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Equipment and Monitoring – What is in the Future to Improve Safety?

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Keywords: equipment, safety, human factors, education, training
Summary

There have been a number of recent developments in the practice of anesthesia and intensive care aimed at improving outcome both in terms of reducing morbidity and mortality, as well as other less defined factors, such as quality of service provision. Significant advances have been made in airway devices such as pediatric tracheal tube designs, Microcuff® tracheal tubes, and new laryngoscopes. Non-invasive monitoring devices, including continuous hemoglobin analysis and near infra-red spectrometry, are being increasingly used in pediatric anesthesia. Other, ‘scaled-down’ versions from adult anesthesia care, however, have not universally been shown to result in improved safety and outcomes in pediatric anesthesia.

The future for improving the safety in pediatric anesthesia may not lie primarily with new equipment and monitoring, but in the investment in good quality initial training followed by fostering an environment which encourages and supports continuing education and training in our specialty. This review spans the last decade with particular emphasis on its latter half.

Minimum Standard Monitoring

The introduction of the Harvard Medical School minimum standards for patient monitoring during anesthesia in 1986 was a milestone towards the improvement of patient safety. Almost a quarter of a century later these same seven principles (continuous presence of anesthesiologist/nurse anesthetist throughout the conduct of general and regional anesthesia, five-minutely blood pressure and heart rate monitoring, continuous electrocardiography, continuous monitoring of respiratory gases (for example inspiratory oxygen and expiratory end-tidal carbon dioxide and
monitoring of gas flows), continuous use of ventilator disconnection devices, oxygen
analyser and the ability to measure temperature) (1) are observed routinely in most
developed countries. Additions to the list include the monitoring of inspired/expired
volatile anesthetic agents and other anesthetic monitoring for certain specialized
surgeries. It seems logical that the development of new equipment and monitors
would lead to improved safety and patient outcome. The evidence base for this is,
however, limited.

The application of human factors to new developments in equipment and monitoring
to improve safety in pediatric anesthesia is not recent. The importance of human
factors in the establishment of an interaction between the patient and their
environment (anesthesiologists, surgeons, nurses, anesthetic machines, drug delivery
systems) is only now becoming more apparent. It is this feature of our relationship
with our surroundings that may represent the greatest area for development (2).

Equipment

Airway - Cuffed tracheal tubes
The cuffed/non-cuffed endotracheal tube debate has reached a climax with the
publication of the prospective randomized controlled trial by the European Paediatric
Endotracheal Intubation Study Group (3). This trial demonstrated that the use of
Microcuff® tracheal tubes is effective and safe in neonates and young children
although its routine use may be hard to justify (4). The clinician would consider using
such a tracheal tube when it is imperative to keep the number of tracheal tube changes
to a minimum, when it is essential to maintain a minimum leak and when superior
protection of the airway to foreign material is sought. Previous pediatric-sized
tracheal tubes were 'scaled-down', suboptimal versions of those used in the adult
population. This was especially true regarding the cuff design, and anything but short-term use has been a dominant focus of discussion within the pediatric anesthesia community for years. A tracheal tube, Microcuff® PET, with an anatomically designed high volume-low pressure tube cuff with a recommendation chart for tube size selection has recently become available and investigated in a large prospective randomized multicenter trial (2,246 children aged from birth to 5 years old). The results indicated that the use of cuffed tracheal tubes in small children provides a reliably sealed airway at cuff pressures of ≤ 20cmH₂O, decreasing the need for tracheal tube exchanges (2.1% versus 30.8%). There was no difference in the rate of post-extubation stridor compared with uncuffed tracheal tubes (4.4% versus 4.7%) (3). The availability of cuffed tubes (from ID 3.0 upwards) represents substantial improvement allowing particular surgeries, such as laparoscopic and thoracoscopic work, to be more easily achieved, without compromising patient safety.

The study however is only valid when the Microcuff® tracheal tube is used and the cuff pressure is limited to ≤ 20cmH₂O. No data are provided by the study regarding the rare long-term problems of tracheal intubation in general, for example laryngeal damage or tracheal stenosis, or its long-term use in the neonatal or pediatric intensive care unit environments. It is conceivable that they would be safe in these two settings but this remains unverified.

