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Review

Historical vignette – The Mapleson G, an original pediatric anesthesia circuit

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Abstract

A previously unpublished pediatric anesthesia circuit is presented here. It was invented and constructed by Dr Bernard-François Gribomont (hence called BFG circuit) around 1965 as a response to the important pediatric case load in the university hospital of Lovanium, near Leopoldville (now Kinshasa, DRC). The original objective was to find a simple solution that would enable the manual ventilation (assisted or controlled) of young children during ENT surgery, remaining very close to the child to reduce dead space while at the same time keeping far enough away from the surgeon in order to avoid obstructing their work.

It includes a short coaxial single piece circuit devoid of any mechanical valve connected to an in-line fresh gas ventilation bag; it does not fit into any existing Mapleson category. Hence, the authors propose to classify it in a new Mapleson G class. Its main advantages are conceptual simplicity, inherent safety, very low dead space accounting for minimal rebreathing and thus reduced fresh gas flow, small size and weight, and ease of use even during prolonged manual ventilation in small children. Its main drawback is difficult scavenging of expired gases. For logistical reasons it was abandoned in the nineties but could be of renewed interest in low-income countries.

Keywords: **Anesthesiology/instrumentation, pediatrics, pulmonary ventilation, Mapleson.**

Introduction

Origin and rationale of the design

This original accessory breathing circuit was invented and constructed by Dr Bernard-François Gribomont (hence the usual acronym of BFG circuit) around 1965 when he was the only anesthesiologist in the university hospital of Lovanium, near Leopoldville (now Kinshasa) the capital of the young Republic of Congo (now Democratic Republic of Congo). Pediatrics provided one-third of the surgical activity of that hospital.

The main goal was to find a simple solution that would enable the manual ventilation of young children during ENT surgery, remaining very close to the child's airway to reduce dead space to a minimum[1,2] but staying far enough away from the surgeon in order to avoid obstructing their work.

The inventor opted for a coaxial concept where dead space is reduced to the tubing volume downstream from the outlet of the fresh gas conduit. The circuit had also to allow the child to breathe spontaneously and to revert easily to manually assisted or controlled ventilation using a standard breathing bag.

At the time neither pulse oximetry nor capnography were available. As the patient's chest and face were draped for ENT surgery, it was of utmost importance to observe the child's respiration visually when the child was breathing spontaneously, by monitoring the movement of a breathing bag.

In the working conditions prevailing in Lovanium in the 1960s (and still today in many places in Sub-Saharan Africa) sudden failure of the fresh gas source was not a rare event, making manual ventilation and inhalational anesthesia

impossible. In such circumstances, the system still allows for spontaneous breathing at zero fresh gas flow, due to a very small total dead space (including both expiratory and inspiratory limbs) and minimal resistance to the entrainment of room air through the opening of the expiratory limb. Total dead space must therefore be inferior to the tidal volume of a small child[1,2].

We describe here the original device as it was conceived in Lovanium and developed in the university of Louvain (UCLouvain, Belgium) after the inventor returned from the Congo.

In this paper, the term BFG device refers to the piece of equipment allowing for gas exchange. The term BFG system or circuit will refer to the device assembled with its breathing bag, itself connected to a source of fresh gas able to carry a halogenated anesthetic vapor. The term distal refers to the patient side and the term proximal to the side of the fresh-gas inlet, where the anesthetist is ventilating the patient.

Material requirements

The material had to be chemically resistant to anesthetic vapors (initially diethyl ether, chloroform and halothane), nitrous oxide, solvents such as ether, detergents, disinfection solutions such as methyl, ethyl or isopropyl alcohol, chlorhexidine and Dakin hypochlorite solution.

The device had to be unbreakable and impossible to kink, translucent or transparent to see the mist of the expired breath, it had to be easily washed and sterilized. It should neither provoke allergic reactions nor skin lesions due to rough surfaces or acute angles.

Last but not least, it had to be made of materials that were available locally at that time. Correct size tubing used for Extra Corporeal Circulation was used for the outer tube and a rectal tube for the inner tube, both made of polyvinylchloride. The latter expanded end allowed for a tight fit inside the outer tube. They were assembled with xylol glue, a solution that effectively "melted" both tubes together and made them definitively inseparable. The drawback of this solvent is that it needed several months of degassing to lose its pungent smell before the device could be used.

Design requirements

For the sake of simplicity and safety, the device had to be made of one single piece or at least without any loose or removable parts. The patient end must fit to a 15 mm diameter standard endotracheal tube connector or facemask connector without close contact between that connector and the outlet of the fresh gas conduit (red in figure 1 drawings). To avoid facial lesions and undue traction on the endotracheal tube, it had to be lightweight without exterior sharp edges. It had to be fool-proof, e.g. would not allow assembly errors like inverting patient- with fresh gas- connections. It had to feature smooth inner surfaces without blind volumes, to avoid the build-up of patient secretions.

