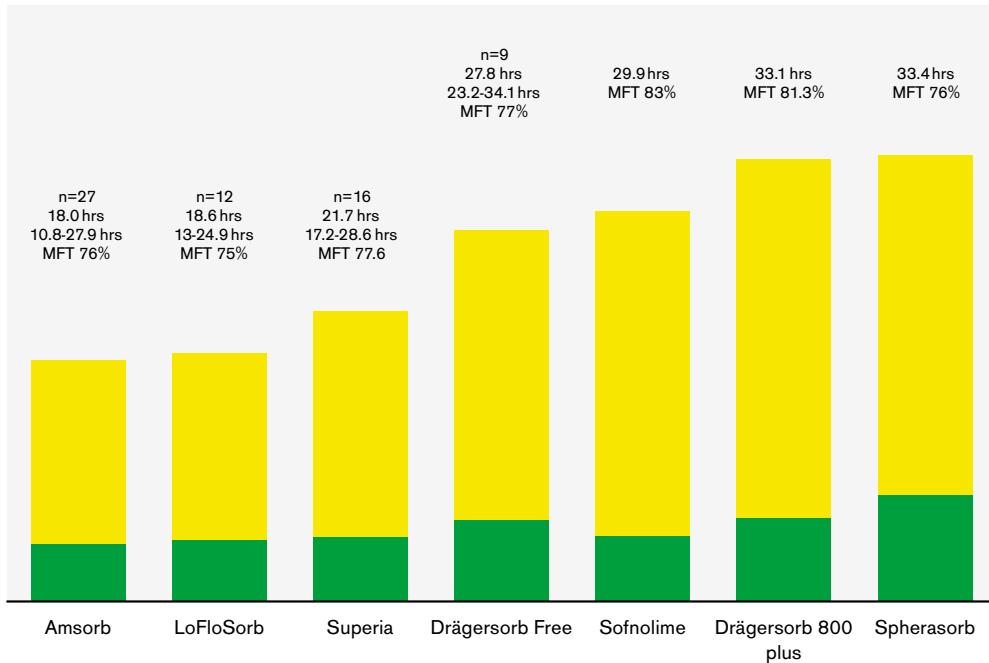


Fig. 25.3
Utilisation time of different carbon dioxide absorbents, determined in clinical practice during routine performance of minimal and closed system anaesthesia (1.5 L Jumbo-absorber). Legend downwards:
n: number of the respective measurement runs; mean utilisation time; range of utilisation times; MFT: percentage of time using extremely low fresh gas flow rates between 0.5-0.25 L min⁻¹.

26. Are there specific requirements on the composition or the handling of carbon dioxide absorbents in low flow anaesthesia?

Due to the reduced wash out of trace gases in low flow anaesthesia, any generation of foreign gases must be a matter of concern. This holds for both, conventional soda lime, containing sodium and potassium hydroxide, but also for potassium free soda lime.

Especially dry soda lime reacts with all inhalational anaesthetics by absorption and degradation. This applies not only to desflurane which is degraded to carbon monoxide but also for sevoflurane. This agent reacts in a strongly exothermic reaction with desiccated soda lime in which the agent's molecules are completely destroyed generating multiple partially still unidentified toxic products. Thus, all measures have to be taken to prevent both, not only carbon dioxide rebreathing due to soda lime exhaustion but also accidental desiccation of the absorbent.

Soda lime should be discharged whenever signs of exhaustion of the absorption capacity occur, or, in routinely used anaesthetic machines, according to a fixed time scheme, at least once a week. The filling date should be written down on an adhesive strip attached to the surface of the canister. If the routine discharge of the absorbent in seldomly used machines seems to be too wasteful the canister should be disassembled from the breathing system after use and stored separately sealed by suitable caps. Obligatory, however, according to identical instructions of all the manufacturers of soda lime, the absorbent has to be discharged routinely latest after a period of four weeks.

Following measures prevent accidental desiccation of the soda lime:

- A breathing system equipped with an absorber canister must never be dried out by switching on a continuous gas flow at the flow control system, or by opening the Y-piece and switching on the ventilator, while the machine is idle during night or at the weekend.
- All needle valves at the flowmeter block should be turned off after each anaesthetic. Additionally, when the daily list is finished, the pipeline connectors should be disconnected from the sockets of the central gas piping system.
- The absorber canisters of anaesthetic machines left idle for a longer period of time should not be filled with absorbent. To safely protect the absorbent from desiccation it should be stored in the unopened original packaging near to the machine. The canister should then be filled only in case of use. However, if the machine has to be used urgently, leaving no time for filling of the canister, a fresh gas flow rate equalling the minute volume will provide adequate elimination of expired carbon dioxide out off the breathing system via the exhaust port.
- As recommended by the manufacturers, opened original packaging containing carbon dioxide absorbents should be carefully closed again after use.

- Special care is recommended if pre-packed single use canisters are used: These canisters should be wrapped separately each, sealed within a tape impermeable for water vapour, and labelled with the expiration date.
- If any sign justifies the assumption of accidental desiccation of the absorbent, instantly the soda lime has to be discharged and a newly filled canister fitted to the breathing system.
- In any case of a sudden strong increase of the canister's temperature, a delayed increase of the agent's concentration within the breathing system, or a sudden change of the colour of the absorbent's indicator dye, the absorbent instantly has to be discharged and a newly filled canister fitted to the breathing system. Contrary to malignant hyperthermia, in case of severe degradation of the absorbent by desiccated soda lime no simultaneous excessive increase of the expiratory carbon dioxide concentration can be observed.

Absorbents containing the normal amount of water do react with halothane, but much more vigorously with sevoflurane by forming haloalkenes. This holds not only for conventional but also potassium free soda lime. These absorbents react with sevoflurane by generating compound A. Referring to all the currently available data, however, the formation of compound A no longer should be a matter of clinical concern: even high loads with this compound, gained during long lasting low flow anaesthesia, never did result in any significant impairment of renal function. Any restriction with respect to the fresh gas flow used in sevoflurane low flow anaesthesia does not seem to be justified any more.

According to current knowledge, Drägersorb Free, Calcium Hydroxide Lime or Non-Caustic Lime do not react with anaesthetic agents, neither in desiccated nor in normal wet condition. Consistent use of these absorbents would be the safest way to get rid of any concern about the generation of possibly harmful degradation products.

27. Do anaesthetic machines need any special preparation for carrying out low flow anaesthesia?

Older types of anaesthetic machines from the fiftieth and sixties in general are not suited, but even not designed, for low flow anaesthetic techniques. During technical maintenance leakages were tolerated rendering difficult to reducing the fresh gas flow rate even to 2.0 L/min.

Conventional anaesthetic machines, lacking in anaesthetic gas reservoirs and fresh gas flow compensation of the anaesthetic ventilator, can be operated using a fresh gas flow of 1.0 L/min in routine practice, if they have been properly maintained. In principle it may be possible to use even lower fresh gas flows - provided that the breathing system and the ventilator would be sufficiently leaktight - however the anaesthetist then must pay special attention to monitoring the circulating gas volume so that any changes in the ventilation pattern can be detected and corrected at an early stage.

