Review article

Opening the upper airway – airway maneuvers in pediatric anesthesia

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Keywords: Upper airway: opening maneuvers; respiratory obstruction; anesthesia.

Introduction

Maintenance of a patent airway is the most important aspect of the safe administration of anesthesia in children. However, in spontaneously breathing, anesthetized children, upper airway obstruction is a frequent problem (1) and failure to maintain a patent airway can rapidly result in hypoxemia, bradycardia or even cardiac arrest.

Upper airway narrowing is most likely to appear in pharyngeal structures (2–4). Since the entire airway is composed of soft tissue and is kept patent during inspiration by the dilating action of the pharyngeal airway muscles, any drug that leads to a reduction of muscle activity can reduce airway patency and thus increase upper airway resistance (5). Children are particularly susceptible to upper airway obstruction because of the smaller dimensions of their airways and the high incidence of tonsillar and/or adenoidal hypertrophy which causes increased resistance to flow (6).

During anesthesia and basic life support, positioning of body, head and neck as well as airway maneuvers such as jaw thrust and chin lift are commonly used to improve the patency of an obstructed or partially obstructed upper airway (7, 8). The importance of these maneuvers has been known for a long time; Jacob Heiberg wrote in 1874 that during chloroform anesthesia, noisy, obstructed breathing, particularly during inspiration, can be prevented by pulling the jaw forward (9), while other authors have even earlier advocated opening obstructed airways by pulling the tongue forward (10–12).

This review focuses on the mechanisms and efficacy of different, simple methods to open and maintain a patent airway in spontaneously breathing children undergoing anesthesia, which include body, head and neck positioning and airway maneuvers such as mouth opening, chin lift, jaw thrust or the use of continuous positive airway pressure (CPAP).

Site of obstruction

The anatomy of the upper airway changes progressively during childhood. Of special interest for the pediatric anesthesiologist are the developmental changes of the soft tissues, in particular the tonsillar and adenoidal tissue in relation to the skeletal growth. Results obtained in various studies are conflicting. Based on analyses of lateral radiographs, Jeans et al. (13) reported that the soft tissues of the nasopharynx grow more rapidly at the age of 3–5 years than does the skeletal part of the nasopharynx. This leads to narrowing of the diameter of the nasal airway. A new period of increasing growth of
the bony nasopharynx starts at the age of nine (13), while at the same time the volume of the soft tissues remains constant. These findings are supported by another study showing the airway to be smallest at the age of four (14).

Using magnetic resonance imaging, Vogler et al. (15) reported the adenoids to continuously increase in size throughout the first decade of life and reach their maximum between 7 and 10 years of age before continuously regressing during adulthood. This finding is underlined by studies evaluating lateral cephalometric radiographs that show a change of shape in the soft tissues (mainly of the adenoids) from convexity to concavity with increasing age (13, 16). Here, the growth of the adenoids is the major contributor to the enlargement of the upper airway soft tissue resulting in the convexity observed on the radiograph (13).

In contrast, a more recent magnetic resonance imaging study shows a linear growth of the lower face skeleton of healthy children between the first and eleventh year of life (17). In this study, the surrounding soft tissues (including tonsils and adenoids) grow in proportion to the skeletal changes ensuring airway patency (17).

Although children have a smaller airway size compared with adults, most children snore very little and have less obstructive apneas and hypopneas (18). This might be caused by the upper airway in children being more resistant to collapse than the airway in adults (19–21).

Disproportional growth between these structures might predispose to upper airway narrowing (17, 22, 23) and consequently obstruction of the upper airway can occur at different anatomical levels of the upper airway (2, 3, 24, 25).

An obstruction proximal to the oropharynx can occur in the nasal or the oral cavity; it is assumed that as long as either remains open, an obstruction is unlikely to substantially decrease airflow. In patients with isolated adenoid hypertrophy, the nasal airway is compromised. However, a substantial number of children, especially those undergoing ear–nose–throat surgery, present with a narrowing of their upper airway because of adenoidal and tonsillar hypertrophy similar to the findings in the majority of children with obstructive sleep apnea syndrome (OSAS). Magnetic resonance imaging studies show that patients with OSAS have a significantly smaller volume of the upper airway as well as significantly larger adenoids and tonsils than patients without OSAS (22, 23). The soft palate is also thickened in children with OSAS, thus restricting the upper airway even more (22, 23). However, the volumes of the tongue and/or mandible is similar in patients with and without OSAS (23). The narrowing of the upper airway is not confined to a discrete region but rather occurs in the entire upper two-thirds of the airway in the region where adenoids and tonsils overlap (22).