Description of the Mapleson G (BFG) pediatric anesthesia circuit (Figure 1).

This description is based on measurements made on two existing examples of the original BFG.

The device is basically a short rigid coaxial circuit made of two concentric pieces of tubing. The 1.5 mm thick outer tube measures 220 mm in length with an external diameter of 22 mm at the fresh gas (proximal) connection and 18 mm at the patient's (distal) end. Its inner diameter is 12 mm at the fresh gas inlet and has a slightly conical outlet at the patient end to tightly fit a standard 15 mm diameter connector. At its proximal end the external tube fitted a standard 0.5 L latex breathing bag with gas flow inlet and a 20 mm diameter semi-flexible outlet connector.

The initial 77 mm of the proximal part of the outer tube (called here after the handle) is enlarged, to provide a good grip for the anesthetist. A side hole is located 7mm from the distal end of the

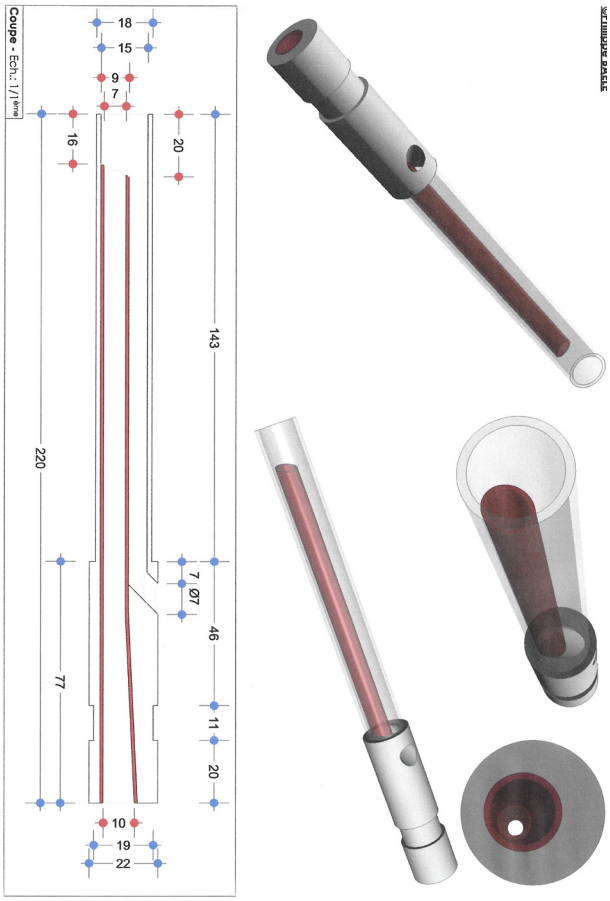


Fig. 1

handle. The hole is 7 mm in diameter and bored at a 45° angle connecting the expiratory conduit to the atmosphere and allowing for the thumb to occlude it when needed. At its distal end the outer tube has a diameter of 18 mm.

The inner tube, or fresh gas conduit (red in figure 1), is 16 mm shorter than the outer tube. The 1mm thick tube is narrower at its distal end than at its proximal end. Proximally, its outer diameter is 12 mm and 9 mm at its distal end. Its inner diameter is similarly tapered from 10 to 7 mm within the handle. It is glued inside the proximal (fresh gas) portion of the outer tube; its distal tip ends 16 mm from the end of the outer tube and is bevelled so it never touches nor occludes the endotracheal tube connector whose maximum length is 15 mm.

The inner tube forms the exclusive inspiratory conduit. The space between the outer and the inner tubes up to the side hole of the handle forms the exclusive expiratory conduit. Only the small volumes of the endotracheal tube connector plus the few mm of the outer tube facing the bevel of the inner tube could be considered as potentially shared between inspiratory and expiratory conduits under normal utilization conditions, i.e. with some fresh gas flowing into the system. The fresh gas conduit volume is 7 ml and the expired gas conduit about 7.5 ml.

Based on the above dimensions it can be calculated that, when the device is not connected to the breathing bag and both its orifices are open, the total resistance through the expiration channel is 6.5 times smaller than through the fresh gas conduit. This is a purely theoretical situation because under normal circumstances a breathing bag is always connected to the proximal end and some gas flow adds to the resistance through the fresh gas conduit.

Both ends of the device have different external diameters so that the breathing bag cannot be fitted the wrong way around (i.e. at the patient end).

