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PERSPECTIVE

Going around in circles. Is there a continuing need to use the T-piece circuit in the practice of pediatric anesthesia?

Abstract

Anesthetic equipment, including breathing circuits, has evolved over time. The T-piece circuit, in its various forms, was designed to meet the needs of its time. As equipment and techniques have moved on, it is timely to consider the place of the T-piece in modern pediatric anesthetic practice. Today the circle system is a ubiquitous part of anesthesia. When integrated with a modern anesthetic machine it offers precise control of ventilation together with continuous monitoring of airway pressure and flow: but at the cost of complexity. In comparison the T-piece offers a simple cheap lightweight design, so ergonomic in use that it almost becomes part of the anesthetist: but lacks the control and the barriers to unsafe use of more sophisticated systems. In addition, it requires high fresh gas flow adding to cost and environmental pollution. This pro-con debate discusses whether there remains a case for continuing to use the T-piece circuit in preference over other options. Possible indications for the T-Piece are discussed together with alternative strategies. The limitations of the circle system, the T-piece, and other alternative (such as self-inflating resuscitator bag) are discussed with respect to pediatric anesthetic practice.

JK: When I finished medical school in 1997 and started my residency in anesthesiology, at the University Hospital of Cologne, I had my first and last contact with T-piece in anesthesia. Most of the operating theaters, including the ENT theater, were located in separate buildings. At that time, it was the usual procedure to transfer children still endotracheally intubated from theater to the post-anesthetic care unit (PACU) and for extubation to be performed by PACU nursing staff. A "Kuhn-System," comparable to Jackson Rees System, was used during transfer and in PACU until extubation. It allowed the PACU staff to immediately ventilate the intubated child. The perceived advantage, of transferring the child still intubated, was to allow the anesthetist to return more rapidly to the operating theater and began anesthesia, for the next child, before the first child was extubated. Complications such as laryngospasm, apnea, or severe coughing were frequent, and the consultant anesthesiologist in charge of the theater and the PACU often had a busy job. Additionally, since children were often transferred to the PACU still exhaling large amounts of Halothane, the elder colleagues told me that I would be tired at the end of each day working in the ENT theater. Their predictions were right. Shortly thereafter, standard of practice was changed, due to the high rate of complications in the PACU, and patients were extubated prior to leaving the operating room. This removed the need for use of the T-piece in PACU or during transfer. I never saw a T-piece in anesthesia again.

After I finished my specialist training in anesthesia, I started an additional residency in pediatrics medicine. Residents were in charge of our own delivery room and six others in hospitals without an attending pediatrician. In these external hospitals, there were two types of respiratory equipment—a self-inflating valve resuscitator bag and a T-Piece modified to allow adjustment and measurement of inspiratory and expiratory pressure. Especially for the non-pediatric specialist, such a T-piece makes it easier and more reliable to apply long inspirations with a definitive inspiratory pressure and PEEP as recommended by guidelines. To be honest, this is almost impossible to provide with a self-inflating bag or an unmodified T-piece with manually applied inspiration pressure. However, this application of the T-piece is very different from anesthesia since no volatile anesthetics are involved, and adjustable measured airway pressure is applicable.

PA: The T-piece, and its history, followed me through my initial years of practice. As a registrar, I worked at Newcastle General Hospital in the city where Philip Ayre first described the use of a T-piece circuit with continuous gas flow in pediatric practice. An "original" T-piece in a wooden frame was mounted on the department seminar room wall. Later, and ever since, I have worked at Alder Hey Children's Hospital in Liverpool: the department now named in honor of Gordon Jackson Rees. The innovations made by both individuals were major steps forward in the anesthetic care of children and designed to address specific problems of their time. Dr. Ayres was providing care for small children undergoing repair of cleft palates. His patients were spontaneously breathing with an endotracheal tube.[1,2] His original paper describes the problems of inadequately anesthetized children with respiratory distress and hypercapnia. This was consequent on poorly designed anesthetic circuits and the use of a simplified circuit with a low dead space and resistance greatly improved this situation. Twenty years later, Dr. Jackson Rees[3] was

addressing a different set of problems. Advancements, such as neuromuscular blockers and positive pressure ventilation, were reducing peri-operative mortality in adults and, together with others, he recognized the advantages of applying these techniques to children. This allowed the development of major surgery in small infants and later cardiac surgery and intensive care. The image of such pioneers we have today is that they disappeared into their workshops with a few tools and emerged with finished devices. The truth is that these innovations were born of clinical need, of a deep understanding of science, and of methodical application.