Purchasing costs remain a substantial consideration as well as the reported kinking of the Microcuff® tubes. The latter resulted in a Medical Device Alert by the UK’s Medicines and Healthcare products Regulatory Agency (MHRA) in September 2007 and a subsequent product recall by the manufacturer (5).
Airway - New laryngoscopes

There is an ever-increasing number of laryngoscope devices that assist in indirect visualisation of the larynx, such as rigid optical stylets and flexible fiber-optic scopes. Images from many of these devices may be enhanced by real-time video technologies (6). Many laryngoscope designs are extrapolated from adult practice. Pioneers appreciating the finer nuances of intubating a child have later added adaptations specifically directed to enhance pediatric use (6).

Airtraq®

The Airtraq® is an anatomically-shaped disposable optical laryngoscope which acts as a visual guiding system for either routine or complex airway intubation. Its high-definition optical system provides a magnified view during laryngoscopic procedures. It is available for pediatric and neonatal use.

Videolaryngoscopes

Most modern devices are indirect visualisation laryngoscopes, one of them being the Glidescope®. This uses a miniature camera to transmit an image to a small attached screen. The on-screen view of the larynx is equal to or better than that of direct laryngoscopy (7).

The Berci-Kaplan video laryngoscope with direct laryngoscopy uses conventionally shaped laryngoscopy blades which provide better views than direct laryngoscopy at the expense of time to intubation and may primarily be useful as a teaching tool for supervised direct laryngoscopy (8).

There are several case reports of the application of these devices advocating their use in the normal and difficult pediatric airway as well as rescue scenarios (9-11).
However, large prospective clinical trials comparing each device are currently lacking and their use depends on departmental preference and expertise.

Each new device requires familiarization and training with most studies reporting an increase in time to successful intubation (12, 13).

**Ventilation**

Breathing circuit compliance and fresh gas flow affect tidal volume delivered by traditional anesthesia ventilators in volume-controlled ventilation. A new generation of anesthesia machine ventilators addresses the problems of volume-controlled ventilation by adjusting for the fresh gas flow and for the compliance of the breathing circuit (14).

**Ventilators**

One study evaluated four anesthesia ventilator systems (Smartvent 7900, Avance, Aisys and Apollo ventilator system) to determine the accuracy of volume delivery to the airway during volume-controlled ventilation. It concluded that these newer generation systems were able to deliver small tidal volumes accurately to the airway under conditions of normal and low lung compliance during volume-controlled ventilation (14). So far, there are no outcome data to support any of the new airway or breathing devices in terms of improvement in patient safety.

There has recently been renewed interest in the cuirass ventilator as a means for alternative, non-invasive, ventilation in children. One such ventilator (the Hayek oscillator) has the benefit of being able to operate over a wide frequency range typically 8-999 cycles.min\(^{-1}\). Its other main advantage lies in the fact that it dispenses with most forms of upper airway instrumentation, but positioning of the cuirass over
the thorax and abdomen limits its intra-operative use to head and neck or limb surgery.
Unsurprisingly, specific pediatric data on such use are lacking.

**Pressure-support ventilation (PSV)**

Modern anesthetic machines provide the ability to ventilate using PSV. PSV has proven to be effective in eliminating the work of breathing associated with the tracheal tube, circuit and ventilator while also maintaining the patients spontaneous ventilation with supraglottic airway devices (15). A reduced intrathoracic pressure attenuates the effects of mechanical ventilation on cardiac output especially in neonates (15). However, safety and outcome studies are still missing.

**Circulation**

Irrespective of the method of induction, the majority of anesthetized children will end up with some form of intravenous access. This commonly takes the form of a peripheral venous cannula for the less sick child. However, numerous children will either present with central venous catheters in-situ or have them sited post-induction of anesthesia. There are many peripheral and central venous catheters available offering variously cited advantages from decreased incidence of infection to improved stability.