A modern version has recently been produced (see last chapter). Its detailed dimensions are shown in figure 2. Figure 3 features both original and modern versions of the device.

Using the BFG

The pediatric anesthesia BFG accessory breathing circuit was designed for children up to 15 or 20 Kg. Without its balloon, the total gas volume of the device is less than 15 ml, divided approximately equally between fresh gas and expiratory conduits. The fresh gas flow should be set to inflate the breathing bag sufficiently, whilst avoiding over-inflation at the end of expiration. This can be further adjusted by partially occluding the exhaust orifice using a thumb or a piece of tape. Controlled or assisted ventilation can be achieved by intermittently occluding the exhaust outlet a fraction of a second before squeezing the breathing bag with the other hand during inspiration. Removing the thumb just before interrupting bag compression permits spontaneous expiration without rebreathing. Such a simple coordination between both hands is easy to acquire and soon becomes intuitive. Gradual occlusion by the thumb enables the inspiratory assistance needed by the child to be adjusted breath by breath. The expiration orifice is left completely or partially open during spontaneous ventilation. Reducing

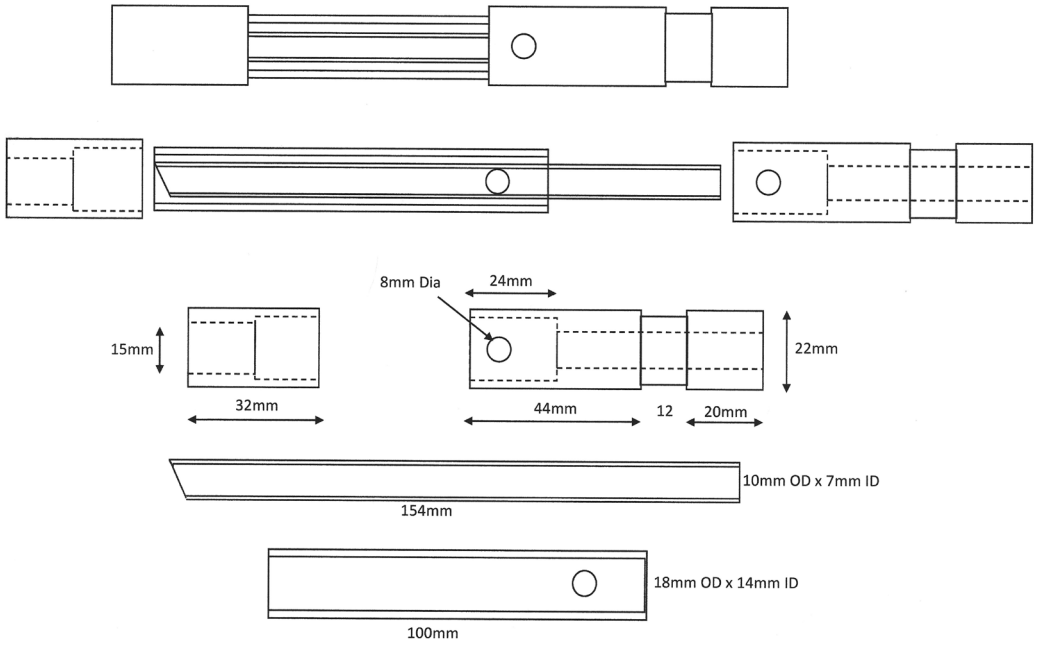


Fig. 2

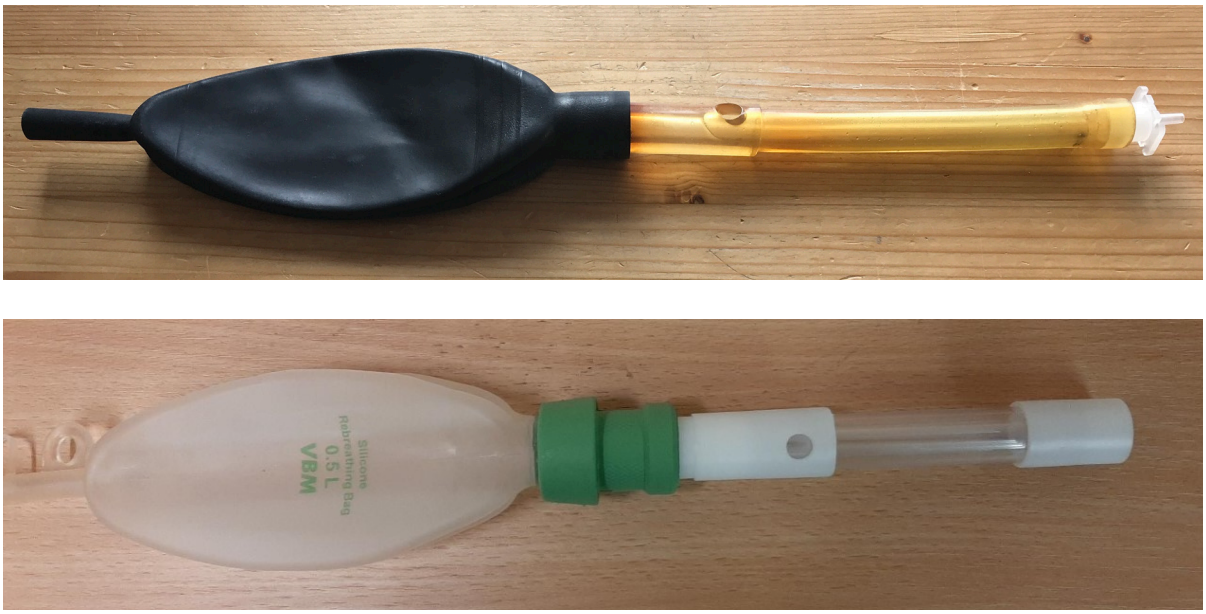


Fig. 3

the expiration orifice provides some CPAP in the circuit. The intrinsic safety provided by direct child-to-anesthetist connection is the main feature of the BFG circuit.

ENT surgery is often associated with upper airway reactivity and/or anomalies. Therefore, many anesthesiologists prefer to keep a child in spontaneous ventilation during the initial phase of induction for ENT surgery. The BFG system allows inhalational induction and quick changes in the concentration in oxygen and halogenated agent. Increased inspiratory pressure can be applied immediately in the event of laryngospasm.

An alternative breathing system was chosen because the circle breathing systems available at that time unduly prolonged induction and soda lime supply was unreliable (and still is in most low-income countries). The main safety concern with all alternative circuits comes from accidental occlusion of the expiratory limb[3-5]. This is impossible with the BFG device unless the anesthesiologist himself falls asleep while keeping his thumb on the exhaust orifice.