The new generation anaesthetic machines, in general, are equipped with an anaesthetic gas reservoir by which short lasting gas volume imbalances can be compensated . The anaesthetic ventilators feature fresh gas flow compensation, thus, the tidal volume delivered to the patient is not influenced by any alteration of the fresh gas flow rate. The flow controls are graduated and working precisely in the low flow range. Furthermore, the compact breathing systems of these machines are particularly leaktight. All these machines are suited for Low Flow - and Minimal Flow Anaesthesia in daily clinical practice. If the use of nitrous oxide is omitted even Closed System Anaesthesia can be realized in routine clinical practice with these machines.

Proper maintenance of the anaesthetic apparatus provided there are no special preparations needed to safely carry out low flow anaesthesia.

28. Are there more demanding requirements for disinfection or sterilization of anaesthetic machines?

No! The rate of bacterial contamination of the breathing system is not increased by the reduction of the fresh gas flow rate and the resulting increase in warmth and humidity of the breathing gases. In the everyday clinical practice of low flow anaesthesia there are, therefore, no specific procedure-related additional requirements for sterilizing or disinfecting routines. However - whatever the fresh gas flow selected - an increase in the contamination rate with the clinically relevant germ pseudomonas has been found at site II (Fig. 28.1), the connection between the breathing system and the manual bag or the hose to the ventilator. The contamination rate further increases, again with no relation to the fresh gas flow rate used, if the breathing system is not cleaned after use, and remains idle for several days. Very unlikely is the propagation of bacteria by the stream of breathing gases at high, as well as low fresh gas flows.

Anaesthetic machines, used routinely for low flow anaesthesia, should be cleaned and disinfected in accordance with acknowledged guidelines, i.e. DGAI guidelines.

- The hosing should be changed after each patient or, alternatively, a bacterial filter, changed after each patient, should be attached to the tube connector. In this case the hosing can be used over the period of the whole daily list.
- At the end of each working day, the breathing systems should be disassembled and all hoses and the manual bag should be washed and thermo-disinfected.
- Where re-usable bacterial filters are used, these must be sterilized every day.

- After the system has been reassembled, the hose between the anaesthetic system on the one hand, and the ventilator or the manual bag on the other, should not be connected until just before the anaesthetic machine is going to be used again.
- All the gas-conducting parts of the breathing system and the ventilator must be sterilized once a week in an autoclave. When the anaesthetic machine is not likely to be used for a longer period of time, it should be cleaned and disinfected after use and only left idle in this condition until next use.

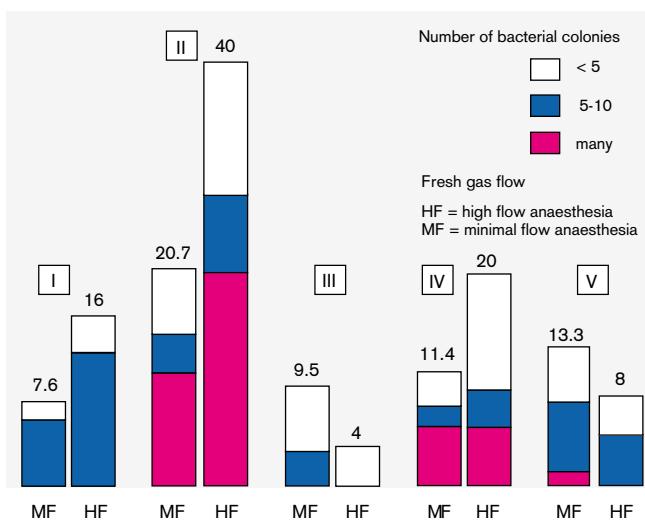


Fig. 28.1
Percentage of positive
bacteriological samples
(in relation to the total number
of samples taken at each
sampling point).

29. What are the technical preconditions for Closed System Anaesthesia?

The technical preconditions, needed to perform Closed System Anaesthesia, are mainly determined by the composition of the carrier gas. If the carrier gas consists of a mixture of oxygen with nitrous oxide or xenon, the total gas uptake follows a power function. Only by electronically controlled gas delivery systems the gas and agent supply can be precisely adapted to the continuously changing uptake. This is the more indispensable for the realization of Quantitative Closed System Anaesthesia, as the different components of the anaesthetic gas have not only to be delivered independently but also as precisely as to meet exactly the respective quanta of uptake. Actually, two anaesthetic machines are available offering electronically controlled gas and anaesthetic agent supply according to the individual uptake: the PhysioFlex and the Zeus anaesthetic workstation.

If, however, the carrier gas composition is simple, for instance if pure oxygen or a mixture of oxygen and air (nitrogen) is used, the gas uptake remains nearly constant during the course of anaesthesia. Thus, after wash in of the desired inspiratory oxygen concentration, the fresh gas flow can be reduced to just that amount of oxygen taken up by the patient. The weak point of this concept remains the fact, that, using vaporisers outside the circuit (VOC), the supply of the anaesthetic agents is directly linked to the fresh gas flow. Thus, using very low fresh gas flows, the amount of anaesthetic agent delivered into the system may be too low to meet the respective uptake. This holds the more for the higher soluble older volatiles like halothane, enflurane, and isoflurane, than for sevoflurane and desflurane. To establish a desired anaesthetic concentration still needs a sufficiently long initial high flow phase, after which the flow can be reduced to the individual oxygen uptake, and the agent's concentration can be maintained with the resulting small amount of anaesthetic vapour. Conventional anaesthetic machines, featuring low flow gas controls, anaesthetic gas reservoir, fresh gas flow compensation and highly gas tight breathing systems like Cato, Cicero, Fabius and Primus, meet the needs for Closed System Anaesthesia with simple carrier gas composition.

5 Advantages of low flow anaesthesia

30. Does performance of low flow anaesthesia improve temperature and humidity of the anaesthetic gases?

The importance of adequately humidifying and warming the breathing gases for the preservation of the function of the ciliary epithelium and for the mucociliary clearance is generally accepted. After three hours of ventilation with dry gases there will be considerable morphological damage to the airway epithelium, resulting in mucous retention, obstruction of the bronchioles, and a tendency for the generation of microatelectasis. During anaesthesia an absolute humidity of 17-30 mg H₂O/L and a temperature of 28-32°C should be provided.

Low flow anaesthesia performed with markedly reduced fresh gas flow rates improves climatisation of the anaesthetic gases.

The humidity of the breathing gases starts to increase immediately after the reduction of the fresh gas flow rate, reaching a value of 17 mg H₂O/L already during the first anaesthetic of the daily list, latest after 30 minutes. During the further course of the working day always a humidity is gained in the desired range if a flow rate ≤ 1.0 L/min is used (Fig. 30.1a). With higher fresh gas flow rates the humidity of the anaesthetic gases significantly decreases (Fig. 30.1b), and becomes as low as 10 mg H₂O/L at a flow rate of 4.0 L/min, despite the use of actively heated hosings to optimize climatisation (Fig. 30.1c).