Just as the challenges faced by Jackson Rees were different from those faced by Philip Ayre, the challenges we face today are again different. Does the T-piece, and its modifications, still have a place in modern pediatric anesthetic practice? It would be uncommon today to have a child breathing spontaneously throughout a cleft palate repair, and the quality of mechanical ventilators available avoids the need to provide manual positive pressure ventilation for long periods. The circle system has become the ubiquitous means of providing anesthesia and improvements in design mean it is suitable for even the smallest infants. I would argue that while the role of the T-piece is reduced it remains a valuable tool and would identify three principal indications:

1. For assessment of the airway and respiratory compliance when access to the chest is limited
2. For provision of positive airway pressure via a facemask to a child with laryngospasm in the recovery room
3. For inhalational induction in an uncooperative child

In addition, the ergonomic design is an advantage to the single-handed anesthetist while its simplicity makes it a circuit of last resort in the face of failure of more technologically advances equipment.

Dr. Kaufman, to address the third of my indications. When using a circle for gas induction how do you optimize its use to ensure a smooth induction?

JK: I have never observed or conducted an inhalational induction using a circuit other than a circle. At the beginning, these machines were quite simple, but all provided an ability to scavenge excessive gas. Contamination of the theater air due to the higher flow required during induction was therefore minimized, although still polluting the wider environment. With modern machines, we use pressure support ventilation as soon as possible, including during the phase of induction. This enables optimal ventilation with defined and limited pressures and avoids inflation of the stomach. Nevertheless, high flow rates are still necessary for a quick and smooth induction while using a circle system. An inspiratory air flow of 4 L/min is enough although frequently 8 L/min is used, and the APL valve should be set in the lowest position before fully open to apply some PEEP. However, this technique of inhalational induction solely works if the face mask is firmly applied to the child and fully tightened from the surrounding. Applying the mask firmly to the face frequently irritates anxious children and sometimes traumatizes them. I know a few children old enough to talk about their experiences, who after such an induction preferred a needle for the next occasions.

The big difference is that as soon as the child is asleep, the fresh gas flow can be markable reduced. Even with the oldest machines from the 1970s, under the condition of a well-sealed airway, low-flow anesthesia was possible. A vigilant conductor, closely observing the air bag reservoir and carefully adapting fresh gas mix via the air flow tubes, could even use this as a functionally closed circuit. Today we are more aware of environmental pollution and carbon dioxide footprint of our practice. In addition, reducing anesthesia gas consumption as far as possible will reduce costs.

This leads on to my next question. A feature of the t-piece, especially the traditional and widely used variant with an open-ended bag, is that it is difficult and usually ineffective to attempt to scavenge anesthetic vapors. The high gas flows required to use a T-piece will inevitably lead to the release of greater quantities of vapor. This increases cost and adds to atmospheric pollution. How do you attempt to limit this?

PA: I think we have just discovered another important difference in practice. When I, and my colleagues in Liverpool, perform a gas induction we often do not always apply the face mask closely to the child's face. In a more anxious child, we will often start with the face mask 1–3 cm away or with the end of the circuit within a cupped hand. As the child becomes sedated the mask is tolerated better and we bring it closer. This can be performed with either a T-piece or a circle: it is necessary to partly occlude the end of the bag or tighten the APL valve slightly to direct the gas flow toward the patient. It may also be necessary to use higher flows. Often staff, and parents who may be holding the child, will smell some vapor. I think you do not use this technique, feeling that the resultant occupational exposure is not acceptable. We find it a useful approach with selected children.