Checking the system[6] before use is a short and straightforward procedure. The fresh gas supply is checked by feeling gas flowing out of the incoming tube. The fresh gas source is then connected to the tail of the breathing bag, ensuring that it fills correctly and without leaks when occluding (using both thumbs) the distal and the exhaust orifices of the BFG. Finally, the anesthetist checks that the expiration conduit is free by removing the thumb from the exhaust orifice.

Discussion

Classification, a new Mapleson – G – circuit ? Figure 4

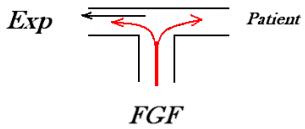
TIn the BFG, the breathing bag is an in-line part of the afferent circuit, an exclusive and mandatory passage of the fresh gas flow. This is a unique feature among all described accessory breathing systems[7-10].

Provided fresh gas flow exceeds the child's minute volume the breathing bag of the BFG circuit only contains fresh gas at any phase of the respiratory cycle, in spontaneous as well as manually controlled or assisted ventilation. So, inspired oxygen and halogenated vapor concentrations are expected to be identical to those in the fresh gas supply entering the breathing bag. The absence of fresh gas dilution by expired gas accelerates anesthesia induction and emergence3.

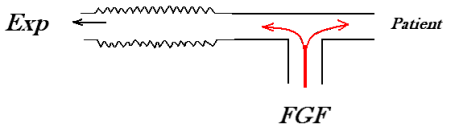
This makes it totally different from the Mapleson B, C, D and F breathing systems (including Jackson-Rees modification of Mapleson F circuit with the exhaust orifice at the tail of the bag or Kuhn's with a side-hole in the breathing bag)[11-13].

Nor can the BFG circuit be compared to the Ayre's T piece (with or without expiratory limb prolongation) or Mapleson E circuit because the BFG allows for manually assisted or controlled ventilation. To allow for controlled ventilation Ayre's T piece and E circuits must be occluded during inspiration, a modification of their original design which increases rebreathing.

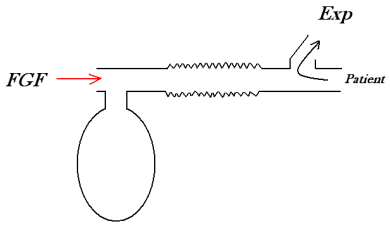
Unlike Mapleson A, B, C, D, Bain's or Lack's breathing systems the BFG circuit has no mechanical valve; instead, the anesthesiologist's thumb controls the opening of the orifice located