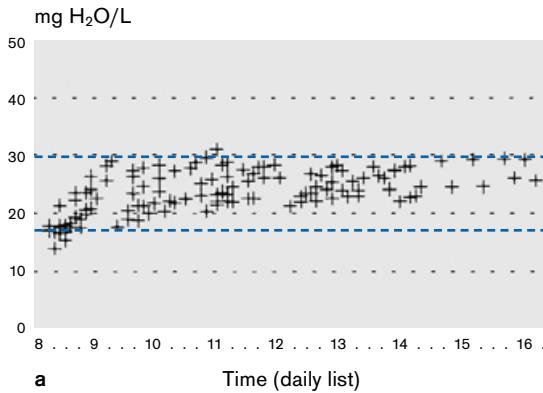
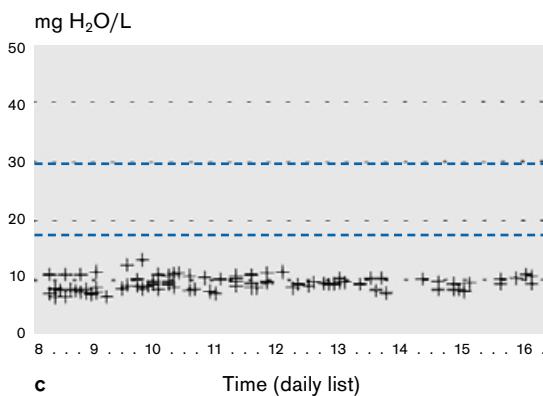
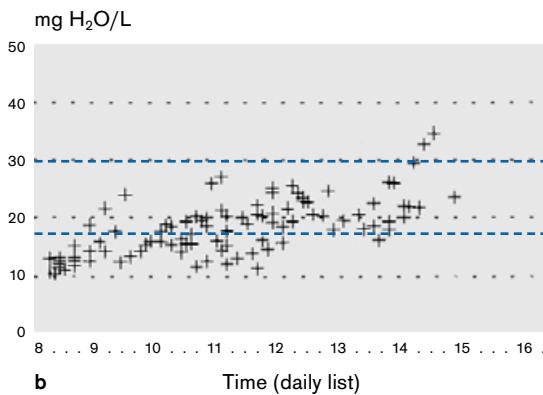


Fig. 30.1
Inspired humidity at the tube connector during the course of daily lists:
a. normal hosing,
flow 0.5 L/min;
b. heated hosing,
flow 2.0 L/min;
c. heated hosing,
flow 4.0 L/min.
Desired range: 17–30 mgH₂O/L.



The temperature of the breathing gases, however, depends mainly on the temperature loss at the inspiratory limb of the hosing system - much less on the fresh gas flow rate itself (Fig. 30.2a). If the loss in temperature can be reduced, for instance by the use of heated hoses, optimum temperature will be gained even at high fresh gas flow rates (Fig. 30.2b). Active heating of the hosing essentially improves the climatisation of anaesthetic gases, which will then reach optimum values in low flow anaesthesia.

Although the positive effects of adequate climatisation of the breathing gas are beyond question, clinical research has not yet demonstrated that this will also lead to a reduction of post-operative pulmonary complications.

Improved warming and humidification of anaesthetic gases also reduces energy loss via the airways. Even if this loss accounts for only about 10% of the overall energy loss of about 150 kcal/h from an uncovered, anaesthetised patient, better conditioning of breathing gases can, nevertheless, contribute to the maintenance of body temperature.

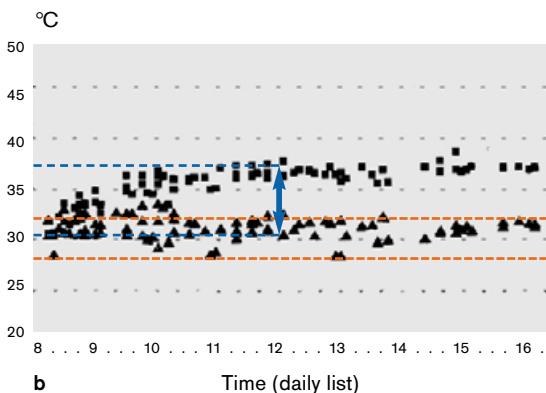
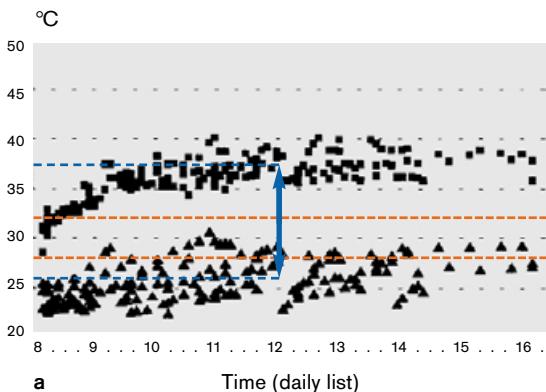


Fig. 30.2
Inspired temperature at the outlet of the circuit (squares) and the tube connector (triangles) during the course of daily lists:
a. normal hosing, flow 0.5 L/min;
b. heated hosing, flow 4.0 L/min.
Desired range: 28-32°C.
Temperature difference between circuit outlet and tube connector (double headed blue arrow): normal hosing about 12°C, heated hosing about 6°C.

31. What are the ecological benefits of low flow anaesthesia?

The consistent use of rebreathing systems alone with the nitrous oxide flow reduced to 0.5 L/min (Low Flow Anaesthesia) or even 0.2 L/min (Minimal Flow Anaesthesia) can reduce the concentration of nitrous oxide at the workplace to 29 or 15 ppm respectively (Fig. 31.1). As well as falling below the limit value of 50 ppm stipulated by the administration of some countries in the Federal Republic of Germany, these values meet even the stringent recommendations of the American National Institute of Occupational Safety and Health which stipulates a concentration of 25 ppm as the limit concentration. Reducing concentration in the workplace by reducing the consumption of anaesthetic gas is particularly helpful in all those areas where there is no central gas scavenging system.

Furthermore, the uncritical emission of anaesthetic gases into the atmosphere via gas scavenging systems is increasingly becoming a matter of ecological concern. This concern is all the more justified as the emission of anaesthetic gases essentially consists of wholly unnecessary releases of large, unused amounts of excess gas.

Nitrous oxide contributes to the warming of the atmosphere, the greenhouse effect and also, via a nitrogen oxide cascade, to the destruction of the ozone layer. The molecule is very stable and has a life expectancy of 150 years, and the increase in concentration in the atmosphere is 0.25% per year. However, an overwhelming proportion, 52% of the global nitrous oxide emission, comes from bacterial decomposition of nitrates used in agriculture to fertilise soil, 27% from industrial plants, 16% from combustion of fossil fuels, with less than 1% coming from medical use.

Inhalation anaesthetic agents belong to the partially-substituted chloro-fluoro-carbons (CFCs) which have a short life time in the atmosphere of only 2 to 6 years and which are said to have no more than highest 5% of the ozone-damaging potency of the fully-substituted CFCs used in industry. The annual production of about 5000 tons of volatile anaesthetic agents represents only about 1% in quantity of the annual production of fully-substituted CFCs. However, with the production of fully-substituted CFCs decreasing, this ratio will change to the disadvantage of partially-substituted CFCs.

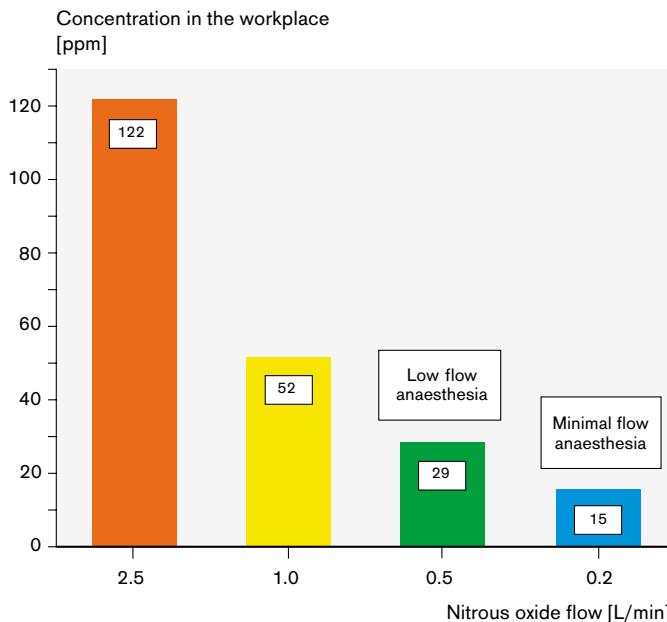


Fig. 31.1
Nitrous oxide workplace concentration (modified according to Virtue, 1979).