Obstruction distal to the oropharynx during anesthesia is mostly due to a posterior displacement of the hyoid bone, which leads to a down-folding of the epiglottis that reduces the airway diameter as the rims of the epiglottis approach the posterior pharyngeal wall during inspiration (3, 24). Upper airway obstruction can also be caused by a collapse of laryngeal structures, e.g. the arytenoids (26).

The range of transmural pressures encountered during quiet unobstructed breathing is 2–4 cmH₂O, which is sufficient enough to collapse the upper airway of a small infant when the muscle activity that maintains the airway is depressed during anesthesia (27). Until recently, it was thought that airway obstruction during anesthesia was caused by a reduced genioglossus muscle activity and, therefore, posterior displacement of the tongue (3, 28). This traditional view is now questioned. Findings in anesthetized children and also adults suggest that the area between the tip of the epiglottis and the posterior pharyngeal wall is the narrowest part of the airway (4, 29–31), whereas the largest anteroposterior diameter is found at the level of the tongue. Furthermore, while the entire upper airway narrows with increasing depth of sedation, this effect is most pronounced at the level of the epiglottis (32–36).

**Influence of anesthetics on airway patency**

Sedative agents such as barbiturates and benzodiazepines are well known to cause loss of airway muscle tone and to increase airway resistance (5, 35, 37). An increasing depth of anesthesia is associated with a decreased size of the upper airway (32–36). Barbiturates cause greater depression of the main upper airway dilating muscles activity (genioglossus and geniohyoid muscle) than of the diaphragm in...
adults (35, 36). Although the activity of these muscles may reflect the activity of the upper airway in general, it is likely that other muscles are equally important in maintaining upper airway patency. This is underlined by the fact that genioglossus activity increases following airway obstruction during sleep but may fail to restore airway patency (38–40).

Ketamine causes significantly less upper airway obstruction in adults than midazolam (34). Electromyographic activity of the upper airway is significantly reduced with midazolam but remains unchanged after the administration of ketamine (34). This can be attributed to the muscle relaxant effect of benzodiazepines.

Under different levels of propofol sedation, the upper airway changes shape (41). During sedation, the upper airway is oblong shaped with the anterior-posterior diameter being larger than the transverse diameter, while during awakening, the transverse diameter increases (41). The cross-sectional area remains constant in spite of the changing diameters during sedation and awakening. This might be explained by the differential effects of propofol not only on the diaphragm and the upper airway but on separate pharyngeal dilator muscles (32, 41). Unfortunately, apart from propofol, the effect of all the other anesthetic agents on the upper airway in children is unclear.

Feedback mechanisms between different airway muscles

Airway obstruction leads to different responses in the muscles of the upper airway. Patency of the upper airway is partially dependent on the genioglossus muscle activity (42–46): in adults, a decrease of electromyographic activity of the genioglossus muscle is associated with upper airway obstruction, whereas a return of activity from this muscle leads to a reestablishment of upper airway patency (43–47). Thus, upper airway obstruction is the result of a relative decrease in upper airway dilator muscle activity (43–47). The response of the genioglossus muscle is greater than that of the diaphragm during and following airway occlusion in infants, facilitating the maintenance of airway patency (48–50). Suction pressure in the upper airway also increases the activity of upper airway dilating muscles while at the same time it inhibits the diaphragm (51). The other airway muscles, e.g. the laryngeal muscles or the alae nasi alter the resistance to air flow but are less important in resolving airway obstruction (52–54).

With regard to the impact of the body positioning on genioglossus muscle activity, the greater activity of the genioglossus muscle in the supine position can be explained by a greater narrowing of the upper airway due to gravitational forces compared with the lateral position (55). All previous described results have been obtained in sleeping individuals; therefore, it still remains to be proven whether these results also reflect the feedback mechanisms in patients undergoing anesthesia.

Position of the body

Simple body positioning has been shown to be able to influence the patency and the probability of upper airway obstruction (56, 57). Isono et al. demonstrated in eight paralyzed adult subjects with OSAS that the lateral position structurally improved the patency of the pharynx by reducing the effect of gravity on the pharyngeal soft tissue (56). In addition, improvement of OSAS has been shown with the patient in the lateral position (57). Thus, changing the patient from a supine to a lateral position, often done on awakening from anesthesia, may stabilize the airway by reducing the gravitational force on the epiglottis and the soft palate, preventing these structures from passively falling backward against the posterior pharyngeal wall.