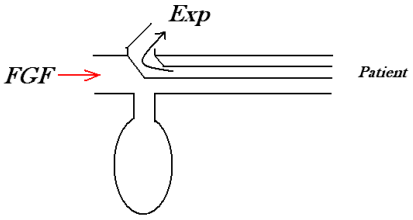
Ayre's T piece



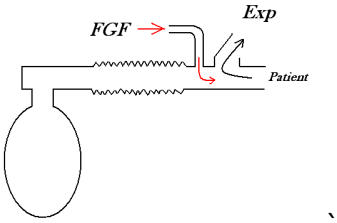
Ayre's T piece with corrugated tubing



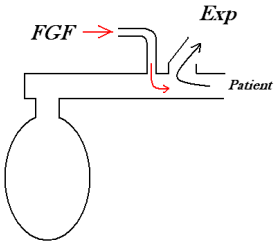
Mapleson A, Magill attachment



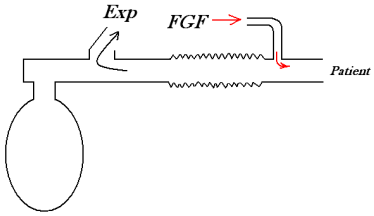
Lack, modified Mapleson A



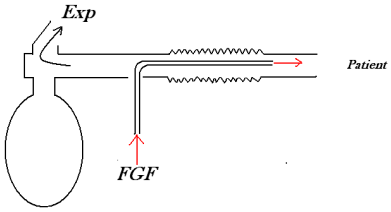
Mapleson B



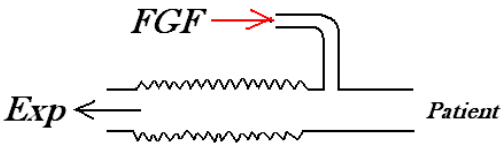
Mapleson C



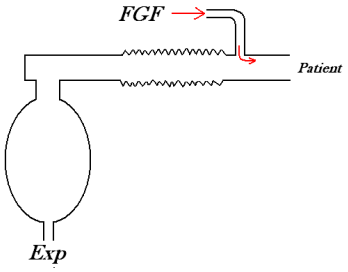
Mapleson D



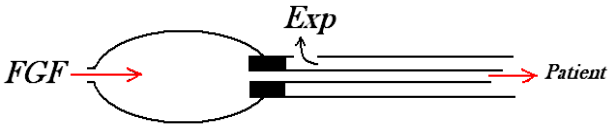
Bain, modified Mapleson D



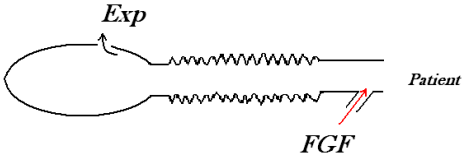
Mapleson E



Mapleson F, modified Mapleson D



BFG circuit, proposed as Mapleson G



Kuhn (Jackson-Rees), modified Mapleson F

Fig. 4

in the handle (part of the exclusive expiratory conduit), hence controlling the inspiration-expiration rhythm and pressures.

Last, as exhaled gases never reach the BFG inspiratory limb, and as it allows for manually controlled ventilation, it may neither be considered a variant of the Magill's or Mapleson A circuit.

The BFG circuit utilizes the principle of the coaxial Bain circuit, i.e. to position the inflow of fresh gases at the edge of the endotracheal tube connector, as close to the patient as feasible. The Bain's circuit has sometimes been described as a modification of Mapleson D system, with a major difference, however, as the Bain circuit drastically reduces the chances for expired gases to reach the breathing bag. An interesting property of the coaxial design is that the fresh gas flow coming out of the inner tubing produces some resistance to expiration thus providing some CPAP into the circuit itself. Although this property was not taken into account when the BFG system was designed, it is currently considered important to prevent atelectasis due to loss of CRF induced by general anesthesia.

However, there are also important differences between the BFG circuit and Bain's. First, the BFG is a totally open circuit where the driving force comes from an excess of fresh gas while the Bain circuit has been mainly used as a (long) part of a closed, circle circuit including a CO2 absorber. Bain's circuit has also been used as a coaxial Mapleson A circuit, which also includes a mechanical valve. Second, both inspiratory and expiratory channels of the BFG device are rigid and very short, precluding any effect of tubing compliance on patient ventilation.

The anesthetist's thumb plays the role of a calibrated valve, featuring a real time breath-to-breath adaptability that no mechanical valve can provide. The expiratory and fresh gas channels are strictly separated and cannot be confused; incidents such as those initially described with Bain circuits (kinking or disconnection of the fresh gas hose) are impossible: accidentally mixing expiratory gases with fresh gas flow is impossible with the BFG circuit. Finally, the respective dimensions of inspiratory and expiratory channels are such that the resistance to flow is considerably higher in the inspiratory conduit; this leads to largely preferential inspiration and expiration through the expiratory conduit in case of fresh gas failure, hence preventing expiratory gas build-up in the breathing bag under such circumstances.