32. What are the cost savings resulting from Low Flow, Minimal Flow, or Closed System Anaesthesia?

The cost savings which result from reducing the consumption of anaesthetic gases depend on the following factors :

- they increase as the duration of the anaesthetic procedure increases;
- they increase as the price of the anaesthetic agent increases:
isoflurane (60,22 € /250 mL) < desflurane (85,26 €/240 mL) < sevoflurane (185,94 €/250 mL)*;
- they increase as the proportion of long lasting surgical procedures increases;
- they increase as the extend of fresh gas flow reduction increases.

In clinical routine work, doing a list with a high proportion of short surgical procedures (for example a routine gynaecological list with several laparoscopies), a decrease in the cost for anaesthetic gases by 55-65% may be expected. When there, however, is a high proportion of lengthier surgical procedures cost savings may amount to 75% or even more.

*Prices: stand July 2002

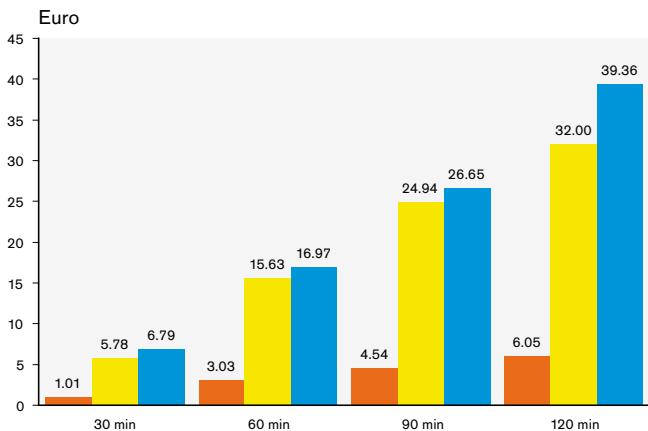


Fig. 32.1
Cost savings by Minimal Flow Anaesthesia.

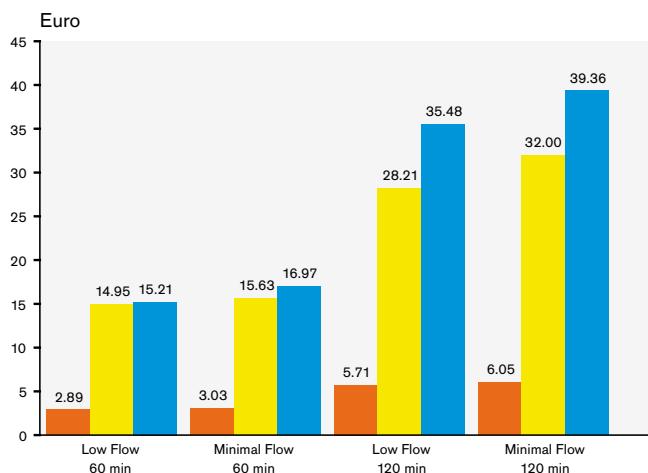


Fig. 32.2
Cost savings by Low Flow-versus Minimal Flow Anaesthesia.

33. Does the omission of nitrous oxide increase the cost of inhalation anaesthesia?

If consistently the use of nitrous oxide is renounced the costs for anaesthetic gases - calculated for 2 hours Minimal Flow Anaesthesia - increase by about 1.50 - 2.50 €, resulting from the increased consumption of inhalation anaesthetics.

According to the author's experience additional costs for supplementary opioids amount to 0.12 - 0.25 € per patient. This increase of costs is partially balanced by the savings of about 1,25 € , a sum which would result from additional N₂O consumption during 1 hour of anaesthesia. The astonishingly low potential of savings, resulting from omission of nitrous oxide in our calculation, must be explained by the fact that in Minimal Flow Anaesthesia the nitrous oxide consumption was already extremely low. If, however, with the omission of nitrous oxide Closed System Anaesthesia is routinely performed, the costs resulting from increased agent consumption and supplementary use of opioids are pretty well balanced by the savings resulting from leaving out this gas (Fig. 33.1). In all these calculations additional costs resulting from nitrous oxide logistics, technical maintenance of the central piped nitrous oxide supply system and nitrous oxide cylinder bank, and from the technical measures needed to reduce the work place concentration to values as low as stipulated, remain unconsidered.

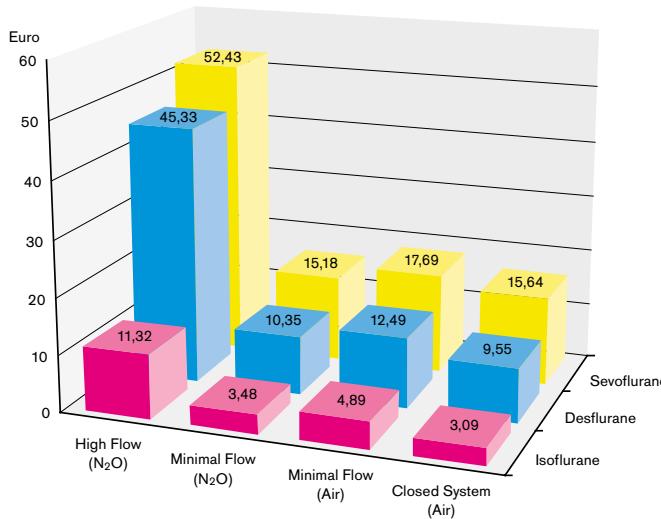


Fig. 33.1
Costs resulting from anaesthetic agent consumption, calculated for 2 h inhalation anaesthesia. Compared: high flow - (4.5 L/min) and Minimal Flow - (0.5 L/min) with nitrous oxide versus Minimal Flow- and Closed System Anaesthesia without nitrous oxide.

34. How much can the efficiency of inhalation anaesthesia be improved by the reduction of the fresh gas flow?

To estimate the efficiency of an inhalation anaesthetic technique Ernst recommended to use the efficiency coefficient C_{Eff} . It can be calculated by dividing the amount of anaesthetic agent taken up by the patient \dot{V}_U by the amount of agent delivered into the breathing system at the same time \dot{V}_D :

$$C_{Eff} = \dot{V}_U / \dot{V}_D$$

In high flow anaesthesia the efficiency of the inhalation anaesthetic technique is low, however, it can be improved significantly by any reduction of the fresh gas flow rate (Fig. 34.1), as it inevitably reduces \dot{V}_D . Sevoflurane or desflurane are both characterized - on the one hand - by low solubility and correspondingly low individual uptake, and - on the other hand - by comparatively low anesthetic potency and correspondingly high anaesthetic concentrations to be applied. If such agents are used with high fresh gas flow, the efficiency becomes extremely small. From economical reasons, the use of such anaesthetics only can be justified with low flow anaesthesia.