Position of the head and neck

In sedated or anesthetized children, two ways of positioning the head and neck are advocated: first, the use of shoulder elevation of c. 5–10 cm by placing a bolster under the shoulders of the child (1–8 years) (58). Secondly, the use of the pediatric ‘sniffing position’ pillow which consists of a foam head and neck support designed to maintain partial cervical flexion and complete atlanto-occipital extension in the anesthetized or sedated infant. Both techniques are suitable to maintain upper airway patency in sedated children and there is no significant correlation between the degree of cervical spine or atlanto-occipital flexion and pharyngeal diameters (58).
The sniffing position might be superior in children who are predominantly nose breathers because the nasopharyngeal patency is maintained to a greater extent (reflected by a greater nasopharyngeal diameter) compared with the shoulder elevation technique (58). This is of special importance in smaller infants where the large epiglottis is in constant contact with the soft palate preventing effective mouth breathing (59) and where the likelihood of nasopharyngeal collapse increases during deeper levels of sedation or anesthesia.

In conscious adult patients, flexion and hyperextension of the head and the neck increase upper airway resistance (60–62). In unconscious patients, neck flexion can result in complete airway obstruction as shown by radiographical control (3). The shoulder elevation technique can lead to hyperextension of the neck, which can be especially hazardous in patients with pharyngeal tumors, as the tumor mass may occlude the pharyngeal airway (63).

Chin lift (single-handed airway clearing maneuver)

During anesthesia with the head in the neutral position, the epiglottis is posteriorly displaced because of gravitational forces. This can be counteracted by the chin lift maneuver (64, 65). During this maneuver, the anesthesiologist lifts the chin of the patient at the inferior border of the mental protuberance with one hand until the upper and lower rows of teeth are in close contact and the mandible does not protrude (Figure 1).

This airway maneuver causes a widening of the anteroposterior and transverse diameters of the entire pharyngeal airway (Figure 2a and b) (31). The degree to which this increase takes place depends on the degree of muscular tone in the geniohyoid and genioglossus muscles (42). In the complete absence of muscle tone (e.g. after application of neuromuscular blocking agents), chin lift leads to a greater increase of the glottic opening compared with conscious or spontaneously breathing patients who have higher muscle tone (65).

In spontaneously breathing, anesthetized healthy children without hypertrophic tonsils or adenoids and in patients with a flaccid upper airway, chin lift alone has been shown to improve and preserve a patent upper airway (31, 66). In contrast, problems can occur when the pharyngeal wall is altered by tonsillar hypertrophy or fat in the case of extreme obesity (67, 68). In more than 50% of unconscious children (1–9 years), chin lift was not able to open the upper airway whereas jaw thrust resulted in a patent airway with no clinical airway obstruction in 90% of children (7). The low success rate of the chin lift maneuver was explained by the high incidence of large adenoids and tonsils in this age group (7).

In children with hypertrophic tonsils and adenoids, chin lift has no effect or even exaggerated thoraco-abdominal asynchrony, an indirect measurement of upper airway obstruction (69). Therefore, chin lift without the concomitant use of CPAP should be used with caution in these patients (see below).

Mouth opening and jaw thrust (double-handed airway clearing maneuver)

Only opening the mouth without mandibular protrusion (jaw thrust) does not improve airway patency (70). As shown in adults, the reduced tension of
the upper airway muscles during mouth opening results in an increased collapsibility of the upper airway (70).

Jaw thrust has additional effects on airway patency (64, 71). During this maneuver, the anesthesiologist displaces the jaws with both hands at the mandibular angles in an upward and anterior manner, which forces the mouth open (Figure 3).

Anterior displacement of the mandible generates tension on the suprahyoid muscles, ventrally pulling the hyoid bone towards the root of the tongue and ventrally displacing the insertion of the genioglossus muscle (4, 72). These anatomic shifts lead to an enlargement of pharyngeal space by lifting the epiglottis away from the posterior pharyngeal wall and thereby reversing the narrowing of the laryngeal inlet (33, 64, 73). This finding has been confirmed in children by an increased glottic opening score and clinical signs (e.g. stridor score) when compared with the unsupported neutral head position (74). Furthermore, significant increases in tidal volume, minute ventilation, peak tidal inspiratory flow and peak tidal expiratory flow are associated with the jaw thrust maneuver whereas neither inspiratory time nor respiratory rate change compared with measurements in the neutral head position (24).