Going back to earlier Miller's definitions[7,9,14], the BFG circuit is certainly neither a junctional nor an efferent reservoir system (where the reservoir branches off the expiratory limb of the system), nor is it technically speaking a Miller afferent system because the reservoir does not branch off the fresh gas circuit, but fresh gas passes through it, therefore preventing any backflow into the bag.

Having no valve, the BFG system has no moving part and is made as one single piece, in addition to the breathing bag. If it basically acts like on-line non-rebreathing valves, it shares none of their possible safety issues[3]. So-called downstream and upstream leaks are under exclusive control of the anesthetist's thumb: the absence of moving parts prevents such dysfunctions. Errors of assembling are intrinsically prevented by the difference between proximal and distal outer diameters of the device.

The fresh and exhaust gas circuits being made of rigid materials, the absence of compliant materials like corrugated tubing, the absence of adjustable spring exhaust valves, the only compliance left in the BFG circuit resides in the breathing bag, allowing for the anesthetist's hand to have at any one time a perfect feel of the child's thoracic and airway compliance during controlled ventilation, giving an immediate feeling of the child's respiratory strength or inspiratory attempts during assisted ventilation, allowing for perfect timing and complementarity of inspiratory support with each inspiratory movement of the child. The so-called "educated hand" becomes reality, a concept widely criticized because in other circuits large intermediate volumes distort the hand feeling when squeezing the breathing bag[15].

For all the above reasons, the BFG circuit fits in none of the original Mapleson categories, nor does it qualify as their Lack, Bain, Jackson-Rees or Kuhn offspring. We shall therefore propose to classify the BFG pediatric ventilation accessory circuit in a new Mapleson G category.

Limitations

There are some limitations to the BFG circuit: as in most pediatric inhalational induction circuits still in use today[16,17], scavenging of expired gas is impossible. Neither does the system provide heat or humidity to the fresh gas, and most of the time it requires two hands to achieve controlled or assisted ventilation.

A simple way to ensure scavenging of the expired gases is to tape a pediatric urine collector, itself connected to a scavenging system, over the expiratory orifice. However, in case of fresh gas failure such modification would no longer allow inspiration through the orifice and could induce an undesirable negative end-expiratory pressure and lung atelectasis.

Heat and moisture loss can be reduced by inserting a heat and moisture exchange filter between the circuit and the airway interface, thereby partially reducing the advantage of BFG's low dead space.

Two hands are required to adequately ventilate and get optimal coordination with a child's own breathing movements. This is particularly true at the end of induction, when the child reduces or loses its spontaneous ventilation, which means that the anesthesiologist must be assisted during that phase. Alternatively, tape could also be used to reduce the size of the exhaust orifice so permitting one-hand ventilation while holding the face mask with the other hand. Most anesthesiologists used to place such a piece of tape on the main shaft of the device before the start of induction, ready to be moved for that purpose. Partially occluding the BFG expiratory orifice with a piece of tape may also be useful during anesthesia maintenance: the added outlet resistance allows for limited-time one-hand ventilation during an uneventful surgical phase and if the patient is stable.

Leaving a child completely on his/her own breathing spontaneously during deep anesthesia is never a good option, no matter the circumstances or the circuit.

Follow-up

After Lovanium, the pediatric BFG system has been hand-made locally in UCLouvain academic hospitals in Herent and Brussels and used daily for nearly 20 years in a dozen Belgian hospitals affiliated to the French-speaking section of the Catholic University of Louvain (UCLouvain, Belgium). It was mainly used for induction of, and emergence from anesthesia but anesthesiologists often fell back to its use when neonates or small infants could not be adequately ventilated mechanically during intervention[1,2,18]. Typical examples were bronchospasms, sudden ventilation difficulties, major abdominal or thoracic procedures, difficult weaning from extracorporeal circulation, need to constantly adapt respiratory movements to surgeon's actions. The capacity to adapt breath by breath one's ventilation to the response of the child and to the needs of the surgeon was a major asset of the device. In many instances BFG ventilation could be safely maintained for many hours, without capnometry or blood-gas analysis evidence of rebreathing.

The BFG system fell into disuse at the end of the nineties because one of its components could no longer be found at the correct size, not for reasons of safety or ease of use. Although no photograph has stood the test of time, the device illustrated a popular children's book published in 1996 (figure 5). At the same time low-cost disposable Kuhn version of the Jackson-Rees modification of Mapleson F circuits became available and soon dominated the market. Unfortunately, this solution has been criticized[17,18] among other reasons because it is associated with higher end-tidal CO_2 readings, precluding prolonged manual ventilation. Moreover, using the circle circuit of modern ventilators to induce anesthesia became more and more popular. The use of so-called T-piece accessory breathing systems has been hotly debated for years, but only the most advanced and expensive anesthesia ventilators could already compete with manual ventilation in all circumstances. For reasons of cost, maintenance, or power supply stability, such machines will not be available before long to a large part of humanity[3,4,17,18].