In closed system anaesthesia the efficiency coefficient of inhalational anaesthesia comes very close to 1.0 as - except the amount of gas needed to establish the respective gas concentration within the gas circulating within the anaesthetic machine - all the anaesthetic agent delivered into the breathing system is taken up by the patient, and no excess gas at all is lost.

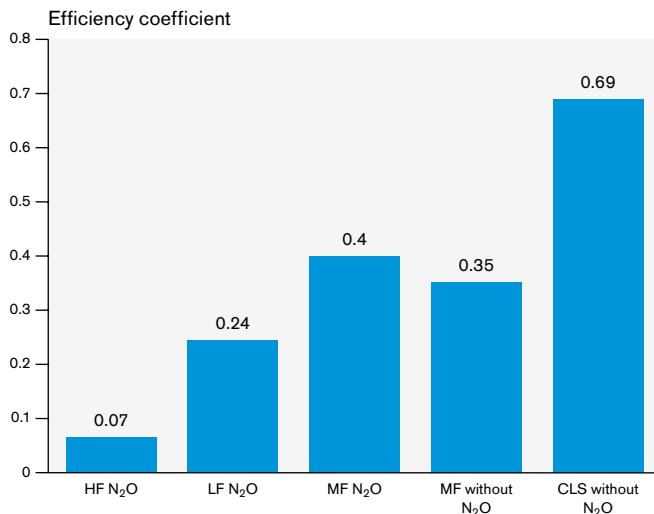


Fig. 34.1
Increase of efficiency of inhalation anaesthesia by conducting different techniques of low flow anaesthesia.
(HF N₂O, LF N₂O, MF N₂O: High (4.4 L/min)-, Low-, and Minimal Flow Anaesthesia with nitrous oxide; MF and CLS without N₂O: Minimal Flow- and Closed System Anaesthesia without nitrous oxide. Assumptions for the calculation: Adult normal body weight patients, 2 hrs. anaesthesia, inspiratory desflurane concentration about 6.0%)

35. Is low flow anaesthesia worth being carried out even in short surgical procedures, for instance in day cases?

The extent to which the benefits of low flow anaesthetic techniques are utilised depends not only on the extent of flow reduction but also on the duration of the anaesthetic:

A decrease of anaesthetic gas consumption and a decrease of atmospheric pollution with anaesthetic gases will directly and immediately result from any reduction of the fresh gas flow rate. Under this aspect low fresh gas flow rates should be used as early as and whenever possible.

The improved climatisation of anaesthetic gases applies directly with any reduction of the flow rate. This also is an argument in favour for early and consistent fresh gas flow reduction.

Cost savings, resulting from decreased anaesthetic gas consumption, also immediately will be gained whenever the fresh gas flow rate is reduced. This is shown by the example of a sevoflurane anaesthesia in a small child: During the initial mask induction lasting 7 minutes anaesthetic agent consumption sums up to about 11 €, whereas during the following 23 minutes of Closed System Anaesthesia sevoflurane consumption results only in costs as low as 0,50 € (Fig. 35.1).

Any emission of possibly harmful substances, as defined by national regulations, should be minimised as far as the level of technology available allows. This also applies to all anaesthetic inhalation agents and gases for which a maximum concentration in the workplace is laid down. This also speaks in favour for consistent and early flow reduction.

Thus, it should be a matter of course nowadays, when using rebreathing systems, to reduce the fresh gas flow rate whenever possible. The duration of the initial high flow phase, which has to proceed every flow reduction, only should be sufficiently be adapted to the carrier gas composition, the pharmacokinetic and pharmacodynamic properties of the anaesthetic agent, and the extend of the fresh gas flow reduction.

In every inhalational anaesthetic, lasting longer than 10 to 15 minutes, the fresh gas flow rate consistently should be reduced to its minimum in accordance with the respective technical preconditions.

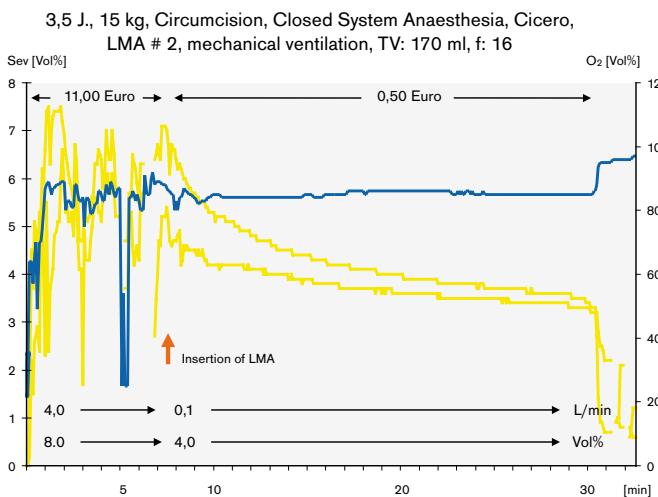


Fig. 35.1
Essential cost savings resulting
from the performance of
Closed System Anaesthesia
during short lasting day-case
surgery.

6 Limitations and contraindications for low flow anaesthesia

36. Can low flow anaesthesia be universally applied?

In principle, no anaesthetic technique at all is universally applicable, as the selection must always relate to the current preconditions and each individual case. In problem cases, the anaesthetist should always select the technique, with which he is most familiar.

Low flow anaesthetic techniques are not suitable for the following procedures:

- short term anaesthesia with a face mask;
- procedures with imperfectly gas-tight airways (i.e. bronoscopies with a rigid bronchoscope);
- use of technically unsatisfactory equipment with a high gas-leakage;
- inadequate monitoring (i.e. malfunction of the oxygen measuring device).

Low flow anaesthesia via a face mask is the province of an experienced anaesthetist pretty well familiar with this technique. However, even relatively short low flow anaesthetics can be carried out without any problem when a laryngeal mask is used to secure the airway. A laryngeal mask, which is in the correct position, is sufficiently gas-tight and - in the majority of cases - even allows controlled or intermittent mandatory ventilation (Fig. 36.1).

When its size has been selected properly the use of an endotracheal tube without cuff for paediatric anaesthesia does not mean that adequately adjusted fresh gas flow reduction is out of question. Especially, as the total gas uptake of neonates and infants is very low and, correspondingly, the excess gas fraction comparatively high.

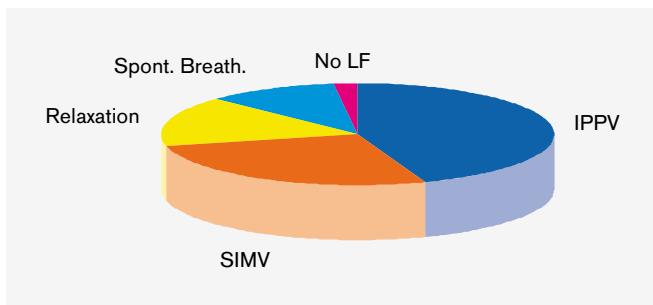


Fig. 36.1
Satisfying performance of Minimal Flow Anaesthesia via the laryngeal mask: 45% IPPV, 27% SIMV, 16% mechanical ventilation only possible with muscle relaxation, 11% spontaneous breathing, 2% no low flow anaesthesia possible.

37. Which foreign or trace gases may accumulate during low flow anaesthesia?

Due to the decreased wash-out effect principally there has to be considered the possibility of accumulation of trace and foreign gases in low flow anaesthesia. The risk of foreign gas accumulation increases with the extend of fresh gas flow reduction (Fig. 37.1).

