Zahid Hussain Khan *Editor*

Airway Management

Springer

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Foreword

> Wherever the art of Medicine is loved, there is also a love of Humanity.
>
> —Hippocrates

Airway management is an integral part of a multitude of medical specialties, including critical care, emergency medicine, pulmonary medicine, surgery, and of course, anesthesia. It is difficult, if not impossible, to properly credit the first person to "manage the airway," in part because many maneuvers are now considered an integral part of managing it: proper head and neck positioning, artificial ventilation, tracheotomy, cricothyrotomy, laryngoscopy, and tracheal intubation. To wit, we need only recall the vast number of pieces of equipment found in the modern "difficult airway cart," all of which are designed to help manage the airway. Regardless of how the clinician accomplishes it, the ultimate purpose is to establish an unobstructed pathway for exchange of oxygen and carbon dioxide.

Over 5,500 years ago, Egyptian tablets depicted the earliest known method of managing the airway in the description of tracheotomy. In the fourth century BCE, the Greek physician Hippocrates warned against the dangers of lacerating the carotid artery when tracheotomy was not performed expertly, and described tracheal intubation in humans. Around the same era, another Greek physician, Aesculapius, and the Roman anatomist Gallenus described the insertion of a hollow reed stem into the trachea to perform artificial ventilation. A thousand years later, Avicenna, around the year 1,000 CE, described tracheal intubation using a tube made of gold and silver. At the turn of the last century, tracheal intubation was perfected by the German surgeon Franz Kuhn, who was also among the first physicians to describe nasal intubation of the trachea under topical anesthesia (the so-called "cocainization" technique).

In modern anesthesia, the *sine qua non* of airway management consists of effective mask ventilation and/or endotracheal intubation. The last century has seen the most explosive growth of medical equipment and techniques purported to facilitate perioperative management of even the most difficult of airways. It is perhaps unreasonable to expect today that a single clinician might be able to use properly and efficiently all of the available medical devices and techniques available; it would be even more unreasonable to expect that one clinician be an “expert” in their clinical use and application. And that is precisely the brilliance of the textbook edited by Prof. Khan. To be sure, Prof. Khan is internationally known for his seminal work on airway assessment and anatomical factors that may portend a difficult airway. I first became aware of his expertise in airway management over a decade ago, as I read his first description of the upper lip bite test (ULBT) in one of the premiere anesthesia journals, *Anesthesia & Analgesia*. It is not an exaggeration to write that the ULBT test, alongside the Mallampati classification, has revolutionized assessment of our patients. Since that time, I have followed Prof. Khan’s scientific contributions to obstetric anesthesia, perioperative pain management, thermoregulation, and education. As the current Editor of Patient Safety Section for *Anesthesia & Analgesia*, I have also had the privilege of reviewing many of his manuscripts that have been published in the journal—so I can attest to his significant contributions in the field.

Because of his international prominence, Prof. Khan has been able to gather an enviable list of experts in the field to contribute their experience with airway management in a multitude of clinical settings. The critical appraisal of the airway authored by the editor, Prof. Khan, sets the stage for the important preoperative tests that may alert the clinician of the potential for a difficult airway so that appropriate plans can be made. The formidable “guest list” of authors spans the world, and encompasses clinicians from Malaysia, the United States, Pakistan, India, Denmark, Singapore, Germany, Canada, and Iran. What is equally remarkable is the list of topics discussed in the textbook, and the varied clinical settings in which airway management is likely to pose particular and unique challenges: pediatrics; patients with cervical spine injury and those with traumatic brain injury; ambulatory surgery; patients with obstructive sleep apnea; and obstetric patients. The textbook also addresses the latest in technological advances that can aid the clinician in diagnosing and managing the difficult airway, such as ultrasonography, and also describes surgical approaches to managing the difficult airway, such as cricothyrotomy. Finally, underscoring the truly international appeal of the textbook, and acknowledging the potential technological limitations of the developing world, a chapter is dedicated to the use of indigenous devices in managing the difficult airway.

In short, this textbook is a welcome and needed addition to the library of any clinician, and its international flavor assures that it will provide excellent guidance to clinicians worldwide for the benefit of all patients.

November 2013

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Preface

And now, by all the words the preacher saith,

I know that time, for me, is but a breath,

And all of living but a passing sigh,

A little wind that stirs the calm of death.

—Hakim Omar Khayam (1048–1131 CE)

I am reproducing the above couplet from our article entitled. “Contribution of medieval Islamic physicians to the history of tracheostomy,” Anesth Analg 2013; 116:1123–32 with permission as it conveys the gist of our book, *Airway Management*.

When I received the first formal invitation from the publisher to edit a book, I plunged in to reminiscences of the past when I wrote a romantic story, “Angel at midnight.” That I could manage all by myself and got published. But this time, things were altogether different. I put the e-mail on the shelf for the interim. Later, I cudgelled my brains to real task. I have read books edited by single authors and those where there were more than one contributor. Undoubtedly, the latter could attract considerable attention. After having chosen *Airway management* as the title for the book, my next step was to invite contributors whom I knew and whom I decidedly thought had a colossal experience and expertise in the sub-titles that I was interested in. You can well imagine the thought and mental ingenuity spent on this work. After having completed the list of topics, the publisher and myself started sending invitations to friends and colleagues. In the beginning the response was abysmally low but divine elements conspired me to keep up the struggle and tempo. Later, the influx of authors increased and everything went in tandem with my coveted and cherished goals, and it appeared that the ears were attuned to the sounds of my supplication. When everything worked as planned and when I started writing the preface for the book, I exhaled as if I had shed the final responsibility from my soul. I contented myself by resolutely and inflexibly adhering to my last homework, i.e., preparing and writing the preface.

I was weighed down with great anxiety as the time of submitting the entire book became nearer and nearer. This was but natural, because if there was a comma out of place, I was accountable for it.

I had registered a vow that I should deliver my soul upon the book and now when the book is reaching its final stages of completion, I get the solace that my struggle has been rewarded.

I honestly believe that we cannot understand everything at once and we cannot begin directly from perfection. We must first of all fail to understand a great many things.

That is a subtle divine law and a code of life. We should not harness the idea that all and everything that has been said and written about *Airway Management* could be done neither otherwise nor better. Science is not stationary and static. It is in an evolving state and this subtle fact remains in my failing memory as an indelible sign. The final word about airway and its management is yet to come. We, as the contributors of this book, would cede our place to others. That is how life goes on.

I believe in this axiom that the little things are infinitely the most important. The human airway had been the darkest Africa for me; there are many things about it that I do not know. More than a decade back, I thought that the architecture of the teeth and the temporo-mandibular joint played pivotal roles in the ease or difficulty of airway management. I seized on this new concept, eagerly analyzed it in all its ramifications, in all its aspects, and the more I immersed myself in it, the more I absorbed it. Finally, it culminated in a new airway assessment classification, “the upper lip bite test,” that added new apparel to the innumerable airway assessment tests that are currently in vogue and being routinely practiced by our fellow anesthesiologists worldwide. The upper lip bit test was the harbinger and predecessor of the “upper lip catch test,” another airway screening test for edentulous patients that also got published recently.

The difficult airway is the product of many anatomic and pathological variables. A rational approach includes detailed history, a thorough physical examination, and x-ray and imaging tools when needed. If mask ventilation becomes difficult or virtually impossible in an anesthetized patient who is paralyzed, emergency maneuvers are initiated. For those who have fathomed it, it is a deadly urgency. A person should keep his little attic brain stocked with all the paraphernalia and the plans that he is likely to use. If measures such as laryngeal mask airway or else combitube prove ineffective, trans-tracheal jet ventilation using a large bore intravenous catheter or cricothyrotomy is to be considered. However, a hurried surgical cricothyrotomy under sub-optimal conditions entails its own inherent risks and complications.

It needs proper positioning of the patient and an access to the right instruments, otherwise this simple procedure would take too long to accomplish and incur incalculable harm to the patient who already might have sustained some degree of hypoxemic episodes during the difficult scenario of abortive mask ventilation. The laryngeal mask airway and the combitube are supraglottic devices and their inherent weakness is that they cannot solve a glottic or a subglottic problem. In such circumstances, the glottic or the subglottic problem can be safely averted and targetted by ventilator options below the lesion such as transtracheal jet ventilation or a surgical airway. In the same vein, catastrophic events during failed intubation became the protagonists of the introduction of the available preoperative airway assessment tests and in this regard some proved indispensible in saving many lives. This revolution in itself highlights the importance of such tests in obviating a catastrophic outcome. During residency training, residents learn the basic concepts of airway management but fall short of acquiring the necessary skill with the techniques that are needed in an emergency situation.

The present book is comprehensive, covers all physiological and pathological aspects of *Airway Management* related to the neonate and the adult, the obstetric patient and those having sustained cervical spine and head injuries. It will serve to be of value both for the practicing anesthesiologist and for those undergoing fellowship and sub-specialty training in airway management. Although airway management needs hands on practice in real clinical scenarios, the book provides novel and indigenous techniques written by experts in fields that would enable everyone to learn and acquire the several techniques of airway management.

All of my friends and colleagues have expounded on their subjects and chapters with such indubitable talent and expertise that I was overwhelmed when reading their write-up, and would be failing in my duties as an editor of this book if I do not acknowledge their devotion, sincerity, ineffaceable conviction, and cerebral enthusiasm in helping me with this gigantic task which if left to myself in its entirety would never ever have reached your hands. Everyone did a wonderful job, a venerable one, and I take off my hat to everyone. I enjoyed the company of such erudite and well-versed researchers, and it was enlightening to say the least.

You cannot imagine how much my health these passions and worries have taken away, and how much of my feeble health shall be usurped and taken away by my unfinished tasks that still lie in the deepest recesses of my brain and soul. If the vigor and life was there, I would be approaching you again for a second edition of this book to incorporate your new insights and research works.

There are many who have expatiated on the subject of airway but the human airway and its management is an unfathomable phenomenon. It must be solved with complete exactitude and for that to occur, we need to evolve and invent new and exemplary tests, tools, gadgets, and devices in the future.