**Ultrasound (US)**

US is becoming widespread to guide the placement of lines for both vascular access and regional anesthesia.

US-guided central venous catheter (CVC) placement in children is associated with decreased number of anatomical sites attempted and decreased number of attempts to gain placement (16). It also decreased the number of inadvertent artery punctures. In
one study however ultrasound did not improve the success rate of CVC placement (16). These results are replicated by a review of the results from the Central Line Emergency Access Registry Database (16). However, this review did highlight a decreased number of total punctures per attempt. Ultrasound is not a new technology. It is merely the non-use of ultrasound for central venous and arterial catheter placement that is becoming more difficult to justify, as evidenced by the issuing of a guideline on technology appraisal by the National Institute of Clinical Excellence (NICE) in the UK which advocates the use of US technology for the placement of CVC’s where possible (17).

**Vein Viewer®**

The Vein Viewer® uses near-infrared light and other patented technologies to project a digital image of patient vasculature directly onto the surface of the skin in real-time thus providing assistance with, for example, difficult intravenous access (18). The Smartneedle and pdAccess are devices that consist of a hand-held monitor and single use needles designed to provide auditory US-guided access to arteries and veins during catheterization procedures (19).

**Safety Cannulae**

Needlestick injuries to patients and staff are an important health economic consideration (20). A range of ‘safety cannulae’ has been introduced into hospital practice without sufficient consideration to their suitability to pediatric and neonatal anaesthesia. The Vasofix® Safety and Introcan® Safety peripheral cannula devices incorporate a uniquely designed, tamper-proof self-activating safety clip which is housed in the hub of the cannula, activating automatically on withdrawal of the needle.
These are the cannulae of choice in well over a third of National Health Service (NHS) hospitals in the UK.

One prospective study revealed that there were significantly more total splatters or spills with new cannulae, when placed by attendings, but not when placed by trainees, potentially increasing the risk of exposure to blood-borne pathogens (21).

Interestingly, healthcare professionals, as opposed to patients, are most likely to be protected from inadvertent needlestick injury by the newer devices (22).

**Intraosseous needles**

Intraosseous infusion is well-established intervention to vascular access in pediatric emergencies but it is rarely used in routine pediatric anesthesia. One study has concluded that intraosseous access represents a quick and reliable alternative for pediatric patients with prolonged difficult or failed intravenous access after inhalational induction of anesthesia (23). Various intraosseous devices are available, from the manual system (Cook®) and the spring-loaded (Bone Injection Gun, BIG®), which inject needles to a preset depth, to the battery-powered devices that drill the intraosseous needle into the bone (EZ-IO®) (24).

**External cannula-fixation devices**

Intravenous infusion systems have become more reliable, especially at very low infusion rates which has particular importance for the very young patient (25). Fixation and post insertion care is important to reduce infection and unintentional displacement. An external device fixed to the skin called a StatLock® Arterial Pediatric Stabilization Device is now available. Its manufacturers claim a reduction of 49% in catheters needing to be replaced due to complications such as extravascular migration and phlebitis (26). An intravenous disinfection device for needleless
intravenous connectors called a SwabCap® has been developed due to the fact that many needleless connectors have hard-to-reach surfaces that make them difficult to properly disinfect, even when wiped for 15 seconds and then let dry fully (27). A proven outcome has been the prevention of CVC-associated bloodstream infections, by the introduction of care-bundles rather than the choice of central venous catheter itself. One study reported-a significant reduction in CVC-associated bloodstream infection rates through evidence-based prevention interventions, enhanced communication among caregivers, standardization of CVC insertion and maintenance processes, and empowerment of team members to enforce adherence to best practice (28). [INSERT TABLE 1]

_Regional anesthesia_

Regional anesthesia is now well established in pediatric anesthetic practice. Techniques in use to facilitate more accurate placement of needles or catheters include: [1] surface nerve mapping by transient electrical stimulation of the motor component of superficial peripheral nerves, [2] the use of ultrasound technology, [3] direct stimulation of the nerve roots via a reinforced catheter, or [4] continuous electrographic monitoring via a specially devised catheter (Tsui test) facilitating accurate placement of an epidural catheter introduced via the sacral hiatus (29).