During low flow anaesthesia the following gases of low solubility may accumulate within the breathing system: nitrogen, methane, argon (if oxygen concentrators are used as the source for medical oxygen) and hydrogen. Harmful or dangerous concentrations of these gases, however, have never been found in the breathing systems. Only nitrogen is likely to be present in the system at comparatively high concentrations sufficient to influence the oxygen as well as the nitrous oxide concentration. These low soluble gases can be washed out of the breathing system by intermittent flushing phases using a flow rate of 5 L/min for 5 minutes.

Although the accumulation of these gases is not harmful for the patients anyway, methan accumulation may disturb the measurement of the concentration of inhalation anaesthetics in the breathing gases - especially halothane - if the gas analyzer uses the measurement method of nondispersive infrared absorption.

Trace gases, highly soluble in fat or water, like ethanol and acetone, or binding specifically to tissues or blood, like carbon monoxide, also may accumulate within the breathing system: If a sufficient wash out of acetone in patients suffering from ketoacidosis or ethanol in drunken patients shall be guaranteed, the fresh gas flow rate should not be lower than 1.0 L/min. Short intermittend flushing phases

only would wash-out the small quantities of gases contained in the breathing system and the ventilator. Due to the continuing high partial pressure difference between the tissues and the blood or gas compartment the trace gas concentration would increase readily again after finishing the flushing phase.

Trace gases

Fig. 37.1

- Argon
- Hydrogen
- Methane
- Nitrogen
- Acetone
- Carbon monoxide
- Haloalkenes

Generally, the accumulation of carbon monoxide in the breathing system in routine cases is of no clinical significance: Even in long lasting anaesthetic procedures with extremely low fresh gas flow rates the carboxyhemoglobin (COHb) concentration increases only insignificantly. The mean increase of COHb concentration in the blood during 6 hours closed system anaesthesia amounts to not more than 0.4%. Only in very special cases, i.e. strong smoking patients with significantly compromised general and regional perfusion undergoing mass blood transfusion, it may be recommended to use flows not lower than 1 L/min to safely guarantee a sufficient wash-out and, thus, prevent from carbon monoxide accumulation.

The formation of compound A had been a matter of concern for several years. The use of sevoflurane with a fresh gas flow rate of at least 1.0 L/min is assumed to be safe even in longer anaesthetic procedures by the American FDA. Due to current knowledge no flow restriction at all seems to be justified, as in not a single clinical case renal impairment was found even after long lasting closed system anaesthesia. Judicious selection of the carbon dioxide absorbent is an additional way to minimizing any risk for the patient resulting from trace gas generation: at least potassium free soda lime or non-caustic lime, containing neither potassium- nor sodium hydroxide, should be used, whereas the further use of the highly reactive barium hydroxide lime must be a matter of real concern. Always carefully all measures have to be taken, to avoid any accidental desiccation of the carbon dioxide absorbent.

38. What is the clinical significance of nitrogen accumulation within the breathing system, which is to be observed frequently?

In principle, the accumulation of nitrogen in the breathing system can lead to a reduction in the concentration of oxygen as well as of nitrous oxide.

A decrease of the oxygen concentration, if it were to become clinically significant, should be detected at a very early stage, provided that the lower alarm limit at the oxygen monitor was correctly set.

A reduction of the nitrous oxide concentration is in so far not a problem, as it can't be harmful for the patient, but it may weaken the hypnotic and analgetic effect of the nitrous oxide admixture. During prolonged Minimal Flow Anaesthesia nitrogen concentrations of 6 to 10 vol.% can be observed. These values are rarely exceeded and have no clinical significance (Fig. 38.1).

At an initial fresh gas flow rate of 4 L/min, denitrogenation is completed in 6 to 8 minutes, though the nitrogen dissolved in the body tissues (about 0.7 L for an adult) is released only very slowly.

Following factors may cause a clinically significant high nitrogen accumulation:

- Insufficient denitrogenisation due to a premature reduction in fresh gas flow, or to a change from one ventilator to another (i.e. from induction room to the theatre).

- Entrance of ambient air into the breathing system in case of gas volume deficiency via leakages or via an emergency air intake valve if a negative pressure is generated by any force assisting the expiratory filling of the ventilator (i.e. ventilators with suspended bellows arrangement).
- Return of the sample gas: During low flow anaesthesia, when using side-stream gas analysers, it is strongly recommended to return the sample gas taken from the breathing system to avoid gas volume deficiency. Depending on the gas monitor used, however, the sample gas may be mixed with ambient air which is used as reference or calibration gas. Thus, with the return of the sample gas additional nitrogen can be returned into the breathing system.

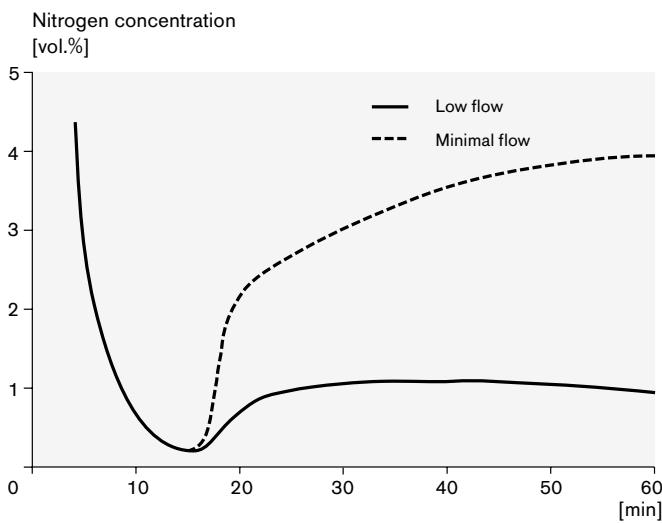


Fig. 38.1
Nitrogen accumulation in
breathing system, patient
weight 75 kg.

39. What are the contraindications for Low-, Minimal Flow -, and Closed System Anaesthesia?

Absolute contraindications:

Whenever a continuous wash out of potentially dangerous gases is required low flow anaesthetic techniques must not be performed. The same applies if extremely high individual gas uptake has to be expected.

- Smoke or gas intoxication,
- Malignant hyperthermia,

Furthermore, all conditions, in which the equipment does not meet essential requirements to ensure patient safety, are generally absolute contraindications for the use of the rebreathing techniques:

- soda lime exhaustion,
- failure of the oxygen monitor (unless pure oxygen is used as carrier gas),
- failure of the anaesthetic agent monitor (if it is part of the dosing system itself).

Relative contraindications

In inhalation anaesthesia lasting less than 10-15 min fresh gas flow reduction is unsuitable - especially if nitrous oxide is used - because there is an increased risk of:

- insufficient denitrogenation,
- inadequate depth of anaesthesia,
- gas volume deficiency.

If using equipment, which does not meet the required technical preconditions, fresh gas flow reduction may become difficult or even impossible:

- due to insufficient gas tightness of the breathing system or the ventilator,
- due to imprecise performance of the gas flow controls in the low flow range,
- during anaesthesia with a face mask,
- in case of rigid bronchoscopy,
- possibly, when using uncuffed endotracheal tubes,
- when using non-rebreathing systems, for instance during magnetic resonance imaging,
- if anaesthetic machines are used featuring no gas reservoir and a ventilator in which the expiratory expansion of the bellows is supported by an additional force, in patients suffering from acute bronchospasm.