"Dans le doute, absteins toi." This French proverb says "when in doubt, do nothing" is applicable to the title of our book. If everyone can take this point fully on board, and communicate it successfully to others that the sense of fatalism in the face of an inevitable catastrophic disaster cannot be challenged single-handedly, perhaps I would have been able to do my humble bit in averting airway-related deaths that if comprehended in time and managed collectively would save many lives.

All the issues and paramount concerns about airway management have been comprehensively tackled with lucid and narrative style but if some are not brought to limelight, I share the blame for failing to address them.

Bravo, my friends and colleagues.

This book is dedicated to the memory of those unfortunate patients who succumbed during the drill of difficult intubation or else sustained irrevocable brain damage, and to all those who voluntarily consented and participated in the innumerable research projects conducted on the planet about airway management. They helped us in designing new tests and appliances. They were the Muse of Olympics. We all owe our achievements and progress in this difficult terrain to their whole-hearted and fervent participation in all our focused research projects.

I am indeed grateful to Professor Brull for having spared his time for writing the Foreword for this book. I am also grateful to the managerial and publishing section of Springer publications for having accepted the book as their own baby and having consented to publish the book under their esteemed and recognized established services.

To conclude, I may put this last sentence that my treasure in life had been my father whom I owe all my achievements in life and under whose oversight I learned a lot.

Zahid Hussain Khan, M.D.

Contents

Chapter 1
Physiology of the Airway

Yoo Kuen Chan

Abstract The airway acts as a conduit to bridge the environment with the gas exchange site. Flow of air under involuntary control occurs to bring oxygen to the gas exchange site and carbon dioxide produced in the body out to the environment. This flow is possible with the process of breathing through a patent airway. Patency of the airway is maintained with tonic control of pharyngeal muscles, constant mucus production with mucociliary clearance and occasional sneezing and coughing. The work done in sustaining this flow regularly is minimal at only less than 3 % of total body energy consumption but can increase substantially with airway obstruction or in the presence of poor compliance of the lung. Depending on the site of airway obstruction, manoeuvres to reduce the obstruction include the use of Heimlich's, suctioning and use of bronchodilators.

Keywords Airway · Flow · Gas exchange site · Airway obstruction · Work of breathing · Patency of airway

Introduction

The airway is the conduit that links the outside environment to the gas exchange site. This conduit allows oxygen to be brought in and carbon dioxide to be brought out. The process is by bulk flow [1] which allows the transfer of adequate volumes to keep up with the needs of the body. In order for this flow to be maintained, the airway must be kept patent.

Patency is maintained by tonic control of pharyngeal muscles, mucus production, mucociliary clearance, sneezing and coughing.

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Flow in the airway is involuntarily controlled by the autonomic nervous system [2]. The process is complex and loss of control can occur due to a variety of reasons including obstruction and inability to create the sub-atmospheric conditions [3] necessary for the movement of air. The latter includes interruption of neuronal control, weakness of the respiratory muscles, pain and loss of consciousness.

Flow in the Airway

The airway serves as the only conduit to allow transfer of oxygen and carbon dioxide between the environment and the gas exchange site.

The flow in the airway is intermittent with the flow inwards during inspiration and outwards during expiration. With each breath, the flow averages 25–30 L/min but since each breath is only slightly over a second, about 0.5 L or 500 ml flow into the gas exchange area with the breath.

In normal low flow breathing, the flow rate is slightly higher during inspiration than expiration at 25 L/min. At peak inspiratory and expiratory flow rates, the expiratory flow can become as high [4] as 280 L/min whilst the inspiratory flow rate 160 L/min. This increased flow is especially useful during exercise [5] to bring in the very much larger volumes of oxygen needed for the efficient conversion of energy sources to ATPs needed for activity in the muscles. The oxygen needs during these periods of time can be up to 10–20 times the basal metabolic requirement of oxygen.

This flow to bring oxygen to the gas exchange site is mandatory to sustain life. Interruption to this flow may be due to a variety of causes, chief of which is obstruction in the airway. Obstruction in the upper airways depending on the cause of the obstruction can be circumvented by providing a passage below the obstruction. Obstruction in the lower airways must be assisted by bronchodilatation, removal of secretions with positional drainage or assistance with chest physiotherapy. If circumvention below the site of obstruction is not an option, cardiopulmonary bypass to bring oxygen directly into the cardiovascular system which then brings it to the tissues, can be a temporary alternative strategy.

Flow is delineated by the Hagen Poiseuille's relation:

$$Q = \frac{\pi \mathrm{Pr}^4}{8\eta l}$$

Q flow
P driving pressure
r radius of conduit
η viscosity of gas
l length of conduit

Whilst the flow in the main distributing part of the airway may be turbulent, this formula helps in understanding some of the clinical applications we use to overcome obstruction in the airway.

Partial obstruction can be circumvented by increasing the pressure of the gas delivered inwards to increase flow. This is widely used in continuous positive air pressure (CPAP) ventilation and bi-level positive airway pressure (BiPAP) ventilation [6]. Similarly flow can be increased by decreasing the viscosity of the gas used to carry the oxygen inwards. Instead of using air which is an oxygen nitrogen mixture, oxygen is used with helium. The latter has a lower density and hence viscosity. This would improve flow in the conduit when used as a carrier gas [7–9].

Inability to create the negative pressure to induce flow can be due to weakness of the muscles either the muscles of the diaphragm or of the intercostals. Paralysis of the nerves supplying the muscles may also be responsible for the dysfunction.

Flow in an Obstructed Airway

Airway obstruction can occur anywhere along the length of the airway. Management strategies differ when managing obstruction in the upper as opposed to the lower airway. In order to distinguish the site of the obstruction, the flow volume loop examinations of patients are useful in assessment [10, 11].

Upper Airway Obstruction

The upper airway is that part of the airway until the level of the carina. The upper airway can be divided into the extrathoracic and the intrathoracic airway. The diameter of the airway is sensitive to the transmural pressure on it and changes during the phase of respiration.

For the extrathoracic airway [10] (Fig. 1.1), the extrinsic pressure on it is related to the unchanging atmospheric pressure. During inspiration in those who are obstructed, the negative pressure in the airway tends to collapse the airway resulting in reduced flow. During expiration, the positive pressure allows the airway to stay fully patent and there is no reduction in flow.

For the intrathoracic airway [10] however, the negative intrapleural pressure during inspiration ensures that it stays patent with no diminution in flow during inspiration. The positive intrapleural pressure during expiration may collapse the airway in those who are obstructed causing the expiratory flow to be reduced (Fig. 1.2).

When the obstruction is fixed [10] (Fig. 1.3), i.e. when there is no change in diameter of the airway during both phases of respiration, limitations of flow will occur during both inspiration and expiration.

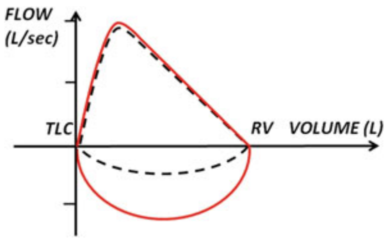

Fig. 1.1 Extrathoracic airway obstruction. Note the reduced flow (*dashed black lines*) during inspiration whilst the flow remains unchanged from normal during expiration

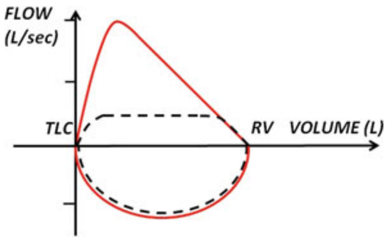

Fig. 1.2 Intrathoracic airway obstruction. Note that the flow (*dashed black lines*) is normal during inspiration but reduced during expiration when the airway collapses from the positive intrapleural pressure

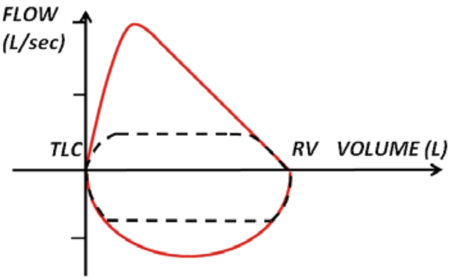

Fig. 1.3 Fixed airway obstruction. Note the decrease in flow (*dashed black lines*) both during inspiration and expiration

Lower Airway Obstruction

In patients with airway obstruction in the peripheral airways, restriction of flow occurs during the terminal volume of the expiration (Fig. 1.4). In asthma and chronic obstructive pulmonary disease (COPD) the reduced expiratory flow results in air trapping producing an auto-positive end expiratory pressure (auto-PEEP) which in the COPD patients give rise to the barrel chests often seen in them.

In smaller airway obstruction, the distribution [12] of the inspired flow is also affected. The gases in the periphery will move away from the obstructed sites and move through unblocked collateral channels to the gas exchange site. Smaller airway obstruction can be picked up by the single breath nitrogen washout test following an inspiratory breath of 100 % oxygen. In a patient with peripheral obstruction, the alveolar plateau (phase lll of the curve) will no longer be flat but will show a rising nitrogen concentration (Fig. 1.5).

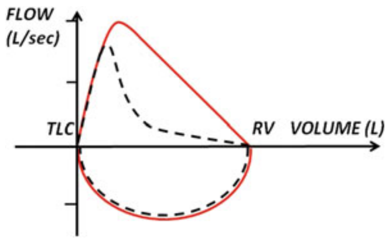

Fig. 1.4 Peripheral airway obstruction. Note the flow (*dashed black lines*) is reduced in the terminal phase of expiration

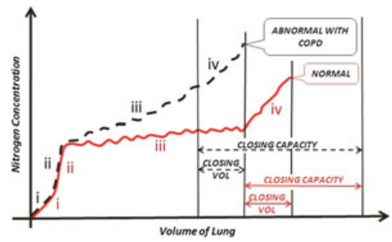

Fig. 1.5 Following a single inspiratory breath of 100 % oxygen, the nitrogen washout concentration of a normal person can be divided into several phases reflecting the distribution of the oxygen previously inspired. Note the non plateau nature of phase lll in those with COPD

Distribution of the Airflow in the Lung and Gas Exchange Area

A greater proportion of the flow is distributed to the lower lungs in the upright position. The alveoli in the bottom portion of the lung are at the ascending or near ascending portion (has high compliance) of the lung compliance curve. The alveoli at the upper end are already fully inflated (has low compliance) or are nearly fully inflated and cannot distend anymore (Fig. 1.6).