One of the major concerns of continuous epidural blockade in pediatric regional anesthesia is the risk of catastrophic trauma to the spinal cord when inserting direct thoracic and high lumbar epidural needles in anesthetized or heavily sedated pediatric patients. Serious complications from epidural insertion are rare but detrimental for the individual (30). Traditionally anesthesiologists have focused research on a low lumbar
approach, threading the catheters in a cephalad direction. This can make optimal catheter tip placement difficult to access.

Two alternative approaches to this problem were reviewed; electrical epidural stimulation for physiological confirmation and segmental localization of epidural catheters, and US guidance for assessing related neuroanatomy and real-time observation of the needle puncture and, potentially, catheter advancement (31).

The epidural electrical stimulation test confirms epidural catheter placement through stimulation of the spinal nerve roots by low electrical current conducted through normal saline in the epidural space via an electrically conducting catheter. A major limitation is that this test must be performed in the absence of significant clinical neuromuscular blockade or local anesthetic in the epidural space.

US imaging can be an excellent tool to identify neuraxial structures in infants and children, especially as their epidural spaces are superficial and the posterior elements of the spinal canal are less ossified than those of adults. US imaging for regional anesthesia takes considerable time and effort to learn. Additional assistance is needed to hold the US probe during catheter advancement. There is still no evidence however that direct thoracic epidural placement can be performed or indeed improves morbidity compared to traditional insertion techniques.

Of all these methods, the popularity of US guidance in regional anesthesia is growing rapidly as it shortens the performance time, the onset time and the number of punctures to achieve peripheral nerve blocks in adults (32). A proven advantage is in reducing the volume of local anesthetic required, which is of huge benefit in small children where the toxic dose is often approached. Unlike in adults, no data on neurological complications following regional anesthesia are available in pediatric anesthesia. (33)
Monitoring

Airway

Pulse oximetry

Pulse oximetry is now considered mandatory during anesthesia in many countries, a standard endorsed by the World Health Organisation ‘Safe Surgery Saves Lives’ initiative. Recent developments have seen the introduction of additional features to standard pulse oximetry and include motion detection/rejection technology, perfusion index and pleth variability index (PVI). The perfusion index is intended as a surrogate marker for peripheral perfusion monitoring (34) whereas the PVI may be useful to predict fluid responsiveness non-invasively in mechanically ventilated patients. (35,36)

Continuous non-invasive hemoglobin measurement

A device has recently been developed which noninvasively and continuously measures the hemoglobin level in the blood - SpHb™. It is also able to give continuous readings for methemoglobin - SpMet®, carboxyhemoglobin – SpCO®, as well as the oxygen content SpOC™ (37, 38). This device is claimed to provide similar results when compared to those measured in blood samples obtained through invasive techniques (37). This technology currently comes at considerably additional expense. However, no data are yet available to support its universal use or whether this device improves outcomes in pediatric anesthesia.

Near infrared spectroscopy (NIRS)

NIRS may provide a real-time window into cerebral oxygenation. There are several reports showing improvement in patient outcomes with applied NIRS for cardiac
surgery (39). A recently-performed case series demonstrated that two-site NIRS monitoring accurately reflects situations in which poor clinical outcomes may occur when declining trends in somatic tissue oxygen saturations, StO$_2$, are not corrected (40). Other studies have concluded that patients who consistently exhibited low tissue StO$_2$ levels following an initial resuscitation had significantly worse organ failure than did patients with normal StO$_2$ levels (41). The current literature on the use of NIRS does not demonstrate improved neurological outcome (42). Although NIRS has promise for measuring regional StO$_2$, the lack of data demonstrating improved outcomes limits the support for widespread implementation. Despite shortcomings in the ability of NIRS technology to accurately reflect validated and directly measured parameters of systemic oxygen delivery and blood flow, NIRS can certainly assist in the detection of low-flow states and may help detect faulty insertion of vascular cannulae (43).

