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Published in:
 Paediatric anaesthesia

DOI:
[10.1111/pan.13515](https://doi.org/10.1111/pan.13515)

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Document Version
 Publisher's PDF, also known as Version of record

Publication date:
 2018

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Barends, C. R. M., Yavuz, P., Molenbuur, B., & Absalom, A. R. (2018). Performance of blow-by methods in delivering oxygen to pediatric patients during transport: A laboratory study. *Paediatric anaesthesia*, 28(12), 1142-1147. <https://doi.org/10.1111/pan.13515>

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Performance of blow-by methods in delivering oxygen to pediatric patients during transport: A laboratory study

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Section Editor: von Ungern-Sternberg

Summary

Background: Providing supplemental oxygen with a blow-by method is used to provide additional oxygen to patients who will not tolerate an oxygen delivery device in direct contact with their face. Blow-by methods are often improvised from parts of standard equipment. The performance is very dependent on the distance to the face and the direction of the gas flow. Blow-by methods are used by anesthetists during transport but their performance in delivering supplemental oxygen has only been tested in static situations. The aim of this nonclinical study was to determine the performance of different blow-by methods in the delivery of additional oxygen to pediatric patients during transport.

Methods: A manikin of a child with a facemask of appropriate size was transported along a 60 m corridor from the operating theater to the PACU. Oxygen delivery to the face of the manikin was measured during transport. Six blow-by methods were tested with oxygen flows of 3, 6, and 10 L/min and with the facemask at 0 cm from the face and at 5 cm from the face. The outcome parameter was: blow-by method reaching and maintaining an $\text{FiO}_2 > 50\%$ during transport from the pediatric operating theater to the PACU.

Results: At 0 cm from the face, five out of six blow-by methods maintained a $\text{FiO}_2 > 50\%$ with all three flow rates. At 5 cm only two of the blow-by methods were able to maintain an $\text{FiO}_2 > 50\%$ and this only at flow rates of 10 L/min. All other blow-by methods provided lower FiO_2 s; in three, the FiO_2 decreased to values only marginally above 21%. The decrease in FiO_2 typically started within 6-12 m from the start of the transport.

Conclusion: It is concluded that the ability of blow-by methods to deliver a $\text{FiO}_2 > 50\%$ depends on the method used and distance from the face.

KEYWORDS

anesthesia, child, hospitals pediatric, hypoventilation, hypoxia, oxygen

1 | INTRODUCTION

Perioperative adverse respiratory events are common in children and are among the most frequently occurring adverse events encountered in the PACU (Postanesthetic care unit).¹ An episode

of hypoxia, defined as an arterial oxygen saturation $< 95\%$, has been reported to take place in approximately 5% of children on a PACU.²⁻⁴ These events can have severe consequences, and indeed, cause 44% of pediatric cardiopulmonary arrests in the PACU.⁵

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Among spontaneously breathing patients, hypoxia may develop during transport from the operating theater to the PACU.^{6,7} While it can be prevented by the use of pulse oxymeter monitoring⁸ and the provision of supplemental oxygen during transport,⁹ additional oxygen can be challenging to administer, as children who are unwell and/or emerging from anesthesia are often uncooperative and may not accept the application oxygen delivery devices in direct contact with their faces. Nasal prongs and face masks are often readily at hand in the operating room and can be used to provide high inspired oxygen fractions (FiO₂).¹⁰ Enclosure systems such as oxygen hoods or tents provide reliable and titratable FiO₂s but require specialized equipment and can be very noisy¹¹ and inherently restrict access to the child. An alternative approach is to transfer patients to the PACU before consciousness is regained, with airway and oxygen delivery devices still in situ. In our institution, this approach is not common practice because tracheal extubation of pediatric patients is considered a high risk process, with common complications and elevated risk of morbidity and mortality¹² and so, in the UMCG, extubation of pediatric patients is performed in the operating theater.