Flow Velocity

As we move from the larger airways to the more distal part, the total cross-sectional area of the smaller airways increases. Flow stays constant but the linear flow velocity decreases as we move further downstream. The linear flow velocity is the flow divided by the total cross sectional area of a given generation of airway.

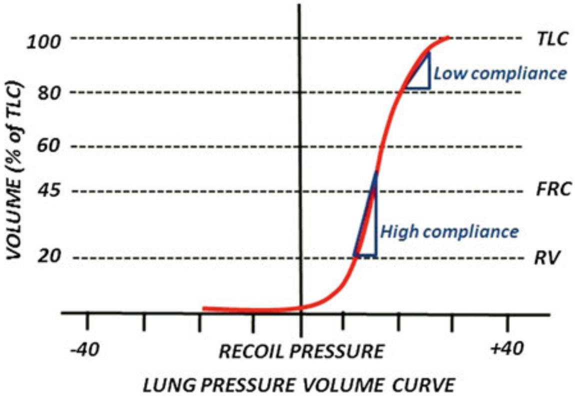

Fig. 1.6 The alveoli at the *bottom* portion of the lung has high compliance and those at the *top* have low compliance

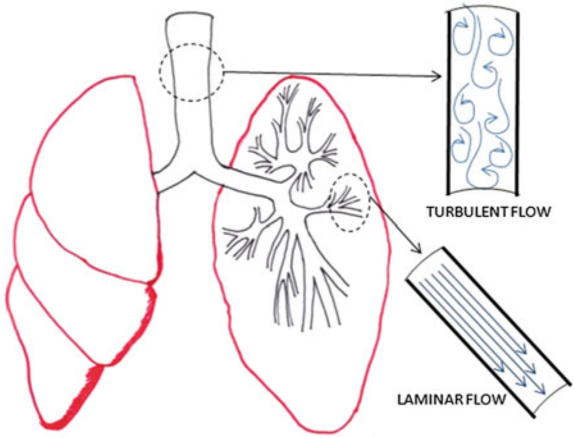

Fig. 1.7 The type of flow present in the airways

Turbulent and Laminar Flow

The linear flow velocity, being larger in the larger airways, causes the flow there to be turbulent. In the smaller airway as the flow velocity decreases, the flow tends to become laminar (Fig. 1.7).

Pressures in the Airway: Spontaneous Respiration and Controlled Respiration

Inspiratory or expiratory flow is induced by difference in pressure between bronchus/bronchioles and the environment. In a spontaneously breathing person, the negative pressure at the start of inspiration is due to increasing negative pressure in the pleural cavity being induced by the descent of the diaphragm and the outward movement of the thoracic chest wall.

The pressure changes during spontaneous respiration in the airway averages around +2 mmHg during expiration and −2 mmHg during inspiration. In controlled respiration, the airway pressure during inspiration may average around 15–20 mmHg and move onto 0 mmHg during expiration.

Work of Breathing

Work done to induce flow during inspiration is for overcoming the elastic forces and to overcome resistance in the airway (Fig. 1.8a and d). The energy of the work done to overcome elastic forces is stored in the lung tissues as potential energy for the subsequent expiration.

The expiratory work to allow flow of air to move from the gas exchange site to the outside environment is only to accommodate forces due to airway resistance and it comes from the potential energy stored with inspiration. With this arrangement, inspiration is active and expiration passive.

In the presence of airway obstruction (Fig. 1.8b), the patient needs to do more work during inspiration to generate a higher differential pressure to overcome the obstruction. This is done by a more forceful generation of increasing negative pressure in the airways when a patient is breathing spontaneously. This generation of a more negative intrathoracic pressure may predispose an unconscious patient (without protective airway reflexes) in a partially obstructed airway situation to aspiration. The intraabdominal pressure may be very much higher than the intrathoracic pressure facilitating the movement of stomach contents into the oesophagus.

In patients with restrictive disease (Fig. 1.8c) however more work is done to overcome the elastic forces in the lungs while the work against resistance remains the same. As the lung is very compliant in a normal patient, the work done does not consume a lot of the body's energy needs and the amount of daily energy expended is less than 3 % of total body energy requirement [13].

Keeping the Airway Clear

Mucous Production and Clearance in the Airway

With volumes of about 300–400 L/h of air, flowing into the lungs, many unwanted particles can be brought in. Mucous forms the first line of defence to trap [14] microbes, dust and other particles brought in during inhalation before they can go further into the gas exchange site. Mucous also prevents the airway from getting dehydrated [14].

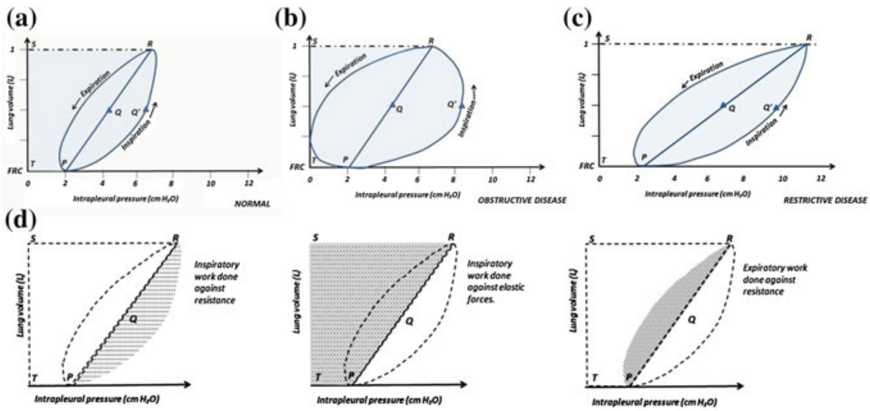

Fig. 1.8 The representation of the amount of work done for inspiration and expiration in **a** a normal patient, **b** chronic obstructive pulmonary disease, **c** a patient with restrictive disease. The key **d** outlines the nature of the work for the various phases of respiration. Note the intrapleural pressures represent increasingly negative values in the direction of the *arrows*

Mucous [14] is a collection of polypeptides, cells and cellular debris bound together by mucin. The latter is made of glycoproteins with glycosylated carbohydrates. Mucins [14] can be either membrane bound for functions of cellular adhesion and pathogen binding or secreted to provide the viscoelastic properties of mucous.

Mucous hypersecretion [14, 15] however causes mucociliary impairment leading to airway obstruction which can then lead to limitation of airflow.

Mucociliary Clearance

Ciliary action is the first line of defence in moving the mucus in the airway. This is especially so in the more distal generation of airways where cough is not a predominant feature in clearance of the airway.

Mucociliary clearance is impaired in the elderly [16]. This may explain why they are more vulnerable and have an increased likelihood of developing lower respiratory tract infection.

Cough

Cough [17] is an extremely important defense mechanism in the airway to keep it clean and healthy. As previously mentioned, normal expiration is a passive process where the airway pressure is not high enough to generate a high enough expiratory flow to remove substances brought in by inspiration. A productive cough can do exactly that.

Cough [18] starts with a deep inspiration usually up to the total lung capacity (inspiratory phase), followed by a closure of the glottis to bring the pressure up to 50 cm H_2O [19] (compressive phase) and then an explosive phase where the flow is many times higher than the normal expiratory flow to facilitate removal of the substance collected in the airway.

In the normal patient, it is the expectoration of mucus that is the main function of a cough [19]. The high velocity flow generated is higher in the central airways (decreased total cross sectional area) than in the periphery. A cough therefore impacts mucus secretion in the proximal airways up to the 7 to 12th generation of airways [19].

The high flow generated in an effective cough breaks the mucus free of the epithelial lining of the airway and brings it into the main air stream to be brought out to the exterior. Thick and tenacious mucus however may need an extremely high flow to do this and explains why they are more likely to be difficult to remove [20].

As the first phase of cough requires the generation of a large inspired volume almost to the total lung volume, patients with muscle weakness are unable to produce effective cough. These patients may have a higher risk of developing atelectasis, post operative pneumonia and onward to respiratory inadequacy [19].

Sneezing

Sneezing like a cough, is another protective airway reflex that allows the creation of a high airway pressure during expiration [21] with the generation of a high flow [22] to remove airway irritants.

A sneeze starts with the activation of afferent nerve endings of the trigeminal nerve in the nasal mucosa and areas around the conjunctiva, cornea, oral mucosa and face [23]. Nerve impulses are transmitted to the sneezing centre in the lateral part of the medulla [24] via the trigeminal ganglion [25].

As in a cough, a sneeze in the efferent limb [21] starts with a deep inspiration followed by an initial closed glottis so that a high pressure up to about 176 mmHg [26] can be generated to expel foreign irritants in the airway through the open mouth and a closed nostril.

Airway Closure

Airway closure is usually linked to the lung capacity existing at the time where there is no longer air flow from the gas exchange site. In the normal patient, airway closure [27] is below normal tidal volume range of respiration or within the functional residual capacity volume. Lungs which are functioning at this range of capacity for air closure are working optimally. There is no work wasted to inflate the closed alveoli where there is need to recruit alveoli to make up the tidal volume.

For those patients who are obese and for those who are elderly (especially when they lie flat) airway closure occurs within the normal tidal range or above the functional residual capacity [28]. In these patients, the work of breathing is increased especially when they are in the supine position as wasted work is needed to open up the alveoli with each tidal breath.

Surfactant and Airway Closure

Surfactant which is produced by the type II epithelial cells [29] reduces the surface tension. A reduced surface tension reduces the pressure inside the alveolus and prevents it from emptying its contents into an adjacent alveolus with lower airway pressure. Surfactant prevents the alveoli from collapsing during expiration.

Surfactant [30] stabilises the alveoli and prevents early airway closure. This therefore reduces the work of breathing as it pre-empts the need to work on opening the collapsed alveoli.

Artificial Control of the Activities in the Airway

In the awake and conscious patient, the process of breathing creates the flow in the airway and this is an involuntary process [2] under the control of the respiratory centre. As this flow is so efficiently carried out and the energy requirement is so minimal, it is not a burden to life. However when there is increased work of breathing, the patient becomes conscious of the burden of the work.