The new version of the BFG circuit (Figure 2)

Anesthesia working conditions have not changed much over the years in low-income countries. Due to the cost of sevoflurane, halothane remains the main anesthestic vapor used for pediatric inductions in those countries. Inhalational induction is often administered through high flow Mapleson A or F accessory breathing circuits, even in high-income countries[16]. For these reasons the authors tried to resuscitate the BFG device. A British company (Diamedica UK Ltd, Grange Hill Ind Est, Devon) succeeded in producing a dozen prototypes made of rigid polycarbonate and Acetal Polyoxymethylene Copolymer resin. It is somewhat shorter (170 mm) than the original version, which gives an inspiratory volume of 5 ml and expiratory conduit of 7 ml, and a calculated inspiratory to expiratory circuits resistance ratio of 7.5. The low dead space remains the hallmark of the system. In the breathing bag, Silicone replaces Latex (0.5 L silicone VBM breathing bag without side-hole, ref 66 00 41 VBM Medizintechnik Sulz am Neckar Germany).

The industry could still improve models based on the general BFG design.

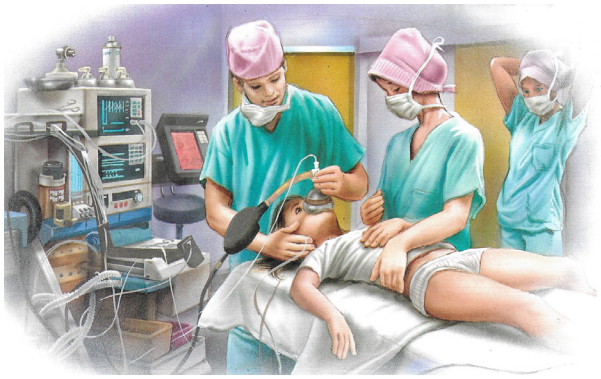


Fig. 5

A pilot study started in West Africa under supervision of Belgian anesthesiologists familiar with the BFG system. Initial experience showed that the optimal fresh gas flow was half that needed by the Kuhn-Jackson Rees circuit, thereby reducing oxygen and halothane consumption, and presumably operating room personnel exposure to halothane. Furthermore, end-tidal CO_2 was easier to maintain below 45 mmHg (6 kPa) as measured by in-line capnometry. Unfortunately, this study could not be brought to completion because the Covid-19 epidemic interrupted international travel.

Conclusion

A previously unpublished pediatric anesthesia accessory breathing circuit is presented here. As a short rigid coaxial device immediately connected to an in-line fresh gas breathing bag, and devoid of any mechanical valve, this so-called BFG circuit does not fit into any existing Mapleson category and therefore the authors propose to classify it in a new Mapleson G class. It also answers most critics addressed accessory breathing circuits. Its main advantages are conceptual simplicity, inherent safety, very low dead space accounting for minimal rebreathing, direct feeling of child airway resistance, small size and weight, reduced fresh gas requirement, and ease of use even during prolonged manual ventilation in small children. For historical reasons it has been abandoned in the nineties but could be of renewed interest, especially in low-income countries. It could be interesting to undertake comprehensive studies to document the clinical qualities of the new version of the Mapleson G system before proposing it for widespread use.

Conflicting interests: NBFG, FAV, BKK, YBK, PLB declare no conflicting interest.
RCN is an engineer working as Managing Director for Diamedica (UK) Ltd., a company working to develop safe anesthesia and respiratory solutions for limited resource settings.
BPW acts occasionally as unpaid scientific consultant for Diamedica (UK) Ltd.
Financing and financial interests: this work did not benefit from any financial support and devices presented here are presented without financial interest.

