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Review

Oral endotracheal intubation in pediatric anesthesia

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Pediatric airway management has been both an integral part of routine anesthesia practice and one of its greatest challenges. Traditionally, it has been thought that the pediatric larynx is funnel-shaped, with the narrowest portion being situated at the cricoid cartilage; the choice of endotracheal tube type, size and insertion depth has been based on this concept. Uncuffed endotracheal tubes have typically been advocated for children younger than 8 years. However, it has recently been determined that the pediatric larynx is conical-shaped, with the narrowest portion of the larynx being situated at the rima glottidis. Therefore, there has been a shift in pediatric airway management, and cuffed tubes have been used without significant differences in post-extubation complication rates. It is critical to use the appropriate type and size of endotracheal tube, as well as to ensure proper insertion depth and adequate visualization of airway structures. Here, we introduce and discuss the optimal type, size, and insertion depth of endotracheal tube, and compare direct and video laryngoscopy.

Key Words: Airway management, Anesthesia, Intratracheal intubation, Pediatrics.

KSPA

INTRODUCTION

Pediatric airway management is crucial in routine anesthesia practice, because any airway-related complications due to improper procedures can have catastrophic consequences in pediatric patients. In pediatric airways, unlike adult airways, the narrowest section has been known to the level of the cricoid cartilage; pediatric airways have a greater risk of swelling, leading to increased airway resistance [1]. If an inappropriately sized endotracheal tube (ETT) is used, it may result in multiple endotracheal intubation attempts or excessive pressure on the tracheal mucosa, with the potential for airway damage [2].

The decision to use cuffed or uncuffed ETT is determined by several formulae based on age and weight [1]. Uncuffed ETTs are typically advocated. However, several recent radiological studies indicated that the narrowest part of the pediatric airway is the rima glottidis [3], and some studies suggested that cuffed ETTs can be used in pediatric patients without any significant difference in the incidence of post-extubation complications [2]. Furthermore, Microcuff ETTs have been introduced as a new type of cuffed pediatric tube [2,3]. Unfortunately, currently available tools used to guide appropriate ETT depth have significant limitations. This has led some researchers to investigate the utility of ultrasonography (US), which has been proposed as an effective tool for quickly and accurately guiding ETT placement [4]. Intubation may also be rendered more difficult by traditional laryngoscope blades, which can limit visibility. Thus, video laryngoscopy has been adopted to enhance the success of pediatric intubation.

Based on advances in airway management techniques in pediatric anesthesia and accumulating evidence-based medical data, we reviewed the literature to assess the optimal type, size, and depth of ETTs, and to compare laryngoscopies

using direct laryngoscopes versus video laryngoscopes in pediatric populations.

OPTIMAL TYPE AND SIZE OF ETT

The optimal type and size of ETTs depends on the individual child. However, selecting the correct size of either uncuffed or cuffed ETTs is difficult, despite the availability of numerous formulae (Broselow tape, Khine's formula, Motoyama's formula, Cole's formula, etc.), albeit these have been validated only for pediatric patients older than 1 year.

Uncuffed ETTs

Traditionally, it has been thought that the pediatric larynx is funnel-shaped, with the narrowest portion being situated at the cricoid cartilage, and then becomes more cylindrical as the child grows with the narrowest portion occurring at the vocal cords [5]. Based on this traditional anatomical concept of the pediatric airway, it has generally been accepted that uncuffed ETTs should be used for children younger than 8 years. This approach has the benefits of achieving a larger internal diameter (ID) of the tube, reducing airway resistance, and minimizing the incidence of edema formation due to mucosal damage caused by cuffs [1].

The appropriate size of an uncuffed ETT may be approximated based on a child's age and weight. ETT size should be standardized based on internal tube diameter, since external diameter varies among manufacturers [2]. The size of uncuffed tubes can be estimated using Cole's formula [ID (mm) = (16 + age) / 4] for children > 2 years [1].

Because of variability in the size of the pediatric airway and outer diameters (ODs) of ETTs, optimal cuff size can easily be over- or underestimated [6]. Age-based formulae for ID may not be accurate, and we should therefore prepare ETTs with IDs 0.5 mm larger or smaller than the calculated size [1,6]. An air leakage test with a sustained inflation pressure of 20 to 25 cmH_2O is recommended after intubation to confirm the correct tube size. If there is significant resistance and no audible/auscultated air leak, the tube size should be changed for one with an ID 0.5 mm smaller [2]. However, in cases without air leakage, we should first check for the presence of laryngospasm, which can be resolved by deep anesthesia, before changing ETT size [2]. If there is excessive air leakage, the ventilatory parameters, exhaled volumes, and end-expiratory gases are unreliable during intraoperative monitoring, and the ETT should be replaced with one that has an ID 0.5 mm greater [2,5]. Thus, uncuffed ETTs may require more laryngoscopies to change the tube.