In the unconscious patient, the control of the flow in the airway may be lost. The ability to conduct the other protective activities to keep the airway healthy is similarly lost. Care providers have to assume these two roles in managing the airway in order to sustain life.

Role of the Heimlich Manoeuvre

In a patient who has aspirated a foreign body, it is usual for providers at the scene to try to remove the foreign body to assist respiration. The choking algorithm is well described in most resuscitation manuals [31] but often the care provider is unable to remember the proper sequence of events required for the proper handling of this potential life threat.

When caught in such a situation [32], it is important to determine if the patient is able to cough or speak in complete sentences. Ability to do so indicate the foreign body is not causing a life threatening airway obstruction. Attempts to remove foreign bodies especially a coin with inadequate back up facilities can transform a non life threatening obstruction to a complete obstruction. A patient who is still able to control his airway demonstrated by his ability to cough or speak, should be monitored closely for his adequacy of respiratory effort until adequate facilities/expert help is available in the hospital setting.

If he is unable to cough [31], then the need to remove the foreign body becomes more urgent. If he is still conscious, one can use the Heimlich manoeuvre which requires the rescuer (standing at the back of the patient) to lock both his hands anterior to the abdomen of the patient and apply an upward thrust at the diaphragm to increase the intrathoracic pressure in an attempt to dislodge the foreign body with the raised intrathoracic pressure.

If the patient is unconscious however, the same manoeuvre is done straddling the unconscious patient [32] who is placed supine on the floor and applying the upward diaphragmatic thrust from the front. After the foreign body is dislodged, it is manually removed and respiration and cardiac massage applied if cardiopulmonary arrest has ensued as a result of the obstruction.

Role of Suctioning of Secretions from the Airway

Sucking of secretions to clear the airway is an important activity undertaken in the critical care of ill patients. The practice varies widely in terms of what is actually being practised [33]. It has to be done under sterile conditions to assist those who are unable to expectorate their secretions.

The most common complication that can accrue from improper suctioning is hypoxemia [34–36]. This can be prevented by preoxygenation, hyperoxygenation and hyperinflation, suctioning for less than 15 s using pressures of −80 to −120 mmHg and limiting the size of the suction catheter to 14 Gauge or less. Careful suctioning reduces damage to the tracheal mucosa [35].

Role of Bronchodilators

Bronchoconstriction in the peripheral airways is best managed with bronchodilators that act on the smooth muscles in the distal airways responsible for the problem. Newer focus has been on 2 different agents [37, 38] to provide synergistic effects of bronchodilatation. They include long acting muscarinic antagonists (LAMA) e.g. Tiotropium, Glycopyrronium and long acting beta agonists (LABA) e.g. Formoterol, Indacaterol.

Common Diseases of the Airway

Asthma and Chronic Obstructive Pulmonary Disease (COPD) constitute the 2 most common airway diseases affecting mainly the peripheral airways. Asthma burdens 300 million people world-wide [39] whilst COPD causes 4–5 % of adult mortality [40]. The main thrust of management is to keep the peripheral airway obstruction under control so that the affected patients can have adequate flow in the airway and keep up with their usual activities of daily living.

Asthma

Whilst most of us understand asthma as a condition with intermittent, reversible high peripheral airway resistance, it is also a disease characterised by tidal volume airway closure [28] where the closing volume is higher than the end expiratory lung volume. This is as a result of inflammation in the peripheral airway mainly associated with airway eosinophilia [41]. Markers of inflammation including exhaled nitric oxide may be of some use to determine the extent of the disease [42, 43] to allow more effective control of bronchodilatation management.

Chronic Obstructive Airway Disease

This is a disease characterised by airflow limitations [40] with acute exacerbations from respiratory infections where peripheral airway obstruction together with parenchyma destruction cause respiratory dysfunction increasing with age. Many have mucous hypersecretions [44] which are difficult to control. Acute exacerbations [45] is best managed with a combination of bronchodilators, corticosteroids and antibiotics together with non-invasive positive pressure ventilation to tide over the period of increased work of breathing.

Conclusion

The airway is a conduit that links the environment with the gas exchange site. Flow is sustained by the process of breathing and can be done with ease when the airway is patent. Patency is maintained by many physiological processes including mucous production and clearance, sneezing and coughing. In addition as providers we may facilitate by suctioning of the proximal airway and use bronchodilators to improve patency of the peripheral airway. In a patient with choking the process of correctly applying the choking algorithm is important in order for the patient to survive.

Understanding the physiological concepts surrounding flow in the airway is certainly an important step in providing appropriate care during the crucial stages of sustaining life. Asthma and COPD are two very common airway diseases that affect a fair segment of the population and pharmacological means to maintain patency of the airway remain the mainstay of management.

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Chapter 2
Airway Assessment: A Critical Appraisal

Zahid H. Khan

Abstract The ability to predict the difficult airway to preempt difficult intubation would decrease the most common damages seen in the administration of anaesthesia. Many tests have been put forth over the years, some necessitating detailed quantitative measurements like the sternomental distance, thyromental distance and inter-incisor gap but others like the upper lip bite test is of a qualitative nature which makes it easier to use and is more precise. The setback in most tests has been their sensitivity, specificity, positive and negative predictive value to allow accurate prediction of the possibility of difficult intubation. Combination of the tests has not improved the various attributes to improve accuracy. The most important impediment to the continued search of a comprehensive test is the low occurrence of the difficult airway. There may be a combination of complex factors interacting in an incomprehensible manner to make the process of intubation difficult.

Keywords Difficult airway · Prediction · Airway assessment tests

History and Definition

The foremost responsibility of an anesthesiologist is to maintain patency of the airway to allow oxygen to move down into the lungs to ensure adequate gas exchange. Inability to maintain ventilation and oxygenation for several minutes after the patient is rendered apneic following induction of anesthesia results in catastrophic complications including death. Such problems account for 30 % of deaths occurring during anesthesia [1, 2]. These figures are certainly high in the developing world. In the published analyses of records of the UK medical defense

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societies, problems with tracheal intubation are the principal causes of hypoxemic anesthetic death and brain damage [3–5].

Closed claims analysis has found that the vast majority (85 %) of airway related events involve irrevocable damage to the brain or death [1], and nearly one third of deaths attributable solely to the process of anesthesia have been related to the inability to safeguard the patency of the airway [3]. Compared with 1985–92, death or brain damage from difficult airway management associated with induction of anesthesia did show a decrease in 1993–99, but death or brain damage associated with maintenance, extubation and recovery was found not to be significantly different in the two line periods [6]. This reflects that although significant advances have been made regarding airway management armamentarium and strategies, the situation still appears far from hopeful.

According to the definition forwarded by the American Society of Anesthesiologists (ASA), a difficult intubation (DI) is one during which the insertion of the endotracheal tube takes more than 10 min, and or requires more than three attempts by an experienced anesthesiologist [7]. Langenstein and Cunitz [8] also defined an intubation as difficult, if a practicing anesthesiologist needed more than 3 attempts or more than 10 min for a successful endotracheal intubation. It appears that the ASA has been too magnanimous in granting a 10 min period for insertion of the endotracheal tube before being labelling a case as that of DI. If a patient cannot be ventilated by mask after being rendered apneic, the 10 min period need to be substantially curtailed in terms of a cut off value otherwise the end result would be a patient with irreversible brain damage who can neither successfully be mask ventilated nor intubated and yet falls within the allowable time period of 10 min not trespassed in milliseconds. The incidence of DI reported in the literature varies markedly between studies, ranging from 0.05 to 18 % [9–11]. These large variations could be attributed to the different definitions used during such studies and the incorporation of different grades of the Cormack–Lehane grading (CLG) for the laryngoscopic view [12]. DI has been defined as repeated attempts at intubation, the use of a bougie or other intubation aid but the most widely used classification is that of Cormack and Lehane [12], which describes the best view of the larynx seen at laryngoscopy. For the ease of understanding different terms and definitions such as DI, difficult tracheal intubation and difficult laryngoscopy (DL) have been introduced into our anesthesia literature but the final inability to perform endotracheal intubation is in fact the total sum of DL, patients' innate anatomical characteristics and other circumstances that are still beyond our comprehension.

To surpass the ever present life threatening risks of the difficult airway, guidelines have been published by North American [13, 14], French [15], Canadian [16], and Italian [17] national societies. Unfortunately, they do not serve to be useful when prompt decisions are to be made as in emergency situations. The flow charts in the European [18, 19] or American Heart Association [20], and Advanced life Support guidelines offer simple steps that could be of value in emergency situations.

Out of the total of 6,750 anesthesia malpractice claims, Cheney et al. [21] could find that 23 % of the respiratory events were exclusively due to DI. Of the first 4,000 incidents reported to the Australian Incident Monitoring study (AIMS), 160 dealt with problems pertaining to endotracheal intubation. Difficulties in intubation were not predicted in 77 cases. Paix et al. [22] concluded that simple tests such as limited mouth opening and/or neck extension could have prevented unexpected difficulties in 32 of the cases.

The Conundrum of a Difficult Airway

The difficult airway can be represented by difficulty with laryngoscopy, intubation and mask ventilation. Before an anesthetic is administered, it is of paramount importance to correctly diagnose and clinch potential airway problems to choose alternative modalities of airway management [13, 23]. It is a kind of dress rehearsal before a potentially hazardous march on the enemy and should under no circumstances be under estimated. Approximately half of all cases of DI are not predicted [24] and this is particularly alarming as it can potentially turn into a life threatening event. This figure is alarming to say the least, and it is because of the inevitable fear of a DI that the American Society of Anesthesiologists Task Force on the management of different airways unequivocally state that all anesthesiologists should have a preformed or preconceived strategy for intubation of the difficult airway [13]. The most generally accepted belief that a Cormack–Lehane grade III and IV laryngoscopic views represent DI has been challenged by Arne et al. [25] on the premise that many of the grade III and IV views were actually easy intubations. Till such time that we have another gold standard with which to assess the degree of difficulty, the CLG system would continue to serve as the gold standard for the assessment of DI, although the different terminologies of DI and DL would be used interchangeably to depict the same problem or malady and this would account for the wide range of figures quoted in the literature for DI and DL.