References

1. King MR, Feldman JM. Optimal management of apparatus dead space in the anesthetized infant. Paediatr Anaesth. 2017 Dec;27(12):1185-1192. doi: 10.1111/pan.13254. Epub 2017 Oct 17. PMID: 29044830.
2. Kerr AA. Dead space ventilation in normal children and children with obstructive airways diease. Thorax. 1976 Feb;31(1):63-9. doi: 10.1136/thx.31.1.63. PMID: 1257940; PMCID: PMC470363.
3. Cazalaà JB, Murat I, Servin F, Dalens B. Pour ou contre les circuits anesthésiques accessoires. I. Arguments pour leur utilisation [Pros or cons of accessory anesthetic circuits. I. Arguments for their use]. Ann Fr Anesth Reanim. 1998;17(5):372-84. French. doi: 10.1016/s0750-7658(98)80055-5. PMID: 9750768.
4. Bourgain JL, Feiss P, Beydon L, Nivoche Y. Pour ou contre les circuits anesthésiques accessoires. II. Arguments contre leur utilisation [Pros and cons of adding an accessory breathing system to the main circle circuit. II. Arguments against their use]. Ann Fr Anesth Reanim. 1998;17(5):385-91. French. doi: 10.1016/s0750-7658(98)80087-7. PMID: 9750769.
5. Safran D. Circuits anesthésiques accessoires: pour ou contre? [Accessory anesthetic circuits: pro or con?]. Ann Fr Anesth Reanim. 1998;17(5):359. French. doi: 10.1016/s0750-7658(98)80050-6. PMID: 9750763.
6. Otteni JC, Cazalaà JB, Beydon L, Bourgain JL, Dalens B, Feiss P, Nivoche Y, Servin F, Safran D. Circuits anesthésiques accessoires: vérification avant utilisation [Accessory anesthetic breathing systems: verification before use]. Ann Fr Anesth Reanim. 1999 Feb;18(2):243-8. French. PMID: 10207599.
7. Miller DM. Breathing systems for use in anaesthesia. Evaluation using a physical lung model and classification. Br J Anaesth. 1988 Apr;60(5):555-64. doi: 10.1093/bja/60.5.555. PMID: 3377931.
8. Mapleson WW. The elimination of rebreathing in various semi-closed anaesthetic systems. Br J Anaesth. 1954 Sep;26(5):323-32. doi: 10.1093/bja/26.5.323. PMID: 13199210.
9. Mapleson WW. Editorial I: Fifty years after--reflections on 'The elimination of rebreathing in various semi-closed anaesthetic systems'. Br J Anaesth. 2004 Sep;93(3):319-21. doi: 10.1093/bja/aeh197. PMID: 15304408.
10. Wenzel C, Schumann S, Spaeth J. Pressure-flow characteristics of breathing systems and their components for pediatric and adult patients. Paediatr Anaesth. 2018 Jan;28(1):37-45. doi: 10.1111/pan.13284. Epub 2017 Nov 17. PMID: 29148150.
11. Dorrington KL, Lehane JR. Minimum fresh gas flow requirements of anaesthetic breathing systems during spontaneous ventilation: a graphical approach. Anaesthesia. 1987 Jul;42(7):732-7. doi: 10.1111/j.1365-2044.1987.tb05318.x. PMID: 3631473.
12. Numa AH, Newth CJ. Anatomic dead space in infants and children. J Appl Physiol (1985). 1996 May;80(5):1485-9. doi: 10.1152/jappl.1996.80.5.1485. PMID: 8727530.
13. Chan AS, Bruce WE, Soni N. A comparison of anaesthetic breathing systems during spontaneous ventilation. An in-vitro study using a lung model. Anaesthesia. 1989 Mar;44(3):194-9. doi: 10.1111/j.1365-2044.1989.tb11221.x. PMID: 2495742.
14. Miller DM. Early detection of "rebreathing" in afferent and efferent reservoir breathing systems using capnography. Br J Anaesth. 1990 Feb;64(2):251-5. doi: 10.1093/bja/64.2.251. PMID: 2107865.
15. Spears RS Jr, Yeh A, Fisher DM, Zwass MS. The "educated hand". Can anesthesiologists assess changes in neonatal pulmonary compliance manually? Anesthesiology. 1991 Oct;75(4):693-6. doi: 10.1097/00000542-199110000-00022. PMID: 1928780.

16. Brands M et al. Waste gas scavenging during inhalational pediatric anesthesia in Belgium: results of a nationwide questionnaire. Acta Anaesth Belg 2018; 69, 211-216.
17. Von Ungern-Sternberg BS, Saudan S, Regli A, Schaub E, Erb TO, Habre W; SWISS PEDIATRIC RESPIRATORY RESEARCH GROUP. Should the use of modified Jackson Rees T-piece breathing system be abandoned in preschool children? Paediatr Anaesth. 2007 Jul;17(7):654-60. doi: 10.1111/j.1460-9592.2007.02228.x. PMID: 17564647.
18. Arnold P, Kaufmann J. Going around in circles. Is there a continuing need to use the T-piece circuit in the practice of pediatric anesthesia? Paediatr Anaesth. 2022 Feb;32(2):273-277. doi: 10.1111/pan.14331. Epub 2021 Nov 16. PMID: 34752679.

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