Anesthetists can choose to provide supplemental oxygen during transport using one of various blow-by methods. Over the years, health care professionals caring for children have devised a myriad of blow-by methods, comprising custom-made combinations of various parts of breathing circuits, tubing, and pressure-sensitive adhesive tape. Anesthetists have also used and devised similar blow-by methods and made informal recommendations on the best or worst ways of providing supplemental oxygen to postoperative pediatric patients with improvised equipment. Tests of some of these methods have been performed in PACUs and Emergency Departments and have shown that their performance varies greatly.^{13,14}

To date, the published studies have only involved testing of these methods in stationary situations. The performance of these devices when the patient is in transit is unknown. Movement of the bed through corridors creates airflow around the patient and around the blow-by method. We hypothesized that this airflow created by the movement of transport is likely to alter the FiO₂ delivered to the patient because it can cause the flow of oxygen to be redirected, thereby diluting the delivered oxygen, possibly causing unpredictable or suboptimal performance. But aerodynamics are not the only difference between stationary and mobile situations. During the transport of patients, anesthetists have to combine monitoring the patient with many other transport related tasks such as pushing the bed, avoiding other hospital traffic, and operating elevators and non-smooth transport also predisposes to the development of hypoxic events.¹⁵ Several studies have confirmed the high incidence of hypoxia among pediatric patients during transport.^{6,7,9} Given this high incidence and the likelihood of distraction from patient monitoring, it is surprising that anesthesiologists rely on improvised equipment based on anecdotal evidence to deliver oxygen to pediatric patients. In the current nonclinical study, we tested the performance of various methods of providing blow-by supplemental oxygen used in our institution and other Dutch University Medical centers. All methods used a face mask as a reservoir and, based on existing

What is already known

- Providing additional oxygen to pediatric patients using noncontact methods is often used but the efficacy depends greatly on the distance between the method used and the face of the patient. It is often used during transport of pediatric patients from the operating theater to the postanesthetic care unit.

What this article adds

- Noncontact methods to provide additional oxygen during transport generally perform poorly, and most methods do not provide an FiO₂ only marginally above that of room air.

literature, we tested their ability to provide at least 50% oxygen at a distance of 5 cm from the face of a child¹⁴ being transferred at normal walking speed on a standard pediatric hospital cot.

2 | MATERIALS AND METHODS

2.1 | Selection of blow-by methods

Interviews were conducted with pediatric anesthetists and anesthetic nurses involved in pediatric anesthesia at our hospital to select the blow-by methods and flow rates used during transport. Additionally, anesthetists involved in pediatric anesthesia from seven other Dutch academic hospitals were asked which blow-by methods they used in their hospital. Eventually six blow-by methods and three different flow rates were chosen. (Figure 1A-E)

2.2 | Model setup

A model of a child receiving supplemental oxygen en route to a PACU was developed using a manikin of a child in a standard children's hospital cot. A face mask of appropriate size (Medisize Aircushion w/ valve, size 0, Medisize bv Hillegom, the Netherlands) was used for all test runs. The methods that were tested are shown in Figure 1 (Figure 1A-E). For methods MVO (Mapleson set, Valve Open) and MVC (Mapleson set, Valve Closed), a Mapleson C breathing set (Medicare Oegstgeest bv, Oegstgeest, The Netherlands) was used with the face mask with the valve either completely open (MVO) or completely closed (MVC). For methods FNT (Filter No Tape) and FWT (Filter With Tape), a breathing filter (DARtm, Pediatric electrostatic breathing filter HME, small, Covidien, Mansfield, USA) was used, the oxygen tubing providing the oxygen flow was connected to the gas analyzer port for the test runs with methods FNT and FWT. With method FNT, the filter aperture opposite the facemask was left open. A piece of adhesive tape was taped over the filter aperture opposite the facemask in method FWT. TC (Tubing Connector) was a method where the oxygen tubing was connected directly to the facemask with a