However, we are all sensitive of the need to reduce pollution from anesthetic gases. Local effects, within the operating suite, can be reduced by use of scavenging and use of lower fresh gas flows. Most of the local pollution occurs during induction and after extubation, and higher levels of volatile are often recorded in the recovery room rather than in the operating theater. High flows will be required during inhalational induction which ever circuit is used, and scavenging is less effective due to leakage around the face mask. If I use a T-piece for induction, which I usually reserve for less cooperative smaller children, I change this rapidly for a circle once the child is asleep. The advantage of the T-piece during the first part of the induction is ergonomics, a lighter circuit with fewer connections, and the "trick" of using the bag itself to distract the child. Once established on the circle the fresh gas flow can be reduced to minimal levels rapidly.

The effect of volatile agents on greenhouse gas effect is frightening and I am sure will lead to large changes in our practice in the next few years. I am far from convinced that the choice of anesthetic circuit for relatively short periods of time will impact greatly on this.

A number of modification, to the t-piece, have been proposed with the objective of scavenging waste anesthetic gases and removing them from the immediate environment.[4] The most widely available, commercially produced system uses an APL valve, with a

scavenging connection, placed between a closed ended bag and the rest of the circuit. The "simplest solution" is to place the open end of the bag within the scavenging tubing: though active scavenging would be required. All these solutions will make the circuit more cumbersome and distract from the ergonomic advantages of a T-piece. It is the opinion of the author that in clinical use they probably offer only a small advantage in reducing local pollution. Much of the pollution will be from leakage at the face mask or in the patients' expired breath. The best way to reduce pollution is to use a circle system and to confine use of the T-piece to situations in which it has a clear clinical advantage. In poorly resourced situations, where a suitable circle system is not available such solutions may provide a means to reduce occupation exposure to anesthetic gases.

To move on, not all circles are the same. Over time anesthetic machines have evolved and improved. Working in well-resourced health systems today we are usually using well maintained and high-quality equipment. Older circles may have considerable disadvantages, including high resistance to airflow during spontaneous ventilation, large dead space, and high circuit compliance (which combined with absent spirometry may lead to inadequate ventilation). Components such as pressure relief valves require maintenance and calibration. Do you think your experience has been influenced by working in a setting where you have the best equipment to hand? What circuit is the best for use in all situations and what is the minimal standard one should demand?

JK: The problem with older circle systems is that they are not sufficiently able to automatically support, or even just passively allow, sufficient spontaneous respiration in smaller children with higher respiratory rates. It is obvious while using older machines that infants get restless, and respiration is insufficient when children breathe spontaneously but need support. The limitation is not the circuit system itself but its ability to detect and support the breathing.

With such outdated machines, support therefore must be manually provided by synchronized squeezing of the bag, which needs some sense of rhythm and training. However, there is still a fundamental advantage besides being more environmentally friendly while comparing to a T-piece: pressure and flow are measurable. The inertia of the system is mainly attributed to detection of patient's inspiration and the mechanical answer of the machine. This generally cannot be provided adequately by bag-in-bottle or comparable systems. In Germany, we observed a tendency in the last years that cheaper circle systems with outdates technique were bought to save money. This is a short-sighted decision.

The development of a fast-circulating air flow in the circuit of newer systems (eg, "Blower ventilation technology") is more efficient in supporting high spontaneous respiratory rates. With additional enhancements of electronical steering and monitoring combined, it is possible to automatically support even extremely low birth weight infants (ELBW) during induction and termination of anesthesia and this should always be used. It can be observed during daily clinical routine, supporting even ELBW infant with respiratory rates of 80/min. They become better ventilated, oxygenated, and observably calm down. The "connection" between machine and child does not make a difference, you can observe this effect with face mask, laryngeal mask, nasopharyngeal tube, or endotracheal tube. I am very convinced and believe you can even see it observing the patients that such modern machines are an improvement of safety and comfort for tiny patients. The costs of such investments in anesthesia equipment should never be considered in isolation. Many economists calculate the economic balance of an anesthesia department in isolation, but this is a very limited view. Safety issues must be prioritized. In the German health system, the care of ELBW infants is associated with substantial financial re-imbursement for hospitals. High quality, specialized anesthetic care plays a vital role in ensuring good outcomes for these children and I would strongly advocate that some of this money should be diverted to maintain standards of peri-operative care.