There are several other methods for determining tube size, for example by using the diameter of the terminal phalanx of either the second or fifth digit, although this method is not reliable [2]. Subglottic diameter measured by US can be taken as the OD of uncuffed ETTs, from which it is possible to calculate an appropriate ID [6]. Recently, based on US, the epiphyseal transverse diameter of the distal radius was suggested to be more reliable than the digit method for determining uncuffed ETT size [7].

Cuffed ETTs

Recently, the pediatric airway anatomical concept has evolved: it is now believed that the pediatric larynx is conical-shaped in the transverse dimension, with the narrowest portion of the larynx being situated at the rima glottidis; that it is cylindrical in the anteroposterior dimension without changing throughout development; and that the rigid cricoid aperture is not entirely circular, but rather slightly elliptical [5,8]. Based on these recent findings, the use of cuffed ETTs has increased in infants and children.

Cuffed ETTs have several advantages, such as requiring fewer laryngoscopies, reducing subglottic pressure and operating room pollution, decreasing the risk of aspiration, and involving no (or minimal) increased risk of post-extubation stridor [2]. However, they show greater variability in OD owing to differences in cuff shape, size, and inflation characteristics.

Cuffed ETT size may be calculated by the Khine formula [ID (mm) = (age in years / 4) + 3], and is smaller than the predicted ID of uncuffed tubes for patients of a given age [1,2]. Thus, cuffed ETTs may be 1–2 sizes smaller than uncuffed ETTs calculated with Cole's formula [1,2]. However, it is important to take into account the fact that there is greater variation in OD for uncuffed ETTs among manufacturers [6]. Cuffed ETTs that are too small may be adjusted by inflating the cuff, thereby reducing the need to change tubes [6]. However, cuff inflation can also result in an undesirably high-volume, high-pressure cuff [9]. Thus, from a safety perspective, the Khine

formula may be more appropriate for cuffed ETTs.

As with uncuffed ETTs, US may be the most robust approach to determining the appropriate size for cuffed ETTs [6]. Subglottic diameter can be used to determine the optimal OD for ETTs, from which an appropriate ID can be estimated. US was recently found to provide a better fit than height- or age-based formulae in 88% of children [10]. Subglottic diameters can also be directly converted to the appropriate ID of cuffed ETTs using the following formula: 0.225 + (0.969 × subglottic diameter) [10]. However, this approach may result in an underestimate of ETT ID owing to differences in ID among ETT manufacturers; it is also possible to underestimate tracheal diameter by measuring the transverse diameter of the subglottic area, which is slightly smaller than the anteroposterior diameter.

While the Pediatric Advanced Life Support guidelines of the American Heart Association recommend the use of cuffed ET tubes as an alternative to uncuffed ET tubes [11], the risks and benefits of cuffed versus uncuffed ETTs in children are still controversial, mainly because of the low quality of existing evidence [12]. Well-designed randomized controlled trials with robust qualitative methodologies should be conducted to shed further light on this subject.

Microcuff ETTs

In the wake of recent changes in the concept of the pediatric airway, a new type of ETT with a polyurethane cuff (Microcuff ETT) has been developed [2,3]. The cuff of this product is typically located more distally on the ETT shaft, and the Murphy eye is eliminated; this allows the cuff to be placed below the non-distensible cricoid ring [2,3,8]. The Microcuff also has a cross-sectional area of about 150% of the maximal internal tracheal cross-sectional area at 20 cmH_2O inflation pressure [2]. In a deflated state, the OD of the Microcuff ETT increases only minimally [2,3].

For safe and effective use of the Microcuff ETT in pediatric populations, the manufacturer recommends the 3.0 mm ID size for full-term infants weighing more than 3 kg and with an age ≤ 1 year, the 3.5 mm ID size for infants age 1–2 years, and ID [ID = (Age in years / 4) + 3] for children ≥ 2 years of age [2,3]. However, Microcuff ETTs are not currently available for preterm infants or those that weigh < 3 kg. Placement of imprinted depth markings on the cuff between the vocal cords makes it possible to locate the Microcuff ETT safely within the cuff-free laryngeal zone without risking endobronchial intubation, which provides results superior to those obtained based on the predicted insertion location using a standard formula [13]. This results in a reduced rate of exchange (from 25% to 2%) of ETTs after intubation in pediatric anesthesia [14]. Furthermore, Microcuff ETTs are associated with a similar incidence of airway-related complications, such as post-extubation stridor, compared with uncuffed tubes [2].