**Ventilation monitoring**

Infrared analysis can determine the inhaled and exhaled concentration of volatile anesthetics. The measurement of the end-tidal anesthetic agent concentration in conjunction with other data such as the age of the child, hemodynamic parameters and intravenous drugs already administered can be used to clinically judge if the child is sufficiently anesthetized. Propofol has some volatility, so it can be detected in expired breath of individuals receiving it via intravenous infusion (44). Sedating critically ill children with propofol has been associated with the propofol infusion syndrome, although its use in children for procedural sedation or for induction or maintenance of general anesthesia is relatively safe (45). How the concentration of propofol in exhaled alveolar gas (c$_p$G)
relates to the concentration of propofol in plasma \( (c_p)_{PL} \) during a constant infusion in children is not known. Their respective time courses in children of differing ages is also not yet known. Whether monitoring \( c_p \) will result in any outcome improvement by way of being able to predict \( c_p \) and subsequently assess the depth of anesthesia and likelihood of awareness has yet to be established. [INSERT TABLE 2]

**Cardiovascular monitoring**

The measurement of cardiac output under anesthesia can be performed by various techniques; indicator-based methods (pulmonary artery thermodilution, transpulmonary thermodilution, lithium and carbon dioxide dilution), bioimpedance (Electrical Cardiometry™), US-based methods, and continuous central venous oximetry (CeVOX). None of these technologies is new, but their pediatric application is with the United States’ Food and Drug Administration approving the use of such technology on adults, children and neonates.

There is, however, no evidence that the availability of these devices alters outcomes in pediatric anesthesia and studies validating the use of these methods in a variety of clinical situations are needed before they will be widely used in pediatric practice (46-49).

Cardiac output monitor development tends to progress from theory and animal models, via adult testing and clinical usage, to pediatric usage, rarely starting with the pediatric group in mind (50). This 'scaling-down' method of innovation together with the large variation in the size of patients is a major factor in the selection of a cardiac output monitor, imposed mainly by the size of the transducer and sensor used. Metabolic rate and consequent physiological changes are different in children which may not be factored into the equipment design. Small children, in particular, tolerate
blood samples less well than larger children and adults, which may again alter the
hemodynamics.

**Neuromonitoring and awareness**

**Brainstem auditory evoked potentials**

Brainstem auditory evoked potentials, very small electrical voltage potentials which
are recorded in response to an auditory stimulus from electrodes placed on the scalp,
are suppressed dose-dependently during anesthesia with a variety of general
anesthetics. A comparison between Bispectral Index (BIS), derived from the
electroencephalogram (EEG) and the composite A-line autoregressive index (cAAI)
derived from auditory evoked potentials and the EEG concluded that the cAAI and
BIS are suitable indicators of depth of hypnosis in children. No conclusion could be
drawn on a change in outcome (51).

**BIS and other EEG-based monitors**

BIS is a quantitative, easy-to-use method of objectively assessing depth of anesthesia
in children that does not require patient stimulation. It remains largely inaccessible
due to the perceived low benefit to cost ratio. The age and head size-appropriate
disposable strip placed on the forehead delivers a value which is a dimensionless,
empirically-calibrated number ranging from 100 in the awake, fully alert patient to 0,
representing an isoelectric electroencephalogram. BIS has been reported to improve
both anesthetic delivery and post-operative recovery, and to decrease the incidence of
intra-operative recall awareness (50, 52).
Wide ranges of BIS values in children may be explained by the fact that primarily adult data are used to derive the BIS index with substantial differences between the EEG of the adult and that of the child (53). The EEG in children during anesthesia is agent dependent and may differ between the hemispheres, potentially leading to the incorrect conclusion that the patient is adequately anesthetized (54,55).

Extrapolation of data from adults to children for neuromonitoring requires an in depth understanding of the physiology behind the data (56) and care should be exercised in their interpretation.

**Future Developments**

The future potential of the use of biological markers and real-time monitoring of plasma drug concentrations has yet to be realised. Biomarkers such as B-type natriuretic peptide (BNP) are of interest to anesthesiologists as BNP can both improve management of intensive care patients with respiratory failure and pre-operative risk assessment (57).