If there is any increased risk of accumulation of potentially dangerous trace gases, the fresh gas flow should be at least 1 L/min to guarantee a continuous wash-out effect. Such contraindications for the use of extremely low fresh gas flow rates - minimal flow or closed system anaesthesia - include:

- decompensated diabetes mellitus,
- the state of long-term starvation,
- anaesthesia performed on chronic alcoholics,
- anaesthesia performed on patients with acute alcohol intoxication,
- heavy smokers suffering from severe restriction of regional perfusion undergoing mass transfusion,

7 Low Flow Anaesthesia techniques in clinical practice – guidelines and schemes

40. What is the safest way to becoming familiar with the different techniques of low flow anaesthesia?

To guarantee the safety of patients the following rules should always be observed when starting to work with low flow anaesthetic techniques:

- The anaesthetic machine must be checked by the technical service to make sure that all the individual components, particularly the gas flow controls, are in proper order and work precisely at low fresh gas flow rates. The tolerances for leakages must not be exceeded.
- The devices to monitoring the concentration of inspiratory oxygen as well as the air way pressure and the minute- or tidal volume must be checked routinely every day and the alarm limits must be correctly set and activated.
- First experiences with low flow anaesthesia should be gained during simple surgical procedures performed on patients without any complicating coexisting disease. In this way there can be a guarantee that the anaesthetist is able to carefully concentrate on the specific characteristics of the procedure.

- The fresh gas flow rate must be adjusted flexibly to suit the technical preconditions and the surgical requirements.
When using conventional anaesthetic machines it is recommended that the flow is reduced in 0.5 to 1.0 L/min steps from the traditionally used high fresh gas flow rates. In this way, the limits of the respective machine can be found at an early stage. The new generation anaesthetic machines, featuring fresh gas flow compensation and an anaesthetic gas reservoir, can be much easier handled than older type conventional anaesthetic machines.
- Residents and young anaesthetists should only carry out low flow anaesthetic techniques under the supervision of an experienced specialist.

41. Standardized concept for Minimal Flow Anaesthesia with nitrous oxide

Initial remarks

All the data given for gas flow and volatile anaesthetic control are clinically proven guidelines. Carefully, however, they have to be adapted in each single case according to the individual reactions of the patient and to surgical requirements.

Premedication

In the usual way, no procedure specific requirements

Induction

- Preoxygenation
- Intravenous application of a hypnotic
- If necessary, supplemental intravenous application of an opioid
- If needed, muscle relaxation
- Endotracheal intubation or insertion of a laryngeal mask
- Connecting the patient to the rebreathing system

Initial high flow phase

- Duration 10 to 15 (max. 20) minutes, depending on the anaesthetic agent and the patient's constitution
- 1.4 L/min oxygen
- 3.0 L/min nitrous oxide
- Vaporiser setting:
 - halothane 1.0-1.3 vol%
 - enflurane 2.0-2.5 vol%
 - isoflurane 1.0-1.5 vol%
 - sevoflurane 2.0-2.5 vol%
 - desflurane 4.0-6.0 vol%

Setting of the alarms

- Inspired oxygen concentration: lower alarm limit 28-30 vol%
- Disconnect alarm: lower alarm limit 5 mbar below peak pressure
- Minute volume monitoring: lower alarm limit 0.5 L/min below nominal value
- Inspired volatile anaesthetic concentration:
Upper alarm limit
halothane, enflurane and isoflurane: 2.5 vol%
sevoflurane: 3.5 vol%
desflurane: 8.0 vol%

Reduction of the fresh gas flow rate

- 0.3-0.25 L/min oxygen
- 0.2-0.25 L/min nitrous oxide
- Vaporiser setting:
halothane 2.5-3.0 vol%
enflurane 3.0-3.5 vol%
isoflurane 2.0-2.5 vol%
sevoflurane 3.0-3.5 vol%
desflurane: increase initial vaporiser setting by 1.0-1.5 vol%
(i.e. 5.0-7.5 vol%)

Emergence and Recovery

- Switch off the vaporiser 15-30 min prior to the end of the surgical procedure
- Maintain a fresh gas flow rate of 0.5 L/min
- Lead patient to spontaneous breathing by manual ventilation , SIMV or PS (ASB)
- Wash-out anaesthetic gases with 5.0 L/min of pure oxygen 5-10 min prior to extubation
- Give patient postoperative care according to the generally used scheme

Alterations of the fresh gas composition**Inspiratory oxygen concentration declines to the lower alarm threshold**

- Increase oxygen flow by 50 mL/min
- Decrease nitrous oxide flow by 50 mL/min

Increasing anaesthetic depth with long time constant

- Maintain fresh gas flow at 0.5 L/min
- Increase vaporiser setting by 1-2 vol%
- When the desired depth of anaesthesia has been achieved, set vaporiser to a concentration about 0.5 vol% higher than desired nominal concentration

Decreasing anaesthetic depth with long time constant

- Maintain fresh gas flow at 0.5 L/min
- Decrease vaporiser setting by 1-3.5 vol%
- When the desired depth of anaesthesia has been achieved, set vaporiser to a concentration of about 1.0-2.0 vol%

Rapidly increasing or decreasing anaesthetic depth with short time constant

- Set vaporiser to the desired inspiratory concentration
- Increase fresh gas flow to 4.4 L/min (1.4 L/min O₂, 3.0 L/min N₂O)
- When the desired depth of anaesthesia is achieved, usually in about 5 min, re-establish again a low fresh gas flow rate of 0.5 L/min (0.3 L/min O₂, 0.2 L/min N₂O)
- Set vaporiser to a value 0.5 vol% above, or 1.0-2.0 vol% below the starting value respectively
- If sevoflurane or desflurane are used, due to their low solubility and the wide dialling range of the vaporisers, the anaesthetic concentration can be increased even if low flow technique is maintained. Doing so, however, anaesthetic agent monitoring is indispensable.
- Alternative option for increasing anaesthetic depth rapidly: intravenous injection of supplementary doses of hypnotics or opioids

Gas volume deficiency: decrease of the peak pressure and the minute volume

- Replenish the anaesthetic gas reservoir by short-term increase of the fresh gas flow
- Check for leaks
- If leakage persists: increase the fresh gas flow by 0.5 L/min and change over to Low Flow Anaesthesia

42. Standardized concept for Minimal Flow Anaesthesia without nitrous oxide

Initial remarks

If the use of nitrous oxide consistently is renounced a higher nominal expiratory anaesthetic concentration has to be used (Isoflurane: about 1.2 vol%, sevoflurane: about 2.2 vol%, desflurane: 5.0 vol%), and sufficient analgesia has to be guaranteed by supplemental application of opioids. Otherwise, the general rules with respect to performance of Minimal Flow Anaesthesia can be applied.