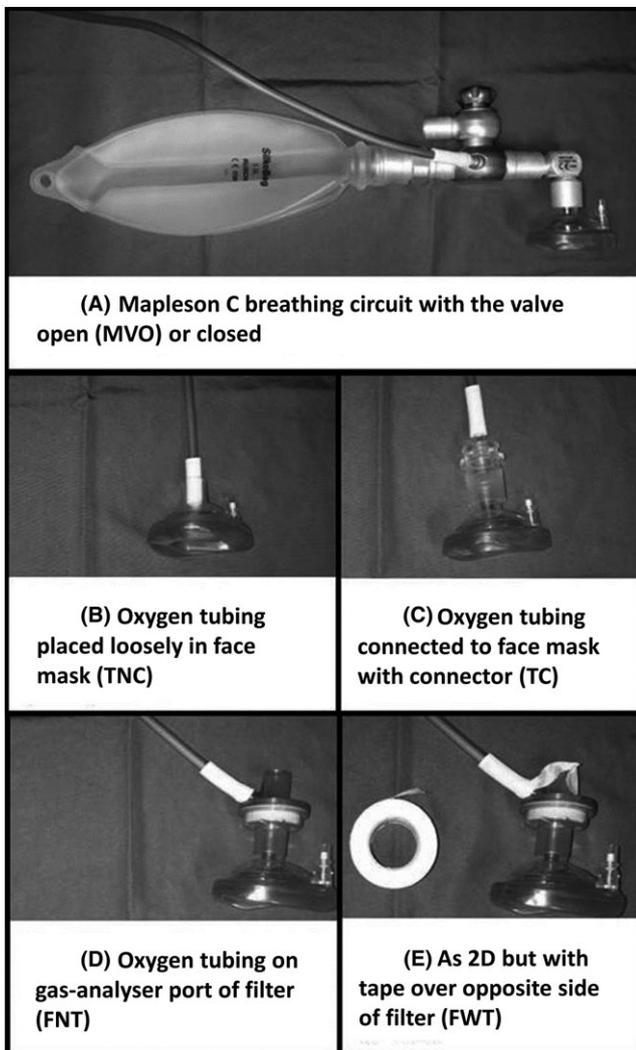


FIGURE 1 A-E, Tested blow-by methods

fitting tubing connector (connector, 22M/25F cannula, Intersurgical Wokingham, UK). Lastly for method TNC (Tubing No Connector), no connector was used, instead the oxygen tubing was placed loosely in the connector part of the breathing mask.

The manikin was placed in the recovery position with the nondependent arm extended to support the body and maintain lateral tilt. FiO_2 was measured using a MySign O oxygen sensor (Envitec-Wismar, Wismar Germany). The sensor's probe was placed directly adjacent to the manikin's oral aperture in the bed.

Markers were placed at 3-m intervals on the floor of a 60-m stretch of corridor, to assist the anesthetist with maintenance of a steady walking speed and to facilitate measurement of FiO_2 at 3-m intervals.

Testing of the performance of the methods presented in Figure 1 (Figure 1) was performed as follows. Each blow-by method was tested at three different flow rates (3, 6, and 10 L/min), and for each flow rate, with the delivery device 0 cm and 5 cm from the manikin's face (ie, six tests per device). This resulted in a total of 36 test runs. (Figure 3A-F and Figure 4A-F)

All test runs were conducted by a single anesthetist to maintain a constant walking speed. Before test runs were started, the FiO_2

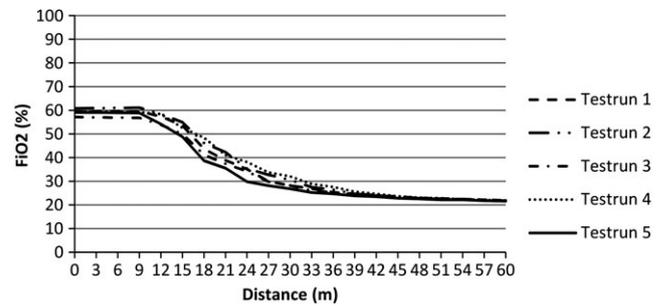


FIGURE 2 Precision test

was allowed to stabilize for every combination of method, flow rate, and distance to the face. Only when FiO_2 was stable in the stationary situation was a test run started. Test runs were undertaken in an empty corridor. When airflow was disturbed accidentally by door movements or passing of personnel not involved in the study a rerun was conducted under optimal circumstances. During the test runs, FiO_2 measurements, distance, and time were recorded for analysis. Walking speed was calculated subsequently from the time and distance data recorded.