Unfortunately, despite their benefits, Microcuff ETTs are not imported into Korea and can therefore not be used in this country. To achieve safer pediatric endotracheal intubation, the Microcuff ETT should be made available in a wider range of countries.

ETTs with tapered cuffs

Recently, an ETT with a tapered cuff was introduced to reduce the incidence of microaspiration associated with conventional cuffs. In an experimental study, an ETT with a tapered cuff significantly reduced the amount of leakage around the cuff compared with conventional cuffs, regardless of the application time or cuff pressure level [15]. However, no clinical studies have been conducted using ETTs with tapered cuffs. Therefore, further clinical investigations are required.

Oral preformed ETTs with/without cuffs

Oral preformed ETTs are commonly used in pediatric anesthesia but often poorly match the child's anatomy, because they bend at variable distances from the tip of the tube (bend-to-tip distance, BTD) depending on the brand. BTD variation among brands for uncuffed tubes (0–4 cm) is greater than for cuffed tubes (0–1 cm) for the same brand and ID, and the BTD of cuffed tubes is longer (0–3 cm) than that of uncuffed tubes of the same brand and ID [2,16]. Because of these differences, there is a high risk of accidental endobronchial intubation (0%–27%) for patients with preformed cuffed ETTs [16]. Preformed cuffed ETTs may also result in impaired vocal cord motion in some clinical settings, such as tonsillectomies, requiring the tube to be bent at the front teeth [17]. This positioning may in turn require the cuff to be placed at a higher level within the airway, compressing the recurrent laryngeal

nerve between the thyroid cartilage and the arytenoid or cricoid cartilage [17].

In summary, some preformed tubes are not well-suited for routine use in children owing to the variation in BTD. Tube tip position must be carefully controlled when preformed ETTs are used in children. Furthermore, considering the significant variation in BTD among manufacturers, we recommend using preformed ETTs from a single manufacturer.

APPROPRIATE DEPTH AND POSITIONING OF ETTS

The appropriate depth and positioning of the ETT tip can be determined using traditional clinical methods based on the following tools: formulae based on weight and age, anatomic markers, imprinted depth marks, palpation of the tube cuff in the suprasternal notch, and deliberate mainstem intubation with subsequent withdrawal.

Formulae based on weight and age

Formulae based on weight and age are commonly used to estimate the insertion depth for ETTs. In neonates, the appropriate insertion depth can be determined with the aid of anatomic markers, such as the nasal-tragus length (the distance from the base of the nasal septum to the tip of the tragus) or sternal length (the distance from the suprasternal notch to the tip of the xiphoid process) [2]. Adding 1 cm to these anatomical lengths provides a reasonable estimate of insertion depth for oral ETTs in neonates, and these methods are comparable to age and weight-based formulae [2]. Furthermore, the guidelines for determining insertion depth can be easily memorized: 10 cm for a newborn, 11 cm for a 1-year-old and 12 cm for a 2-year-old [2]. After 2 years of age, the correct insertion depth for oral intubation may be estimated by the formula: [Age (years) / 2] + 12, [Weight (kg) / 5] + 12, ID of ETT × 3 [2]. However, since this formula shows only 81% concordance with the ETT position determined by X-ray, we recommend that the results be verified by auscultation or chest X-ray [18].

Deliberate mainstem intubation with subsequent withdrawal

Tracheal palpation at the sternal notch achieves satisfactory ETT placement in about 80% of cases, and the number needed to treat is 6.3 for improvement compared with formulae based on age or weight [19]. The deliberate mainstem intubation technique can be used to place the ETT tip above the carina, which is confirmed through auscultation while withdrawing the tube after deliberate mainstem intubation. This offers superior predictability compared with tracheal palpation [20]. After confirming the position of the ETT tip above the carina, the ETT can be further withdrawn based on the previously measured carina to mid-tracheal distance on the chest X-ray, achieving an appropriate ETT position with a 98.5% success rate [21].

Transtracheal ultrasonography

Transtracheal US is an effective tool for quickly and accurately identifying ETT placement with high sensitivity (0.92 to 1.00) and excellent specificity (1.00) [4,22].

For infants and younger children, the midsagittal suprasternal view is commonly used, and the appropriate position of the tube tip is 1 cm above the aortic arch or the superior portion of the right pulmonary artery. This view provides adequate visualization of the ETT tip 80% of the time, and is consistent with X-ray visualization in 73%–100% of cases [4,22]. The visualization of the ETT tip can be improved by the oscillation within a few millimeters in each direction, or by using an US "standoff pad" over the infant's chest and neck. Adequate ETT depth can be confirmed by using the "sliding lung sign" at the bilateral mid-axillary line of the chest.