Premedication

In the usual way, no procedure specific requirements

Induction

- Preoxygenation
- Intravenous application of a hypnotic
- Supplemental intravenous application of an opioid: 0.1-0.2 mg fentanyl, 0.5-1.0 mg alfentanil
- If needed, muscle relaxation
- Endotracheal intubation or insertion of a laryngeal mask
- Connecting the patient to the rebreathing system

Initial high flow phase

- Duration about 10 minutes, depending on the anaesthetic agent and the patient's constitution
- 1.0 L/min oxygen
- 3.0 L/min air
- Vaporiser setting:
 - isoflurane 2.0-2.5 vol%
 - sevoflurane 3.0-3.5 vol%
 - desflurane 6.0 vol%

Setting of the alarms

- Inspired oxygen concentration: lower alarm limit 28-30 vol%
- Disconnect alarm: lower alarm limit 5 mbar below peak pressure
- Minute volume monitoring: lower alarm limit 0.5 L/min below nominal value
- Inspired volatile anaesthetic concentration:
Upper alarm limit
isoflurane: 3.5 vol%
sevoflurane: 5.0 vol%
desflurane: 10.0 vol%

Reduction of the fresh gas flow rate

- 0.3 L/min oxygen
- 0.2 L/min air
- Vaporiser setting:
isoflurane 5.0 or, if possible, 6.0 vol%
sevoflurane 5.0 vol%
desflurane 8.0 vol%)

Emergency and Recovery

- Switch off the vaporiser 10 min prior to the end of the surgical procedure
- Maintain a fresh gas flow rate of 0.5 L/min
- Lead patient to spontaneous breathing by manual ventilation, SIMV, or PS (ASB)
- Wash-out anaesthetic gases with 5.0 L/min of pure oxygen 5 min prior to extubation
- Give patient postoperative care according to the generally used scheme

The procedures with respect to all alterations of the anaesthetic gas composition or of the anaesthetic depth are similar to those already given by the standardized scheme of Minimal Flow Anaesthesia with nitrous oxide.

43. Standardized concept for Closed System Anaesthesia

Initial remarks

In Closed System Anaesthesia the fresh gas flow rate is reduced to its absolute minimum. Halothane and enflurane hardly can be used as inhalation anaesthetics as the individual uptake of these agents is as high that the amount of anaesthetic vapour, which maximally can be supplied into the breathing system, will, generally, not meet the needs. Even if isoflurane is used a desired expiratory concentration of 1.2 vol% in most of the cases hardly can be maintained. Due to its low individual uptake and the high maximum output of the agent specific vaporiser Desflurane is ideally suited for this anaesthetic technique

Premedication

In the usual way, no procedure specific requirements

Induction

- Preoxygenation
- Intravenous application of a hypnotic
- Supplemental intravenous application of an opioid:
0.1-0.2 mg fentanyl, 0.5-1.0 mg alfentanil
- If needed, muscle relaxation
- Endotracheal intubation or insertion of a laryngeal mask
- Connecting the patient to the rebreathing system

Initial high flow phase

- Duration about 10 minutes, depending on the anaesthetic agent and the patient's constitution
- 1.0 L/min oxygen
- 3.0 L/min air

Or alternatively:

- 4.0 L/min oxygen

- Vaporiser setting:
isoflurane 2.0-2.5 vol%
sevoflurane 3.0-3.5 vol%
desflurane 6.0 vol%

Setting of the alarms

- Inspired oxygen concentration: lower alarm limit
28-30 vol%
- Disconnect alarm: lower alarm limit 5 mbar below peak pressure
- Minute volume monitoring: lower alarm limit 0.5 L/min below nominal value
- Inspired volatile anaesthetic concentration:
Upper alarm limit
isoflurane: 3.5 vol%
sevoflurane: 5.0 vol%
desflurane: 10.0 vol%

Reduction of the fresh gas flow rate

- 0.2-0.3 L/min oxygen
- Vaporiser setting:
isoflurane 5.0 or, if possible, 6.0 vol%
sevoflurane 8.0 vol%
desflurane 10.0 vol%)

Emergence and Recovery

- Switch off the vaporiser 10 min prior to the end of the surgical procedure
- Maintain a fresh gas flow rate of 0.5 L/min
- Lead patient to spontaneous breathing by manual ventilation, SIMV, or PS (ASB)
- Wash-out anaesthetic gases with 5.0 L/min of pure oxygen 5 min prior to extubation
- Give patient postoperative care according to the generally used scheme

Alterations of the fresh gas composition

Inspiratory oxygen concentration declines to the lower alarm threshold

- Increase oxygen flow by 100 mL/min (applies only if an oxygen / nitrogen mixture is used as carrier gas)

Increasing anaesthetic depth with long time constant

- When desflurane is the anaesthetic agent, use can be made of the high maximum output of the vaporiser.
- When sevoflurane or isoflurane are used a further increase of the fresh gas concentration is impossible. To increase the amount of anaesthetic delivered into the breathing system needs to increase the fresh gas flow rate to 0.5 or even 1.0 L/min.
- When the desired depth of anaesthesia has been achieved, the vaporiser setting is left unchanged at its maximum but the flow rate again is reduced to 0.2-0.3 L/min. Further alterations of the fresh gas concentration have to be made according to the clinical needs.

Decreasing anaesthetic depth with long time constant

- Maintain fresh gas flow rate at 0.2-0.3 L/min
- When desflurane is used reduce the vaporiser setting to 1.0-3.0 vol%
- When sevoflurane or isoflurane is used close the vaporiser
- When the desired depth of anaesthesia has been achieved, set vaporiser according to the clinical needs

Rapidly increasing or decreasing anaesthetic depth with short time constant

- Set vaporiser to the desired inspiratory concentration
- Increase fresh gas flow to 4.0 L/min (1.0 L/min O₂, 3.0 L/min air, or alternatively 4.0 L/min O₂)
- When the desired depth of anaesthesia is achieved, usually in about 5 min, re-establish again a low fresh gas flow rate of 0.2-0.3 L/min O₂
- Set desflurane vaporiser to a value between 4-12 vol%, or the sevoflurane or isoflurane vaporiser to a value between 3-8 vol% respectively. Further alterations of the vaporisers setting according to the clinical needs.
- Alternative option for increasing anaesthetic depth rapidly: intravenous injection of supplementary doses of hypnotics or opioids

Gas volume deficiency: decrease of the peak pressure and the minute volume

- Replenish the anaesthetic gas reservoir by short-term increase of the fresh gas flow
- Check for leaks
- If leakage persists: increase the fresh gas flow to 0.5-1.0 L/min and change over to Minimal Flow- or even Low Flow Anaesthesia

44. Recommended further reading

J. A. Aldrete, H. J. Lowe and R. W. Virtue (eds.)
Low Flow and Closed System Anesthesia. Grune & Stratton,
New York 1979

H. J. Lowe and E. A. Ernst
The Quantitative Practice of Anesthesia. Williams & Wilkins,
Baltimore 1981

G. H. Meakin
Low-flow anaesthesia in infants and children. Br J Anaesth
1999; 83: 50-57

J. A. Baum
Low-flow anesthesia: Theory, practice, technical
preconditions, advantages, and foreign gas accumulation.
J Anesth 1999; 13: 166-174

J. A. Baum
Low Flow Anaesthesia. The Theory and Practice of Low Flow,
Minimal Flow and Closed System Anaesthesia. 2nd edition.
Butterworth-Heinemann, Oxford, 2001

J. A. Baum
Nitrous oxide: Use in low-flow systems / economics.
In: Tonner PH, Scholz J (eds.) Use of Nitrous Oxide in
Anaesthesia. Baillière's Best Practice & Research.
Clinical Anaesthesiology 2001; Vol. 15, No. 3: 377-388

J. A. Baum and H. J. Whoelck
Interaction of inhalational anaesthetics with CO₂-absorbents.
In: Conzen P (ed.) Toxicity of Anaesthetic Agents. Baillière's
Best Practice & Research. Clinical Anaesthesiology 2003;
Vol. 17, No. 1: 63-76

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