2.3 | Precision testing

To verify reproducibility of the results five additional runs were performed with a single combination of method, flow, and distance. (Figure 2). For each of the five runs for this set up, we recorded the O_2 delivery at each 3-m marking point, and calculated the minimum and maximum recorded O_2 delivery at each point across the five runs.

3 | RESULTS

3.1 | Precision testing

The precision test confirmed the reproducibility of the results, (Figure 2). In the five precision test runs, the mean (SD) FiO_2 at the start of the five runs was 59.2 (1.06)% and the mean (SD) FiO_2 at the end of the five runs was 21.8 (0.11). The mean (SD) difference between the minimum and maximum measurements at each 3 m point was 3.55 (2.67)%. During all runs, there was a comparable decline in FiO_2 and for all precision test runs, the FiO_2 first fell below 50% between 15 and 18 m.

3.2 | Tests with different blow-by methods

The mean [range] time taken for all the runs was 40.2 seconds [38-44], with a mean [range] walking speed of 1.49 m/s [1.36-1.57].

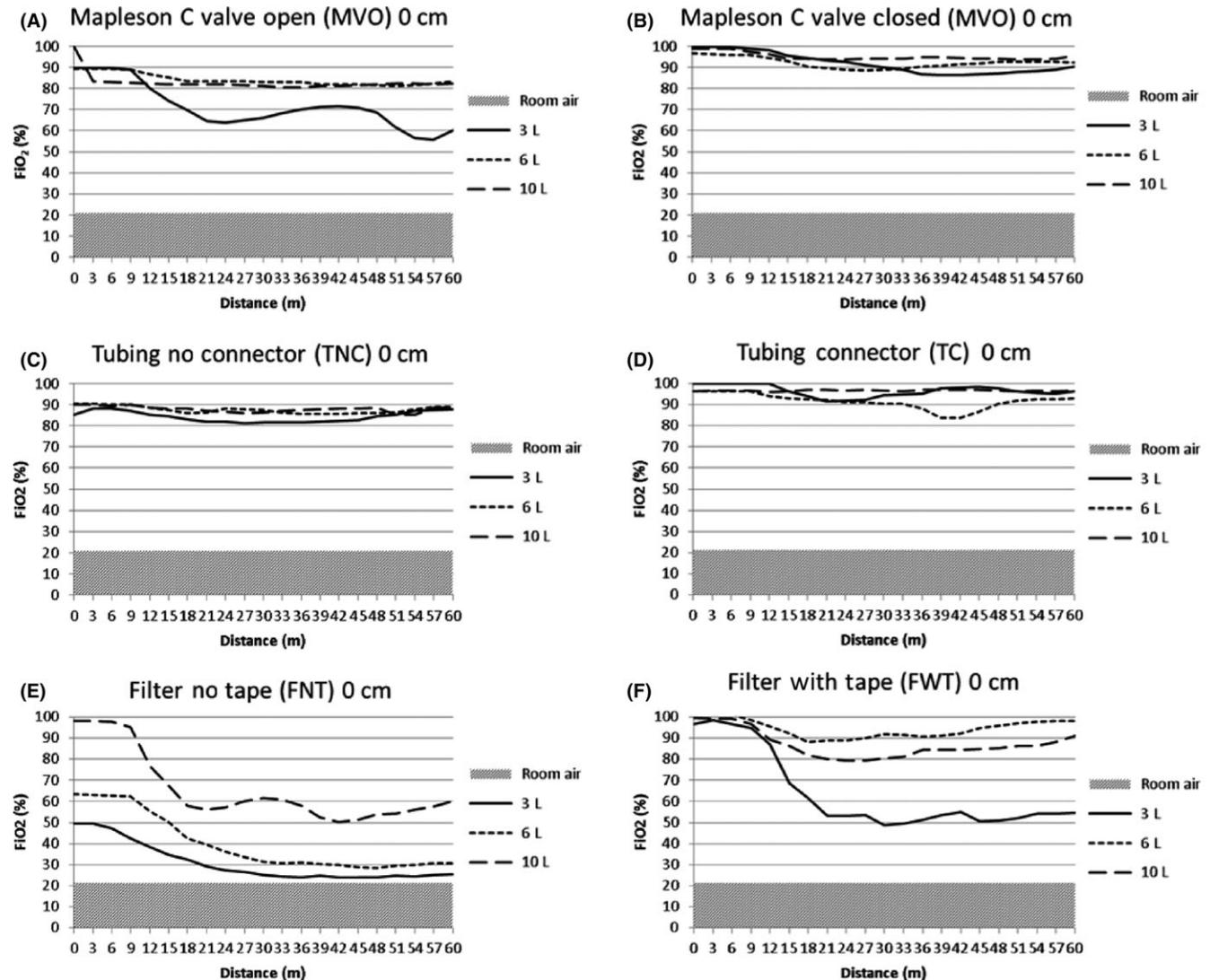
Table 1 presents the blow-by methods' performance of reaching and maintaining an FiO_2 of more than 50% throughout the entire test run at 0 cm and five from the face. At 0 cm distance from the face (ie, delivery device in direct contact with the face), all methods except FNT at flow rates of 3 and 6 L/min provided a high (>50%) FiO_2 during the whole run for all tested flow rates. (Figure 3A-F)