A study using a novel approach that combines two powerful proteomics techniques to identify patterns of potential biomarkers that change after cardiopulmonary bypass (CPB) has recently been published (58). This approach requires only 150µl of plasma per time point and can identify and provide quantitative information on 129 proteins/biomarkers. This may provide additional insight into the mechanisms responsible for CPB-related complications, particularly systemic inflammation. Through this it may be possible to enable preventative measures or treatments to be used during and after CPB procedures, to help reduce the systemic effects of CPB and improve the outcome of pediatric CPB patients.
The understanding of drug delivery to organs such as the brain has been hampered by the inability to measure tissue drug concentrations in real-time. What is needed is the development of a biosensor system capable of continuous, real-time measurement of molecules directly in complex, unprocessed plasma samples. This is not an easy task. Whilst real-time drug concentration monitoring is not yet present in anesthesiology it has been present for some years in other areas of medicine, particularly endocrinology. Several companies have developed and are now selling continuous glucose monitoring devices in the USA.

One study uses the promising Microfluidic Electrochemical Aptamer-based Sensor (MECAS) chip technology which allows the continuous real-time detection of the small molecule drug cocaine at near physiological, low micromolar concentrations directly in undiluted, otherwise unmodified blood serum (59).

This is an exciting area of on-going research and over the next decade only time will tell whether the development of real-time, point-of-care detection devices for a wide variety of molecular targets will ultimately improve outcome in pediatric anesthesia.

The Answer to Improve Safety in Pediatric Anesthesia - Education and Training

Anesthesiology was the first medical specialty to champion patient safety as a specific focus. The Anesthesia Patient Safety Foundation (APSF) was the first independent multi-disciplinary organisation (practitioners, equipment and drug manufacturers and many related professionals) created expressly to help avoid preventable adverse clinical outcomes, especially those related to human error. One of its three core aims is to encourage and conduct safety research and education (60).
As in other industrial domains, accidents and incidents in anesthesia are usually caused by a combination of organisational and operational factors. As many as 80% of adverse events are the result of human factors breakdowns such as poor communication, inadequate monitoring, failure to cross-check drugs and equipment, rather than lack of technical knowledge or equipment problems (61, 62).

Reducing the likelihood of such problems requires anesthesiologists to have an additional set of skills, known as Non-Technical Skills that are used integrally with medical knowledge and clinical techniques. These skills encompass, for example team working, communication, task management, leadership, situation awareness and decision-making. The Anaesthetists’ Non-Technical Skills, ANTS, system is a behavioural marker system developed by industrial psychologists and anesthesiologists and is the first non-technical skills framework specifically designed for anesthesiologists (61). This system is awaiting a fuller understanding of the in-operating theatre validity and reliability before it is recommended for formal summative assessment.

Technology in pediatric anesthesia is here to stay and is constantly evolving so it is paramount that we should adequately teach the limitations of current and new technologies that enter our field of practice (63). The solution lies in the integration of information we gain from technology together with a clear understanding of its limitations, plus a good grasp of physiology and pharmacology of anesthesia. Only then can we form a coherent picture of the patient’s status. Appropriate training, continuous education and extensive clinical practice, as well as avoidance of occasional pediatric practice, remain the best means to reduce both mortality and morbidity (64,65).
A safe anesthetic is not necessarily the most expensive one. This is recognised by the WHO, where its ‘Safe Surgery Saves Lives’ program is training a cohort of pediatric anesthesiologists in Chile, Tunisia and South Africa (66, 67). The World Federation of Societies of Anesthesiologists (www.anaesthesiologists.org) is working closely with the WHO to decrease mortality from surgery and anesthesia. The Children of the World Anesthesia Foundation, COTWAF (www.cotwaf.com) is another organisation that helps in the promotion and development of anesthesia for infants, children and future generations around the world.

It appears intuitive that the introduction of information technology (IT) will improve safety in pediatric anesthesia by virtue of the fact that for example, automated records, allow more time to spend providing direct patient care. Access to online up-to date information such as medical journals and textbooks may also aid decision making processes. Again, there is no evidence to suggest that this in itself improves safety in pediatric anesthesia.