In resource-rich countries, the best available anesthesia equipment should be demanded. The ethical-moral and financial costs caused by a single ELBW with avoidable severe complications are much higher than the cost of several anesthetic machines. For sure, a back-up for the event of an emergent failed anesthesia machine is necessary and as such, a T-piece or a self-inflating bag might be an equivalently suitable device. The same is true for the transport between different units in a hospital might be true, if no higher equipment is available.

When the T-piece is used to deliver positive pressure, especially by less experienced personnel, it is difficultly to judge the actual pressure delivered to the patient.[5] Several papers have discussed the concept of the "educated hand" to describe this but these papers can be interpreted in both directions.[6-11] Personally, I do not really believe in the educated hand. This may be an example of the Dunning-Kruger effect where by individuals often overestimate their abilities, especially those who provide a low performance.[12] The expression "educated hand" at least acknowledges that individual abilities and expertise contribute to performance. It is impossible to judge the individual "hand on charge" and if I could choose, I would always prefer to rely on a modern machine to ventilate my child or myself. This seems closer to a standardized high level of care to me. If using the T-piece, how do you address these concerns?

PA: Misuse of any piece of anesthetic equipment can have disastrous results, that is a reason why we have highly trained and specialized anesthesiologists. The term "the educated hand" was first used by Henry Beecher in 1954[13] with respect to adult thoracic surgery. It describes an ability of the anesthetist to access the adequacy of ventilation and pulmonary mechanics by the feel of the pressure placed on the bag. The concept was later applied to pediatrics and "tested" in a series of bench experiments, with variable results. These experiments were flawed in that they aimed to remove other forms of feedback, including visual and auditory, which are relevant in clinical practice. A situation in which I use a T-piece goes back to my first indication. This is when restarting ventilation during cardiac bypass. I will use the spirometry and other monitoring on the ventilator, I will trust the APL valve on the circle system during recruitment procedures, but I will also use a T-piece to provide test breaths during which I watch the surgical field for lung movement and listen for an audible crackle indicating secretions.

A very interesting study compared the use of the T-piece to the circle during positive pressure ventilation via a facemask[5] and was conducted in actual patients. A larger increase in FRC after emptying the stomach was taken as evidence of gastric inflation. The improvement was greater when a T-piece, rather than the circle, was used by inexperienced staff. The implication is that the use of calibrated pressure valve on a circle system prevented inexperienced staff delivering higher pressures and inflating the stomach. This study did reveal a real limitation of the T-piece in the form currently used and has changed my practice. As pointed out in the accompanying editorial,[14] this does not negate the other advantages of the T-piece, and perhaps, the take home message should be the value of highly skilled anesthetic providers: perhaps a wiser investment than even the best anesthetic machine.

It is possible to modify the T-piece to give greater control and prevent the delivery of high inflation pressures. When we discussed scavenging the addition of an APL valve was discussed and when describing the use in neonatal resuscitation the use of pressure monitoring was mentioned. It should be noted that most APL valves are not calibrated for pressure and the blow off pressure may alter between circuits and at different flow rates.[15,16] Use of pressure monitoring, with or without an APL valve, will allow control of airway pressure and should be considered either as a routine or selectively when caring for more vulnerable patients.

To return to my three indications for use of a T-piece. We see use of a T-piece as an important part of our management of a child with laryngospasm or more generally upper airway obstruction, by application of continuous positive airway pressure. Even as a single operator with two hands I can partially occlude the outflow of the bag, apply pressure behind the angle of the jaw, lift the mandible forward and apply the face mask firmly to the patient's face. If the patient breaths there is no resistance from the valve, as would occur with a self-inflating bag. This is often enough to resolve the situation without the need to administer drugs. This is not possible with a self-inflating bag as the valve prevents spontaneous ventilation. While it is possible with a circle and anesthetic machine the simplicity and ergonomics of the T-piece means I do not need to look away from the patient and a T-piece can also be used wherever there is a source of high flow oxygen, including the PACU. We equip all our recovery bays and our transfer trolleys in this way for this eventuality. How do you manage this situation, especially when you are no longer near to a more sophisticated anesthetic machine?