Difficult Airway and Its Diagnosis

Difficulty in airway management is the most common concern of anesthesiologists as it leads to irrevocable insult. A thorough history would bring to limelight issues such as DI in the past, maxillofacial trauma, facial burns or surgery of the face, neck, pharynx and larynx, and radiotherapy of the neck. The presence of signs such as dyspnea, stridor, dysphagia and or snoring correlate with DI and help the anesthesiologist in carving out an alternative plan for airway management. Certain conditions such as obesity, pregnancy, a short neck, buck teeth, receding mandible and the presence of beard obviously go in favor of DI providing suggestive evidence that a DI might be in the offing.

Accurate preoperative prediction cannot be correctly comprehended with the available quantitative tests which lack in sensitivity (Se) and specificity (Sp), resulting in a low positive predictive value (PPV) for any single test. Nonetheless, different bedside tests are routinely conducted in an effort to rule out DI. We would mention the tests that are commonly employed and later draw out conclusions regarding the feasibility and applicability of the tests when used singly or in combination. We would also focus on other airway assessment aids and tools that are currently used for the prediction of DI.

Mallampati classification: Mallampati et al. [26] towards the end of the last century proposed a classification which estimates the size of the tongue relative to the oral cavity and the ability to open the mouth, and suggested that a large tongue having occupied most of the oral cavity would obscure the oropharyngeal structures thus heralding DI. Based on the structures visible in the oropharynx, with maximal mouth opening, the patient was graded into 3 grades. Later Samson and Young [27] added a fourth grade to the original classification, and presently the modified version is commonly used known as the modified Mallampati test (MMT) (Fig. 2.1). The Mallampati score based on the size of the tongue relative to the oropharynx has a good correlation with the CLG (Fig. 2.2) for visualization of the larynx, however many studies were not promising and have pointed out inter—observer variability with the Mallampati score [28–30]. Mallampati et al. [26] found a Se close to 100 % and a Sp of 80 % for their test, but these figures were not reproduced in studies conducted later. In the original study, Mallampati et al. [26] did not specify whether the patient should phonate or not thus leaving future researchers with the leverage to apply phonation or avoid it during the assessment of the airway. Lewis et al. [31] recommend that the Mallampati test be performed with the patient in the sitting position, the head fully extended, the tongue protruded with phonation. Khan et al. [32] concluded that the Mallampati test in the supine position without phonation had better compatibility in predicting difficult mask ventilation. Frerk [33] reported that the MMT had a PPV of 17.3 %, a Se of 81.2 % and a Sp of 81.5 %. They had included grade 2 in the CLG system in the DI. However, when grades 3 and 4 of the CLG system were applied, the PPV would decrease from 17.3 % to as low as 5.8 %. Yamamoto et al. [34] questioned the reliability of the MMT owing to its very low PPV of 2.8 %. They also found comparatively lower values of 67.9 and 52.5 % for Se and Sp respectively. Cattano et al. [35] demonstrated a good correlation between the Mallampati scale and the CLG system, although the Mallampati scale lacked the sensitivity to be a good predictor when used alone. Owing to a high incidence of false positives, the test was also not specific enough. Contrary to the findings by Cattano et al. [35] in which they demonstrated a good correlation between the Mallampati scale and the CLG, Khan et al. [36] describe a case that had a CLG of 1 on laryngoscopy despite a Mallampati class 4, revealing no correlation and no agreement between the Mallampati class and the CLG.

Thyromental distance: Thyromental distance (TMD) is measured along a straight line from the thyroid notch to the lower border of the mandibular mentum with the head fully extended and categorized as >6.5, 6.0–6.5 or <6.0 cm. The TMD gives us a clue regarding the mandibular space. In patients with a short mandibular space, the tongue cannot be accommodated anteriorly during laryngoscopy and is pushed posteriorly thus obscuring the glottic view. Logically, a

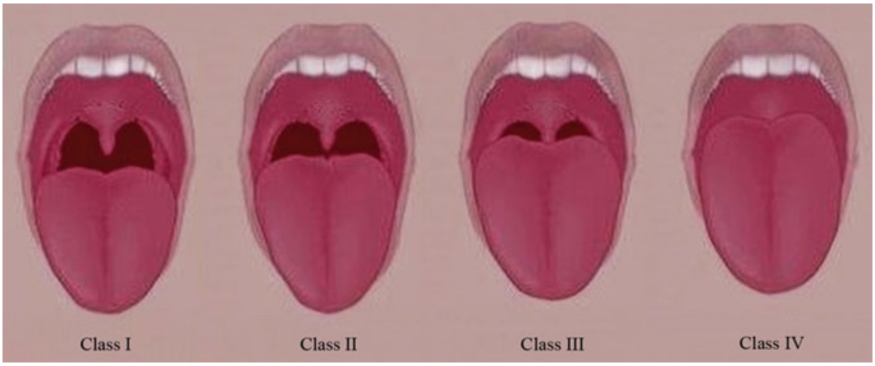

Fig. 2.1 Schematic classification of the pharyngeal structures based on Samsoon and Young's modification of the original Mallampati classification

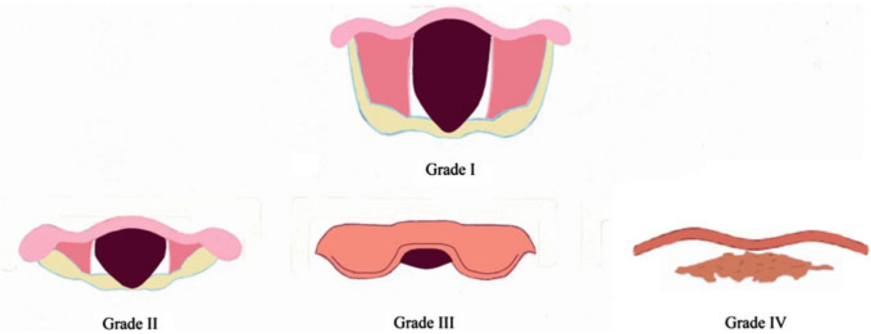

Fig. 2.2 Schematic Cormack–Lehane grading of the laryngoscopic views

short TMD should present problems with intubation. For practical purposes, a distance less than 3 finger breadths between the thyroid cartilage and the mandible is considered to indicate a receding mandible [37]. Different distances have been suggested ranging from <6 to 7 cm but neither the Se nor the Sp of TMD has been high enough to employ this landmark as the only predictor of a difficult laryngoscopy [31, 33, 38]. Although generally regarded to be of poor predictive value [38–41], TMD continues to be popular among investigators and is invariably included in almost every study. In their multivariate risk index study, El-Ganzouri et al. [42] showed that TMD was of exceedingly poor predictive value as it could only correctly predict 7 % of all difficult intubation cases. Similarly, Brodsky et al. [43] also reconfirmed that the TMD failed to show any difference between those with easy and those with difficult intubations. Some investigators [44, 45] have proposed a TMD <6 cm to be related to difficult intubation.

However, an exact reduction in the cut off value of TMD to the desired value to be of significant predictive value is still in its evolving stage. In corollary with other studies that have questioned the predictive value of TMD for difficult laryngoscopy

[29, 30, 38], Wong and Hung [46] failed to find TMD useful in predicting DI in Chinese women raising the often posed question that predictive values based on absolute anatomical measurements were of little value in predicting DI. Bilgin et al. [47] found that TMD had the lowest Se and negative predictive value (NPV), and the highest Sp and PPV compared to other assessment methods.

In Frerk's [48] investigation, a TMD <7 cm could again fetch high scores of 90.9 and 81.5 % for Se and Sp. Tse et al. [39] in contrast reported a Se and PPV for TMD to be 32 and 20 % respectively. These discrepancies cannot be fully explained and can best be attributed to the different definitions used for DI. Butler and Dhara [38] when using a cut off value of 6 cm as the predictor of DL reported values of 62, 25 and 16 % for Se, Sp and PPV for TMD. Surprisingly, there was no correlation with laryngoscopic grading in a large number of patients presenting with TM distances above or below the cut off value of 6 cm.

Hyomental Distance

Hyomental distance (HMD) is measured as the distance from the symphysis of the mandible colloquially called as the chin to the body of the hyoid bone to which the tongue is attached. This measurement also gives the clinician a clue to the potential space where the tongue would be displaced during laryngoscopy. In patients in whom the neck circumference is large, palpation of the hyoid bone would be rather difficult and the test would perhaps fetch a false positive result.

Inter-Incisor Gap

For inter-incisor gap (IIG) or mouth opening (MO), the patient maximally opens his mouth and the distance between the upper and the lower incisors in the midline is usually measured (30–40 mm or 2 large finger breadths). MO indicates movement of the temporo-mandibular joint (TMJ), and that significantly limited MO hinders exposure of the larynx. Several studies based on multivariate analysis indicated that limited MO is strongly associated with DI [30, 42, 49]. There was no correlation between IIG and, view on laryngoscopy [30] in contrast to a previous study by Wilson et al. [49]. Patients with an IIG of 4.6 cm were considered to have easy intubation and those with a mean IIG of 3.8 cm were considered to have DI [49]. Sava et al. [30] are of the opinion that laryngoscopy may be more difficult in those patients where the IIG was <2 cm rather than 5 cm as suggested by Wilson et al. [49] but this is a supposition and requires further study to ascertain its validity. Different cut off values have been forwarded by different investigators but there is hardly any consensus on an IIG that would be able to forecast a true difficulty in terms of DL.

Sternomental Distance

Sternomental distance (SMD) is measured as the distance between incisura jugularis of the sternal bone and symphysis of the mandible with the patient's head in midline neutral position, neck fully extended and the patient lying supine.SMD may be a good indicator of maximum neck extension therefore enabling a more accurate assessment of head extension than any other subjective assessment and avoiding the need for radiological examination which in fact is an infringement on patient's safety. Ramadhani et al. [50] have shown that SMD had a high Se and Sp for predicting DL. Contrary to their observations in which they concluded that SMD was not affected by age, Turkan et al. [51] found that the SMD measurements were affected both by age and sex. Sava et al. [30] found that the SMD, a positive objective indicator of head and neck mobility, was the best of the five preoperative tests.