For older children, the suprasternal transverse view can be used to observe the vocal cords and glottic structures during EIT insertion. The transverse substernal view can be used to assess bilateral diaphragm motion, and the sagittal mid-axillary intercostal view can be used to observe lung sliding. This provides comparable performance to X-rays in terms of determining ETT position [4]. For the evaluation of esophageal intubation, sagittal scanning of the diaphragm at both mid-axillary lines at the lower chest may be useful. The position of ETTs can be assessed in terms of their location relative to the diaphragm. The saline-inflated cuff test, which

is helpful for ultrasonographic visualization of an ETT cuff at the suprasternal notch, can improve the detection of cuffs and rapidly confirm correct ETT insertion depth with a sensitivity of 98.8% and a specificity of 96.4% [20]. Combining this approach with other ETT verification modalities may further enhance the accuracy of ETT position determination [4].

CUFF LEAK PRESSURE MONITORING

Intracuff pressure can increase or decrease in patients undergoing prolonged surgical procedures, and who require positional changes [23,24]. Unintended and prolonged hyperinflation of the cuff can compromise tracheal mucosal perfusion, resulting in complications such as post-extubation stridor. Therefore, it is important to monitor cuff pressure, at minimum periodically and ideally continuously, using an instantaneous or continuous measure to manage air leakage and intracuff pressure [2,3,25]. In particular, if nitrous oxide is used, cuff pressure should be monitored and maintained at an appropriate level throughout the entire anesthetic period [2].

LARYNGOSCOPES

Direct laryngoscopy

It remains uncertain whether direct laryngoscopes with Miller blades truly provide a superior laryngoscopic view compared with laryngoscopes that used curved blades (e.g., Macintosh blades). Traditionally, direct laryngoscopes with straight blades have been recommended [2]. However, it was recently reported that both blades provide similar laryngoscopic views and intubating conditions, although each is better suited for particular external laryngeal maneuvers [26]. For example, the Miller blade is better suited for elevating the base of the tongue to expose the glottic opening, while the Macintosh is better-suited for lifting of the epiglottis [2].

Video laryngoscopy

Video laryngoscopes can provide a direct or indirect view of airway structures without the need to align the oral, pharyngeal, and tracheal axes. Several manufacturers have pediatric-specific designs, and the following video laryngoscopes are available in Korea: C-MAC® (Karl Storz GmbH & Co. KG, Germany), GlideScope® AVL (Verathon Inc., USA), Pentax Airway Scopes (AWS-S200, Nihon Kohden Corporation, Korea), VL400 (UE Medical Devices Inc., USA), and McGrath™ (Medtronic, USA). Some video scopes (e.g., Pentax Airway Scopes) have a groove that directs an ETT towards the center of the viewed image, while others lack such grooves and require a stylet for successful intubation. The midline approach for video laryngoscopy is better than the right-sided approach, because it is associated with a shorter intubation time and lower rates of mucosal injury and aspiration [27].

Compared with direct laryngoscopy, video laryngoscopy requires a similar time for routine tracheal intubation and a similar number of intubation attempts. However, video laryngoscopy is associated with higher glottic opening scores and a reduced need for airway maneuvers during tracheal intubation [28]. Furthermore, in inexperienced users (such as residents), video laryngoscopy can increase the success rate of intubations on the first attempt (88%) compared with direct laryngoscopy (63%) [29]. However, indirect video laryngoscopes with unconventional blade designs (e.g., the GlideScope®) provide relatively poor Cormack-Lehane views [30], which may be associated with longer procedure durations and lower success rates compared with laryngoscopes with conventional blade designs, regardless of user experience [31]. Furthermore, there is still insufficient evidence to recommend or discourage the use of video laryngoscopes for endotracheal intubation in neonates [32].

CONCLUSION

In pediatric airway management, cuffed ETTs may be used instead of uncuffed ETTs if care is taken to choose tubes of an appropriate size and position them correctly. Furthermore, if Microcuff ETTs are available, they may offer a safer means of conducting pediatric endotracheal intubation. Some preformed tubes have variable BTD, and are therefore poorly suited for routine use in children. Since the appropriate size and depth of ETTs cannot be determined with perfect accuracy, care should be taken to ensure a proper fit in each individual case. Furthermore, the intracuff pressure of cuffed ETTs should be monitored (ideally continuously) to prevent post-operative airway complications. Video laryngoscopes are useful for visualizing airway structures during intubation

in pediatric airway management, and are associated with higher glottic opening scores, regardless of user experience. Finally, many further randomized controlled studies are required to generate robust, evidence-based medical data on pediatric airway management.

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