Clinical simulators can create a wide variety of clinical scenarios, providing a valuable opportunity to review uncommon interventions to the experienced physician, or common interventions to the inexperienced physician in an environment without risk to patients. The Best Evidence Medical Education (BEME) Collaboration has reported that high-fidelity medical simulations are effective in the patient care setting (68). The American Board of Anesthesiologists is developing its simulation infrastructure and will incorporate simulation-based learning into its recertification programs, such as the Managing Emergencies in Pediatric Anesthesia (MEPA) course.

Education is time-consuming and costly. The future for improving the safety in pediatric anesthesia may not lie primarily with new equipment and monitoring, but in
the investment in good quality initial training followed by fostering an environment which encourages and supports continuing education and training in our specialty. Perhaps it is time to reconsider the focus for pediatric anesthesia?

Acknowledgements

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70. www.saferneedles.org.uk accessed 20th August 2010


Table 1: Recent equipment developments in pediatric anesthesia

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<td><strong>Airway</strong></td>
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<td>Microcuff®</td>
<td>Anatomically-designed high volume-low pressure tube cuff</td>
<td>(3,4,5)</td>
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<td></td>
<td>Large prospective randomized trial completed</td>
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<td>Videolaryngoscope</td>
<td>Glidescope® - miniature camera with an on-screen view of the larynx</td>
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<td></td>
<td>Berci-Kaplan videolaryngoscope provides better views than direct laryngoscopy</td>
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<td>Operates within a large frequency range 8-999 cycles.min⁻¹</td>
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<td>Dispenses with most forms of upper airway instrumentation</td>
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<td><strong>Circulation</strong></td>
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<td>Safety cannulae</td>
<td>Decrease incidence of needlestick injuries</td>
<td>(21,22,70)</td>
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<td>Vein Viewer®</td>
<td>Assists visualisation of difficult-to-see veins</td>
<td>(18)</td>
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<tr>
<td>Statlock®</td>
<td>An arterial pediatric stabilization device</td>
<td>(26, 27)</td>
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<td>Intraosseous needles – BIG and EZ-IO</td>
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Table 2: Recent monitoring developments in pediatric anesthesia

<table>
<thead>
<tr>
<th>Development</th>
<th>Description</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Airway</strong></td>
<td>Pulse oximeters: SpHb™, SpMet®, SpCO® &amp; SpOC™&lt;sup&gt;TM&lt;/sup&gt; with NIRS&lt;/br&gt;Continuous non-invasive measurement of blood Hb&lt;/br&gt;Also gives continuous readings of methemoglobin, carboxyhemoglobin &amp; oxygen content&lt;br&gt;Real-time window into cerebral oxygenation&lt;/br&gt;Improved outcome in cardiac surgery</td>
<td>(34,35,36) (37,38) (39-43)</td>
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<tr>
<td><strong>Ventilation</strong></td>
<td>Propofol concentration in exhaled alveolar gas (c&lt;sub&gt;a&lt;/sub&gt; G)</td>
<td>May aid prediction of propofol concentration in plasma (c&lt;sub&gt;PL&lt;/sub&gt;) and subsequent depth of anesthesia</td>
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<tr>
<td><strong>Cardiovascular</strong></td>
<td>Cardiac output measurement; Indicator-based methods: Lithium dilution, pulmonary artery thermodilution; Central venous oximetry</td>
<td>Electrical Cardiometry™&lt;sup&gt;TM&lt;/sup&gt; Impedance cardiography End-tidal CO2 measurement</td>
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<tr>
<td><strong>Neuromonitoring and awareness</strong></td>
<td>Brainstem auditory-evoked potentials</td>
<td>Suppressed dose-dependently during anesthesia Requires patient stimulation</td>
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<tr>
<td></td>
<td>BIS and other EEG-based monitors</td>
<td>A quantitative measure of depth of anesthesia ranging from 0 to 100, 100 being fully awake &amp; 0 representing an isoelectric EEG Decreases incidence of intra-operative recall awareness</td>
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