Wilson's Risk-Sum Score

Wilson et al. [49] used weight, head and neck movement, jaw movement, receding mandible and buck teeth and suggested a risk-sum in their prospective study to assess the prediction of DL. This score had a se of 42 % and a sp of 95 % when a risk-sum of 2 or more was considered to be a predictor of DL. Compared to the Mallampati test, the Wilson's score had minimal inter observer variation. It had a false positive rate of 12 % and surprisingly combining it with the Mallampati score increased false positives [28].

Head and Neck Movement

The head and neck movement is measured as described by Wilson et al. [49] by asking the patient to fully extend the head and neck. The range of motion from full extension through full flexion was categorized as $>90°$, 80–90°, or $<80°$. Body weight is categorized as <90, 90–110 or >110 kg [28, 49]. Tse et al. [39] found that a head extension angle $\leq 80°$ to predict DI had a Se of 8 % and a PPV of 21 %. Thus it cannot be used as a reliable test in the prediction of DI. However if there is no limitation in head extension, there would be no intubation difficulty meaning that the test has high Sp and NPV thus providing reassurance that negative results indicate truly easy endotracheal intubation. The test described by Bellhouse and Dore [2] estimates the angle traversed by the occlusal surface of the maxillary teeth when the occipito-atlanto-axial (OAA) complex is fully extended. The test is based on the erroneous assumption that separate movements of the OAA complex and the sub-axial regions are possible. In half of the subjects, a more than 10° subaxial extension occured despite attempts to move the neck as little as possible [52]. The Bellhouse test evaluates an overall extention of the cervical spine and may fail to detect a pathology of the OAA complex if the subaxial excursion is not impeded.

Obesity and Body Mass Index

The impact of obesity on DI has also not been settled. Juvin et al. [53] found that DI was more common among obese than non obese patients while using the scale proposed by Adnet et al. [54], Brodsky et al. [43] on the contrary concluded that neither absolute body weight nor body mass index(BMI) was associated with intubation difficulties. The controversy widens further when others regard an increase in BMI above 30 kgm^2 as contributive to DI [10, 49, 55]. Contrary to the multifactorial system proposed by Wilson et al. [49] which postulates that greater the degree of obesity, greater is the degree and probability of difficulty, Voyages et al. [55] consider that morbid obesity should not be considered to be a more serious factor than moderate obesity (BW95–110 and >110kg). None the less, their recommendation is to opt for an elective awake intubation whenever obesity is accompanied by an inability to see the posterior pharyngeal wall.

Upper Lip Bite Test

The upper lip bite test (ULBT) introduced as a simple beside test by Khan et al. [56] was based on the hypothesis that as the range and freedom of mandibular movement and the architecture of the teeth had pivotal roles in facilitating laryngoscopic intubation, they hypothesized that the ULBT could serve as a predictor of DI. While performing the test, the patient is asked to take a bite of the upper lip with the lower incisors as far as possible and different classes are assigned as under: class 1, the ability of the patient to take a bite well above the vermilion line; class II, the patient fails to obliterate the vermilion line with the bite; class III, the lower incisors fail to reach the upper lip leaving a distinct gap between the upper and lower lips (Fig. 2.3). In the maiden study by Khan et al. [56] where in the ULBT was compared with the MMT in predicting difficulty in endotracheal intubation, they found that the ULBT showed significantly higher Sp and accuracy (Acc) than the MMT. The Se, positive and negative predictive values between the two tests however did not reveal any significant differences. Hester et al. [57] again found that the ULBT was superior to the MMT in terms of Sp and Acc in predicting DI (97 Vs. 75, 90 Vs. 64). Contrary to Khan et al.'s [56] findings which showed no differences between the two assessments regarding Se, PPV, and NPV, Hester et al. [57] found that the ULBT was superior to MMT in all measures (Se 55 Vs. 11, PPV 83 Vs. 9, NPV 90 Vs.79). They also found a strong correlation between ULBT and Cormack–Lehane scale ($r = 0.512; p < 0.001$), but no significant correlation was found between the ULBT and MMT. The ULBT could correctly predict DI 83 % of the time where as the

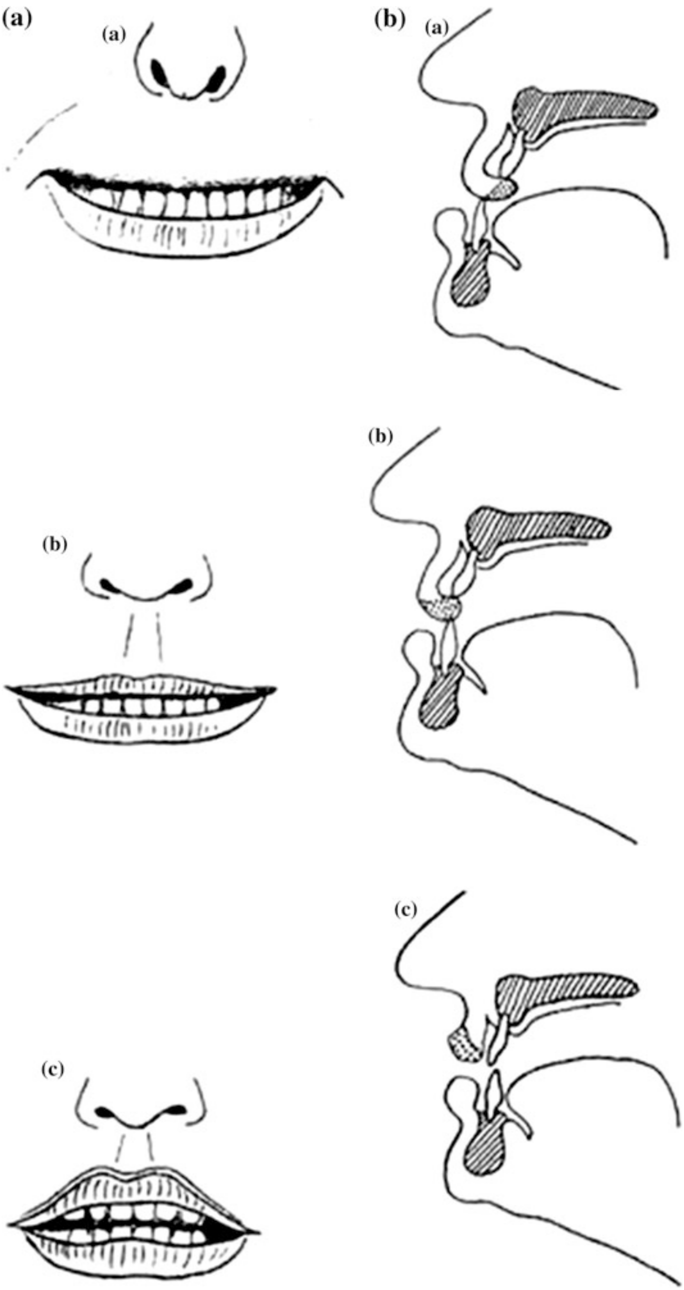

Fig. 2.3 a, b: Frontal and lateral views of the upper lip bite test (Reproduced from from Khan et al. A comparison of the upper lip bite test (a simple new technique) with modified Mallampati classification in predecting difficulty in endotracheal intubation: a prospective blinded study. Anesthesia and Analgesia. 2003; 96:595–9 by permission. (Copyright 2003, Philadelphia, Lippincott Williams and Wilkins)

MMT predicted DI only 9 % of the time. In the study by Tremblay et al. [58] the areas under the ROC curves confirmed that CLG during direct laryngoscopy and upper lip bite score were the most discriminating factors. They found out that poor glottic visualization during direct laryngoscopy and high upper lip bite score are the best predictive factors for challenging intubation with glidescope video laryngoscope. In the trial by Eberhart et al. [59] 11 % of a series of 1425 consecutive patients had to be excluded because the ULBT could not be applied to evaluate edentulous patients, and found out that both ULBT and the MMT are poor predictors for DL when used as single preoperative beside screening tests.

The ULBT simultaneously evaluates buck teeth and mandibular subluxation thus enhancing its value as a predictive test for for DI. Limited mandibular protrusion has been associated with both DI using direct laryngoscopy and difficult mask ventilation [56, 59, 60]. A high ULBT score was found to have a direct correlation with difficult mask ventilation as depicted by its high Se and odds radio [61]. The search for a predictive airway test that has the ease of applicability, reliability and accuracy of prediction(discriminating power) continues. The ULBT seems to meet all these quality factors. Increased inter observer reliability compared with the Mallampati score may be another major advantage of the ULBT.

Radiological Measurements

Cass and James [62] referring to the causes of intubation in their cases enumerated them after x-ray findings as under: (1) short muscular neck with a full set of teeth, (2) receding lower jaws, (3) obtuse mandibular angles, (4) protruding upper incisors, (5) relative overgrowth of the premaxilla, (6) poor mobility of the mandible due to temporo-mandibular arthritis or trismus, (7) large mandible, (8) short descending ramus of the mandible, (9) high arched palate associated with a long narrow mouth (resulting in less space between the angles of the mandible posteriorly), (10) increased alveolar-mental distance, necessitating wider opening of the mandible during direct laryngoscopy. They suggested that the angle of the mandible and the distances from the upper incisors to the posterior border of the ramus of the mandible, from the alveolar margin to the lower border of the mandible can be of significance in predicting DI. This case series reflect that x-rays had been employed more than half a century back to get a clue to the causes of DI, and this armamentarium is used even today to clinch the diagnosis in difficult cases of airway management.

White and Kander [63] while comparing normal and DI groups rated an increase in the posterior depth of the mandible as the most important factor hindering displacement of the soft tissues by the laryngoscope blade. Other factors contributing to DI were cited as an increase in the anterior depth of the mandible, a reduction in the distance between the occiput and the spinous process of C1, the C1–C2 inter-spinous gap and reduced mobility of the mandible associated with temporo-mandibular joint arthritis or trismus. These abnormalities could be elucidated by radiographs obtained in both case and control patients.