During pediatric basic life support (75), the jaw thrust maneuver can be used at the beginning of the assessment of the patient in order to determine the level of the child’s consciousness and at the same time to open a potentially obstructed airway. In this context, jaw thrust should be used in increasing ‘doses’ beginning with only slight pressure in order not to apply an intensely painful stimulus to a
possibly awake subject. In addition, jaw thrust is helpful in assessing whether the depth of anesthesia is adequate for insertion of a laryngeal mask airway (76).

During direct laryngoscopy performed by inexperienced physicians, jaw thrust significantly improves the visualization in adult patients (77). Unfortunately, there are no pediatric data available on this point.

Jaw thrust has also been stated to resolve laryngospasm (78–80). The underlying mechanism is unknown and is thought to be related to an intense painful stimulus increasing muscular tone, including the muscles supporting the upper airway and thus counteracting airway obstruction (80).

Jaw thrust also has its limitations in the case of abnormal tissue masses (e.g. tumor) along the pharynx or in the neck (unpublished observations). These masses can be pressed into the airway during the jaw thrust maneuver, leading to upper airway obstruction.

**Continuous positive airway pressure**

Under anesthesia, the physiology of the upper airway mimics the behavior of a collapsible tube. The application of CPAP creates a continuous positive pressure and thus increases the size of the airways (including the glottic opening) by acting as a pneumatic splint (64, 74). CPAP increases volume and area of the airway in the retro-palatal and retro-glossal regions. Lateral dimensions are more increased than the anterior-posterior dimensions as shown in sleeping adults in the prone position (67). CPAP also stiffens the lateral pharyngeal wall, the most compliant structure in the upper airway (81, 82), and decreases its collapsibility during inspiration (83). In children without hypertrophic tonsils, CPAP decreases thoraco-abdominal asynchrony (69). However, it is also associated with improved tidal breathing parameters, although jaw thrust has been shown to be more effective compared with CPAP (24). Application of CPAP with high pressures should be avoided, as the positive pressure threshold of the esophageal sphincter should not be surpassed (84). High levels of CPAP lead to an increase of functional residual capacity as well as to an increase of the work of breathing and a decrease of respiratory compliance and tidal volume. Additionally, venous return to the heart is significantly impaired by high levels of CPAP.

The combination of either jaw thrust or chin lift with CPAP (10 cmH2O) compared with jaw thrust or chin lift alone results in increased airway patency as reflected by an increased size of the glottic opening (71). On the other hand, the additional application of CPAP with chin lift or jaw thrust can lead to a decrease of the minute ventilation and tidal volumes although pressure differences during inspiration proximal and distal to the oropharynx are decreased (69). It is possible that anesthetized children could not compensate for the expiratory resistive load imposed by CPAP.

**Conclusions for the practicing anesthesiologist**

In healthy children without adenoidal hypertrophy, both chin lift and jaw thrust equally increase the area of the glottic opening compared with an unsupported airway (71), although jaw thrust has proven to be more successful in establishing a patent airway compared with the chin lift maneuver in emergency situations (7). Similar to the jaw thrust maneuver, CPAP improves the upper airway patency proximal and distal to the oropharynx and results in improved tidal breathing although this improvement is smaller compared with jaw thrust (24).

In contrast, in children with adenoidal and/or tonsillar hypertrophy, chin lift can deteriorate upper airway patency whereas jaw thrust increases airway patency (85). Here, airway obstruction can also be relieved by the use of CPAP, although jaw thrust is superior in maintaining airway patency in children with hypertrophic tonsils (85). The combination of jaw thrust and CPAP is associated with an increase in glottic opening (71) and at the same time decreasing minute ventilation in spontaneously breathing children, compared with jaw thrust alone (85).

Therefore, jaw thrust can be effectively used to determine the state of consciousness and at the same time to improve airway patency in children with and without tonsillar hypertrophy. Additionally, jaw thrust improves minute ventilation to a greater degree than chin lift, CPAP or a combination of CPAP with chin lift.
Summary
We conclude that jaw thrust is the most effective maneuver to open an obstructed airway and improve ventilation in anesthetized and unconscious spontaneously breathing pediatric patients. Whereas chin lift is effective in healthy children without tonsillar hypertrophy, it has the potential to obstruct the airway in children with hypertrophic tonsils and adenoids when the mouth is closed. Given the high incidence of large tonsils and adenoids especially in toddlers and preschool children, chin lift is a less reliable measure to improve upper airway patency in this age group. CPAP with or without jaw thrust and chin lift can further improve upper airway patency in sedated or anesthetized children, but may decrease ventilation in some patients.

Acknowledgements
The authors thank J. Etlinger for editorial assistance.

References


Accepted 28 September 2004