JK: Primarily by avoiding this situation. In our hospital, extubation of children is done while still in a fully equipped theater. The child is transferred to the PACU only once stable, and we rarely see laryngospasms there. All children in the PACU have a working intravenous line. If laryngospasm, apnea, or inefficient breathing occurs, we use a self-inflating bag. If laryngospasm is apparent, a small bolus of propofol is immediately administered.

PA: I am going to press you a little on that explanation. In a child making, any respiratory effort a self-inflating bag is a very poor way to assist breathing. Airway problems are not always clear cut. In addition to laryngospasm, a child may have blood in the airway and obstruction due to residual effect of medications. I do not feel it always as simple as giving a little propofol and many of these events can be treated without need to administer further medications. Doctors make mistakes and are subject to other human factors. Transferring a patient too early will occasionally happen. A T-piece is simple, highly portable, and is suitable for both the spontaneously breathing patient being transferred to PACU and the ventilated patient being transferred to PICU. It provides an immediate means to deal with unanticipated airway and ventilation issues.

JK: Every single place in our PACU is equipped with a prepared and ready-to-use suction device and a self-inflating bag. The mask used in the theater is brought with the child and positioned near the patient's head. So immediate suctioning and ventilation is enabled. I agree that assisting spontaneous breathing is not so easy with self-inflating bags. But all the PACU personnel is well-trained and able to conduct this well and immediately if necessary. Most of them finished a special training in pediatric intensive care and anesthesia.

I have two final questions. Firstly, to use a T-piece for induction and then to change to a circle requires an auxiliary gas outlet on the machine. This seems an avoidable source of error, due to use of the wrong outlet. Secondly, do you attempt to humidify the inspired gas when using the t-piece?

PA: Of the three indications I listed for use of a T-piece, it is only induction which requires a separate fresh gas outlet. In other situations, the T-piece can be used with a separate oxygen/air source. This is a concern and I honestly do not have a very good solution to this. We occasionally have incidents, usually a child not going to sleep due to use of the wrong outlet. We have attempted to put in place operating procedures to reduce this and the warnings on the machines are clear, but human error still occurs.

We use heat moisture exchanges for every case but other than this no humidification. But as we are generally only using a T-piece for short periods this is not a major issue. The provision of humidification is an advantage of the circle system, especially at lower flows.

PA & JK: To sum up, the T-piece has a long history of use in a pediatric anesthesia. As technologies have improve, and our concerns have changed, the indications for use of the T-piece have become more limited. It is clear, however, that many pediatric anesthesiologists still find it a useful tool and we would agree that there is not a clear case to restrict the availability of the T-piece to these experienced practitioners. We would also suggest that when using the T-piece the user should ask if it is really the most appropriate circuit and would discourage its use for maintenance of anesthesia over a longer time. Beyond this, our views would diverge. Should we continue to produce anesthetic machines with an axillary fresh gas outlet? Should we be teaching the next generation of anesthesiologists, anesthetic nurses, and PACU nurses to use the T-piece or should we let its use die out with the current generation? JK has provided the highest quality of anesthetic care for many years without use of a T-piece. He would consider it unnecessary and the potential for harm from misuse in inexperienced hands, and the potential for error, mean the continued use is no longer justified. For PA, the use of the T-piece is still very much a part of everyday practice and its advantages out way the acknowledged drawbacks.

As a final word, a reason this is a topical subject today is the growing concern over pollution and the environmental impact of our

practice. To address these concerns will require a more considered and wider reaching approach than the choice of circuit to deliver volatile anesthetic gases.

Reflective questions:

1. What are the situations, if any, in which it remains appropriate to use a T-piece circuit?
2. How reliably can an anesthetist judge the pressure and volume of respiration by the feel of the anesthetic bag alone?
3. What is the potential role of the T-piece in the management of the child with laryngospasm and what are the alternatives?
4. Does the choice of anesthetic circuit impact on release of anesthetic gases into the atmosphere, with local and global effect?

DATA AVAILABILITY STATEMENT

No new data have been created in the production of this opinion article. A data availability statement has therefore not been included.

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anesthesia, airway, children/infants/neonates, equipment

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