Karmath and Bhatt [64] construed that effective mandibular length to posterior mandibular depth ratio of less than 3.74 cm was associated with DI. This finding corroborates with that of White and Kander's [63] observations. Eversince the advent of endotracheal anesthesia, cases of DL and DI started appearing in the literature and a global search in predicting difficult cases made an unprecedented spiral rise. Since an access to anatomical landmarks of the mandible, neck and occiput was only possible through x-ray examinations, researchers resorted to roentgenographic studies to measure the different anatomical distances which they presumed and rightly presumed in playing a pivotal role in DI. Owing to the indispensible role of the mandible in relation to DI, the mandibular configuration has since been analyzed using roentgenography of lateral views of mandible in innumerable studies [2, 62–65].

Mandibulohyoid distance (MHD) has been found to be a determining factor in predicting DI by Chou and Wu [41]. In another study, Chou and Wu [65] suggested that a short mandibular ramus or a relatively caudal larynx could predispose problems in visualization of the larynx with a rigid laryngoscope, and also confirmed that the distance from the occiput to the spinous process of the atlas was an important determinant of a difficult airway. Turkan et al. [41] stated that HMD was the only morphometric measurement that was unaffected by age. While performing the Bellhouse test [2], the subaxial extension occurred independently of the degree of OAA extension, and thus the OAA complex capacity was overestimated by the degree of subaxial extension and was not always accurately evaluated. To overcome these problems of obtaining an erroneous impression from the Bellhouse test [2], radiographic examination could be of a potential value as the only method to make the distinction. Lateral neck radiographs in the neutral position and the extreme of head extension are useful as one of the preoperative airway assessment tests [52]. They also help in determining alternative techniques for airway management when tracheal intubation with a conventional laryngoscope fails [66]. However, radiological measurements have not been found to be successful for the prediction of DI as mentioned by McIntyre [67] and Randell [29]. Furthermore, radiographic studies incur a radiation threat which albeit small but still is an infringement on patient's safety.

Composite Variables or a Combination of Predictors

An effort has been made in the recent past by providing composite variables in improving screening for DI but the addition of variables also failed to increase the Se owing perhaps to the innumerable factors involved in DI. Some improvement in Se was observed but at the expense of Sp which showed a decline.

The Airway Difficulty Score (ADS) proposed by Janssens et al. [44] represents the sum of the points for five criteria of difficult intubation i.e., TMD, Mallampati class, MO, neck mobility and upper incisors whether normal, absent or prominent. For each variable, a score ranging from 5 to 15 is subscribed, and a total score $\geq$8 is declared as a potentially DI. When compared with the intubation difficulty scale

(IDS), they found a 85.7 % Sp, 75 % Se, 98.7 % NPV and a 18.6 % PPV. The use of anatomical indexes associated with the Mallampati score failed to improve Se and PPV [35]. Tse et al. [39] found that Mallmpati score, TMD and cervical mobility were of little value in predicting a difficult airway. The investigator at present is at crossroads as to which predictors should be pursued in future studies since clinical anatomical predictors so far have failed to improve our insight in anticipating a difficult airway. Bilgin et al. [47] found the Wilson risk sum to have the highest Se and NPV among the three tests i.e. Mallampati test, Wilson risk sum and TMD. Oates et al. [28] found that both the Wilson risk sum and the Mallampati test failed to predict as many as 58 % of difficult laryngoscopies.

In an obstetric population, Gupta et al. [68] found a Se of 100 % and a Sp of 96 % when using a combination of Mallampati and the Wilson's scores. Merah et al. [69] could find a Se and Sp of 85 % and 95 % respectively when using a combination of Mallampati 3 or 4, IIG of 4 cm or less, and TMD of 6.5 cm or less for predicting DI.

In an effort to arrive at the best results in predicting DI, it has been suggested that evaluation of the tests be combined, but Tse et al. [39] found that using an oropharyngeal class 3, a TMD $\leq$7 cm, a head extension angle $\leq$80° or any combination of these factors failed to predict DI reliably. The combination of all these tests had the lowest Se. The PPV again had been low in predicting DI when the tests were used alone or in combination. A TMD $\leq$7 cm had a Se of 32 %, a Sp of 80 % and a PPV of 20 %, where as an oropharyngeal class 3 had a Se, Sp, PPV and NPV of 66, 65, 22 and 93 % respectively.

A combination of oropharyngeal class 3, and a TMD $\leq$7 cm had a Se of 21 % and a PPV of 28 % thus showing no improvement. Surprisingly, Frerk [48], reported that assignment to oropharyngeal class 3 or 4 had a Se of 81.2 % and a Sp of 81.5 %, and in the same vein reported still high figures of 81.2 and 97.8 % when using the oropharyngeal class 3 or 4 and a TMD $\leq$7 cm together. Tse et al. [39] however reported high NPV for all the tests alone and their combinations thus providing reassurance that negative results indicate truly easy intubation. Scoring systems such as the IDS [54], and the ADS [45], which include multiple variables are still subject to scrutiny to serve as methods of airway assessment.

El-Ganzouri et al. [42] concluded that application of the multivariate composite airway risk index stratifies the degree of difficulty encountered in visualizing the laryngeal structures better than any of the individual airway assessment criteria used to derive it. Although the Se and Sp are above 90 % for most patient groups, the predictive value is still limited. Arne et al. [25] describe a multivariate risk index for difficulty in intubation which has a high Sp, an improved Se compared to previous studies and minimal detection failure of difficult tracheal intubation thus minimizing false negatives. Despite promising characteristics, the only drawback of this study is that it performs poorly for PPV (30–50 %) which implies that DI is falsely predicted in 2 of 3 patients or 1 of 2 patients. This may result in more time expended or use of extra manoeuvres. Karkouti et al. [70] in their model found that MO, chin protrusion and atlanto-occipital extension had a Se of 86.8 % and a Sp of 96.0 % in predicting difficult tracheal intubation. In the ongoing search for a better predictor of DI, Schmitt et al. [71] found that the ratio of height to TMD (RHTMD = Height (cm)/TMD(cm) had a better predictive value than the TMD. ≥25 cm can be used to predict difficult laryngoscopies in white men and women and suggested that it might not apply to other races. Krobbuaban et al. [72] using a multivariate analysis found that the tests using neck movement ≤80°, a Mallampati class 3 or 4 and RHTMD ≥23.5 were the major factors for predicting DL. This study was conducted on Thai patients suggesting that the RHTMD was equally applicable to other races and not exclusively restricted to the white race as upheld by Schmitt et al. [71].

In evaluating different multivariate models, Naguib et al. [73] found that their model had the highest Se compared to that of Arne et al. [25] and Wilson et al. [49] but the Sp of the models described by Arne et al. [25] and Wilson et al. [49] was significantly higher. The new prediction model described by Naguib et al. [73] considers the TMD, Mallampati score, IIG, and height. This model in which the TMD, IIG and height were measured in centimeters and Mallampati score as 0 or 1 had a high Se (82.5 %) and an equally high Sp (85.6 %).

A meta-analysis by Shiga et al. [75] evaluated beside tests for predicting DI, including the Mallampati classification, TMD, SMD, MO and the Wilson risk score. All these tests had poor to moderate discriminative power when used alone. In this study, the most powerful combination was the Mallampati classification and the TMD.

Another systematic review with a total of forty two studies enrolling 34,513 patients demonstrated that when used alone, the Mallampati class is insufficient to predict a DI. Accurate preoperative prediction cannot be realized with the available quantitative tests, which lack in Se and Sp, resulting in a low PPV for any single test [23].

In a study by Khan et al. [76] a combination of ULBT and the other tests did not show any superiority to the ULBT alone with regards to Sp and also did not enhance PPV, NPV and accuracy compared with those obtained with the ULBT alone. A combination of SMD and ULBT only improved the Se of ULBT when compared with the latter alone.

In another study, Khan et al. [77] compared the labiomandibular morphometry with cervico mandibular morphometry in order to test whether ULBT had a positive correlation with HMD, thyrosternal distance and the mandibular length. A significant agreement was found between the ULBT, HMD and mandibular length and the laryngoscopic view but no such agreement was found between thyrosternal distance and the laryngoscopic view. A stepwise increase in grade III and IV CLG was seen as the ULBT class showed a rise from I to II, and from II to III. A similar cascade of laryngoscope view was noted as the mandibular length and the HMD decreased from their predetermined values of 3.5 and 9 mm respectively. It can be concluded from this study that as the thyrosternal distance does not take into account the state of the oropharynx, thus it fails to be of help in predicting airway difficulty.

Common Limitations of the Test Parameters

The rate of difficult airway in the normal population has been estimated to be around 1:3000 [27]. With this rate, it is impossible for all the tests to be critically appraised in those patients, who truly have difficult airways. The skewed patient population under-represented in the difficult airway range makes the data collected for every tested parameter totally inadequate to represent the risk group concerned.

Whilst so much effort has been put into looking for the panacea of the problem, it must be acknowledged that the difficult airway probably represents a composite sum of many processes and factors interacting to make the process of intubation difficult. These result in the failure to find a truly representative method to predict a difficult intubation.

Conclusion

One of the most important challenges in using SMD, TMD, and IIG is the quantitative nature of these tests [76] whereas the classification of patients based on the ULBT is of a qualitative nature, making differentiation of class easy and precise. Moreover, the differences between the ULBT and the other tests are those between continuous and discrete variables. Thus, the ULBT is associated with the least inter observer variability, which adds to its advantage as an airway assessment test. Risk indexes again have been developed based on quantitative evaluations. Wilson et al. [49] developed a risk scoring system based on body weight, head and neck movement, jaw movement, and the presence or absence of mandibular recession and protruding teeth. The Naguib model [73] also considers quantitative variables such as TMD, Mallampati score, IID and height. The El-Ganzouri multivariate risk index combined and stratified seven variables derived from parameters and observations individually associated with DI [42].

Many researchers have delved deep into the matter by comparing different airway assessment tests but it is difficult to comprehend as to what degree this parallel and such comparisons are possible and fair.

Because of the very low occurrence of DI, it is exceedingly hard to predict it with a reasonable accuracy. Many investigators have expatiated on this subject extensively in order to find a panacea for the problem, but let us not forget that the causes of a difficult airway are usually infinitively more complex and more various than we are in the habit of explaining them afterwards, and are seldom clearly outlined. What I am leading up to is an earth shattering conclusion that it is beyond our intellect and comprehension to guess our way to the truth of very many things about the human airway.