TABLE 1 Ability of different flow rates (L/min) to maintain FiO_2 above 50% at 0 and 5 cm distance for the tested wafting solutions

Method	FiO_2 maintained >50% Distance to Manikin	
	0 cm	5 cm
MVO	10/6/3	10
MVC	10/6/3	10
TNC	10/6/3	
TC	10/6/3	
FNT	10	
FWT	10/6/3	

FNT: filter no tape; FWT: filter with tape; MVC: Mapleson C system valve closed; MVO: Mapleson C system, valve open; TC: tubing with connector; TNC: tubing, no connector.

At 5 cm distance to the manikin's face only MVC and MVO provided a FiO_2 >50% but this was only at a high flow rate of 10 L/min. All other methods had lower FiO_2 s, regardless of the flow rate when used at 5 cm distance. (Figure 4A-F)

**FIGURE 3** A-F, Performance at 0 cm distance from the face

4 | DISCUSSION

Hypoxia after transport to the PACU in patients not receiving supplemental oxygen has been shown to be a common problem.^{6,7,9} Noncontact methods can be used by anesthetists to provide additional oxygen during transport. The aim of the current study was to evaluate the performance of different blow-by methods during transport from our pediatric surgical operating theater to the PACU. When used as noncontact methods at 5 cm distance only methods MVC and MVO reached and maintained a FiO_2 above 50% when used with a flow rate of 10 L/min. A distance of 5 cm was chosen to be a clinically relevant distance to the child's face. Larger distances will only further decrease the performance as demonstrated by Davies et al.¹⁴ Our findings correspond with the 50% FiO_2 limit they have also found in stationary situations at 5 cm distance using a face mask. More methods perform adequately at 0 cm (ie, in direct contact with the face) but this foregoes the purpose of noncontact blow-by methods as these are used for children who do not tolerate direct application of the mask to the face.

Using a blow-by method provides supplemental oxygen to children who are at risk of hypoxia because of hypoventilation. This risk arises because of the residual effects of anesthesia on pulmonary physiology (basal atelectasis, the resultant ventilation/perfusion mismatch, further reduced functional residual capacity) and may be compounded by pulmonary physiological characteristic of neonates and infants (higher oxygen consumption, higher closing capacity, and smaller functional residual capacity than adults). Provision of supplemental oxygen to these patients decreases this incidence of hypoxia during transport.⁹ There is however no literature on the optimal FiO_2 needed to significantly decrease the risk of hypoxia on arrival at the PACU and so ideally oxygen administration should be titrated to the child's need. Pulse oximetry has shown to be helpful in reducing the incidence of hypoxia during transport⁸ and should be used to monitor the effect of administered oxygen.¹¹

Methods MVO, MVC, TNC, and TC have non-obstructed gas flows. The use of the side stream gas analyzer port of a breathing filter (as in FNT and FWT) places a semipermeable obstruction (the filter component) in the airflow pathway and reduces the performance

even at 0 cm distance from the face. For FWT, it would seem that the complete obstruction on the opposite end created by the adhesive tape forces most of the O_2 toward the face yielding a higher FiO_2 . At 5 cm distance, however, these methods raise the FiO_2 only marginally above 21%. Furthermore, among all of the methods not able to maintain an FiO_2 above 50% over a distance of 60 meters, all failed to provide >50% oxygen beyond the 21 m mark.

Previous studies using static setups have shown how oxygen delivery performance of blow-by methods varies depending on flow rate, proximity to the child's face, device used, and angulation.^{13,14} These studies may be used to titrate the FiO_2 to the patients need as measured by pulse oximetry in static situations. However, this needs to be done with caution. During the measurements of our study, not only did we find a great influence of the headwind created by walking but we also found that during the time taken for the sensor to stabilize, it was important that personnel not move around the bed as this would almost invariably decrease the FiO_2 delivered. Only in a windless situation would the FiO_2 stabilize even in a static situation.

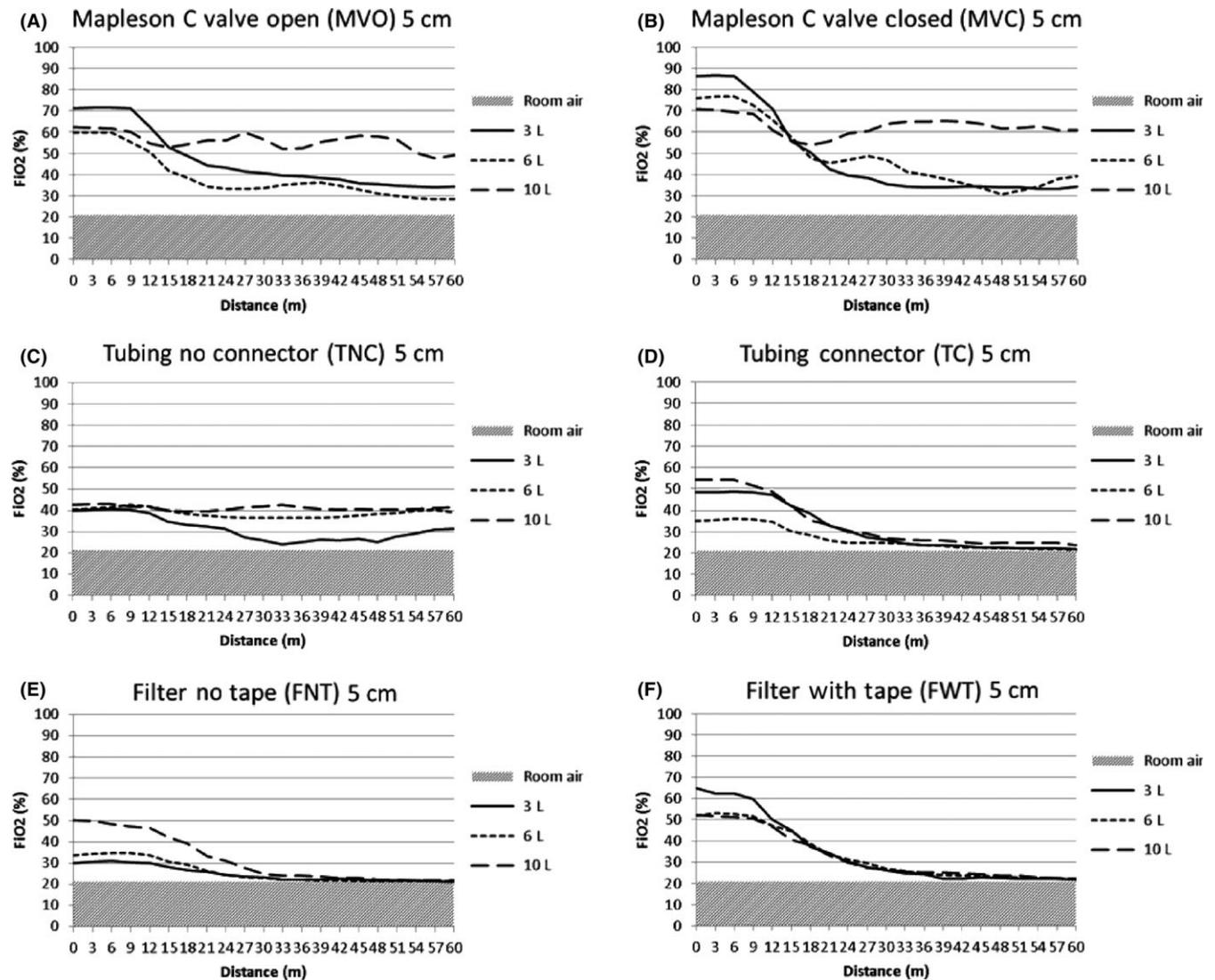


FIGURE 4 A-F, Performance at 5 cm distance from the face

Single test runs were used in this study. Preliminary runs confirmed our notion that due to the physical nature of this test and the constant test circumstances no coincidental results were to be expected. The formal precision test confirms this notion. The six tested methods are not the only possible combinations of equipment that can be improvised from pieces of equipment. Both the facemask and the bacterial filter are not intended for use as blow-by methods and the number of possible combinations of tubing, masks, and connectors is almost infinite. We limited our study to the systems mentioned in our interviews with pediatric anesthesiologists and anesthetic personnel. Davies tested three methods of providing supplemental oxygen and found that the use of a simple oxygen hose in the vicinity of the face was the most efficacious for short-term supplemental oxygen administration.¹⁴ This method is not used by the anesthesiologists questioned prior to this study. It is recommended in the literature to use a cup or face mask as a reservoir and this is considered by anesthesiologists in our institution to be a method useable during transport and in the PACU.¹¹ Davies also recommends the use of a face mask (as in the tested methods) as the system of choice for the non-attended infant because of the larger area with a significant rise in FiO_2 .¹⁴

The optimal FiO_2 for postoperative pediatric patients is unknown and depends on many factors. This study does not provide insight into the optimal method to prevent postoperative hypoxia during transport to the PACU. Many factors determine oxygen uptake and consumption and provision of high FiO_2 does not necessarily prevent hypoxia. Addition of high oxygen flow rates is also not an alternative to vigilance and monitoring since it does not guarantee adequate ventilation and oxygenation. The relevance and significance of our results is that they show that during transport the FiO_2 from a given method applied prior to departure can be far less than expected. For children depending on supplemental oxygen, this may mean that they do not receive the needed FiO_2 while en route to the PACU. For some of the methods we studied, it is questionable whether the increase in FiO_2 is of clinical significance since after only a few meters of transport it was close or equal to that of room air.

Flow rate and distance from the face are important factors determining the performance of blow-by methods. Even flow rates of 10 L/min do not reliably maintain an FiO_2 of more than 50% for many blow-by methods at 5 cm from the child's face. Flow rates of 3 L/min can only be used when the blow-by method is placed directly in contact with the patient's face. Anesthesiologists should be aware of the limitations of these methods and use a blow-by method that will provide a sustainable FiO_2 of 50% or more.

ETHICAL APPROVAL

No ethics approval was obtained: this study did not involve humans or animals.

CONFLICT OF INTEREST

The authors report no conflict of interest.

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How to cite this article: Barends CRM, Yavuz P, Molenbuur B, Absalom AR. Performance of blow-by methods in delivering oxygen to pediatric patients during transport: A laboratory study. *Pediatr Anesth*. 2018;28:1142-1147. <https://doi.org/10.1111/pan.13515>