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Chapter 3
Videolaryngoscopy and Indirect Intubating Aids in Airway Management

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Abstract The use of videolaryngoscopy has been incorporated into the latest revised 2013 American Society of Anesthesiologists Difficult Airway Algorithm, not only as a rescue device, but also as an initial approach to intubation. This chapter provides an overview of some popular videolaryngoscopes and indirect intubating aids which a body of evidence in the literature supports. We outline how videolaryngoscopy differs from direct laryngoscopy, the advantages and disadvantages, tips on how to improve the success of intubation, and how to document when using a videolaryngoscope. The individual characteristics of the Glidescope, CMAC, Pentax Airway Scope, McGrath MAC and McGrath series 5, Airtraq, King Vision, Venner AP Advance, intubating LMA Fastrach and C-Trach, Bonfils, Shikani, Levitan optical stylets are further expounded, with instruction and clinical tips for usage. Their clinical efficacy in the literature, problems and complications, and keypoints are summarized.

Keywords Videolaryngoscopy · Intubating aids · Difficult airway

Introduction

The aim of this chapter is to provide an introduction to some selected videolaryngoscopes (VLs) and indirect intubating aids which a body of evidence in the literature supports. Their clinical efficacy in the literature is summarized. A simple

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classification of videolaryngoscopes and indirect intubating aids is shown in Table 3.1.

The use of videolaryngoscopy and indirect intubating aids has increased tremendously not least due to the dire consequences of failed airway management [1, 2]. Instead of performing potentially traumatic maneuvers to directly visualize the larynx via direct laryngoscopy, videolaryngoscopy uses newer technology to 'look around the corner'. Indirect laryngoscopy refers to a technique where the view of the glottis is achieved through a series of cameras, video technology, fiberoptics or prisms transmitted to an eyepiece or monitor screen. It has been incorporated in the latest revised 2013 American Society of Anesthesiologists difficult airway algorithm not only as a rescue device, but also as an initial approach to intubation [3].

Systematic reviews have shown good evidence that the Airtraq®, Laryngeal Mask Airway (LMA) CTrach®, GlideScope®, Pentax AWS® and Storz V-MAC® achieve better success in subjects at a higher risk of difficult laryngoscopy [4]. Beyond achieving the primary aim of improved intubation success, videolaryngoscopy allows more gentle handing of the airway, thereby decreasing the chance of dental and airway trauma as well as reducing cardiovascular responses to airway stimulation in experienced hands. Ancillary advantages include facilitating airway training, video recording of airway management and potentially allowing telemedicine or tele-intubation. The benefits of videolaryngoscopy and indirect intubating aids are presented in Table 3.2.

Intubation Using the Conventional Macintosh Blade

In order to perform intubation successfully with direct laryngoscopy, one needs to create a line of sight for the operator to visualize the glottis directly. This necessitates placing the patient in an appropriate position before direct laryngoscopy to anteriorly displace the mandible, tongue and other soft tissue. This also clears the path for subsequent endotracheal tube (ETT) entry. This potentially stressful maneuver may result in oral and dental trauma or haemodynamic instability. In patients with limitations in cervical mobility or mouth opening, the line of sight may not be achievable, resulting in poor laryngeal views, difficult or impossible intubation [6].

Intubation Using Videolaryngoscopes

Videolaryngoscopes, on the other hand, have a camera located at the distal third of blade which allows the operator to 'see around the corner' without forcefully achieving the line of sight. Although this avoids the complications of direct laryngoscopy, introduction of the ETT into the trachea may be more difficult as soft tissue is not displaced in the fashion as when classic direct laryngoscopy was

Table 3.1 Classification of videolaryngoscope and indirect intubating aids

Classification	Characteristics	Examples
Macintosh-like videolaryngoscopes. May consists of	(i) The basic design resembles the Macintosh laryngoscope. They may be doubly used for direct laryngoscopy if the video technology was incorporated into the Macintosh-shaped blade	(i) Storz V-MAC®, Storz C-MAC®, McGrath MAC®, Venner AP Advance®
(i) Macintosh blade or		
(ii) Angulated blade	(ii) Angulated blade permits only indirect visualization of the glottis and requires a styletted pre-shaped tracheal tube	(ii) Glidescope®, McGrath series 5®, Storz D-Blade®
Optical or video devices with guiding channels	Not resembling the Macintosh laryngoscope, these devices have guiding channels that guide the tracheal tube into the trachea	Pentax Airway Scope (AWS)®, Airtraq®, KingVision®
Intubating supraglottic devices	These are laryngeal mask airways that serve the dual functions of ventilation as well as intubation, which may be blind (Fastrach®), visually guided (C-Trach®) or guided with a flexible videoscope, e.g. Ascope® (through an AMBU Aura-i®)	LMA Fastrach®, LMA C-Trach®, AMBU Aura-i®
Fiberoptic scopes and optical stylets	These are fiberoptic scopes, which may be flexible or rigid. The rigid scopes are further classified into the malleable or non-malleable types	Rigid Bonfils®, Shikani®, Levitan®
Invasive intubation devices	These devices would include devices for retrograde intubation, or cricothyroidotomy. They are generally used for second line rescue airway management as they are more invasive and potentially cause more morbidity. They are not discussed further in this chapter	

Table 3.2 Advantages and disadvantages of videolaryngoscopes and related intubating aids intubating aids

Advantages
–Greater angle of view and improved laryngeal grade
–Preliminary data suggests improved intubation success, particularly in predicted difficult and difficult intubations and those performed by novices
–Portable and suitable for rugged pre-hospital use
–Intubation possible in unconventional positions
–Video stream of intubation process to facilitate training
–Image recording capability allowing documentation or education
–Video-conferencing and 'tele-intubation'
–Single use which minimizes cross contamination
–Potentially less dental and airway trauma
Disadvantages
–In routine airways: Improved view may not translate to better intubation success. Direct laryngoscopy remains the fastest and most cost effective way to achieve intubation [5]. Intubation times are generally longer with videolaryngoscope due to operator's unfamiliarity, visual attention in 2 different places (monitor and patient's pharynx) and difficulty in introducing the tracheal tube
–Videolaryngoscopes that do not feature Macintosh blades generally requires the use of a stylet, which may potentially increase traumatic complications
–Secretions or fogging which obscures the view
–Cost associated with purchase and maintenance of the device
–Not all devices may be locally available for training purpose

performed. For successful intubation using VL, two things need to occur: (i) optimal blade insertion to view the glottis, and (ii) optimal introduction of the ETT to the vocal cords. Videolaryngoscopes are designed for insertion into the upper airway to provide a glottic image either by one of two methods: (i) in the midline over the tongue; (ii) or along the floor of mouth with displacement of tongue and flattening of the submandibular space [7]. These two methods of laryngoscopy are rarely interchangeable between laryngscopes. A device that functions in the floor of the mouth displacing the tongue and compressing the submandibular tissues (e.g. VLs with Macintosh-like blades C-MAC, McGrath MAC, Venner AP Advance) should not be used over the tongue nor should a device that is designed to pass over the tongue (e.g. anterior angulated blades like Glidescope, McGrath series 5) be used along the floor of the mouth. Correct positioning is critical for successful function of these devices during laryngoscopy and intubation. The steps to achieving successful intubation with a videolarygoscope are summarized in Table 3.3.

Successful intubation with videolaryngoscopy generally requires the use of a preformed styleted ETT [8]. Not uncommonly, the tip of the ETT may be caught on the arytenoid cartilages, inter-arytenoid soft tissues, cricoid cartilage or the anterior commisure of the glottis. Some of the techniques used to improve the passage of the ETT through the vocal cords are summarized in Table 3.4. These problems may be less frequent with laryngoscopes that incorporate a guiding channel to direct the ETT path, such as the Pentax AWS the Airtraq and the King Vision's channeled blade.

Table 3.3 How to perform indirect laryngoscopy using the "mouth-screen-mouth-screen" and optimal blade insertion technique

Step 1	Look in the mouth: Introduce the videolaryngoscope (VL) into the mouth and advance it towards the base of the tongue, taking care to avoid lips and teeth
Step 2	Look at the screen/monitor: Optimise the position of the laryngoscope to obtain the best view of the glottis. Use midline approach for anterior angulated blades (e.g. Glidescope®, McGrath series 5® C-MAC D-Blade). Sweep tongue aside anterolaterally to flatten submandibular tissues as done in direct laryngoscopy if using Macintosh-like VLs (e.g. C-MAC 3,4 blades; McGrath MAC 3,4 blades; A.P.Advance 3, 4 blades) [7]
Step 3	Look in the mouth: Introduce the ETT close to the VL blade edge with care to keep the styletted tip in view at all times
Step 4	Look at the screen/monitor: Direct the ETT between the vocal cords to achieve intubation under visual guidance. As the videolaryngoscope is being withdrawn, examine for any inadvertent trauma caused during intubation

Table 3.4 Tips to improve intubation success with videolaryngoscopes

1. To improve glottic view
   a. Increase lifting force on VL handle
   b. Withdraw and reintroduce the blade (may have deviated from the midline whilst concentrating on screen)
   c. Apply external laryngeal pressure
2. To prevent fogging
   a. Use of anti-fog solution (eg. C-Trach®, Glidescope® reusable GVL, and on tip of disposable plastic blades eg. McGrath®, Pentax AWS®,Venner AP Advance®. The newer Glidescope® stat blades have a patented anti-fogging coating that minimises this need)
   b. Turn on VL 1–2 min prior to use (eg. C-MAC®'s own heating mechanism acts as anti-fog). If view fogs upon entering the patient's mouth (which is warmer), remove blade (to ambient air) and re-insert again, to de-mist
   c. Warm the blade prior to use to prevent fogging
3. To increase the ease of ETT passage between the vocal cords
   a. Relax the upward lifting force eg. lift less
   b. Withdraw the videolaryngoscope blade by 1–2 cm. This allows the glottis to relax into a more posterior position, meeting the tip of the ETT
   c. Use stylet with pronounced curve: 90° angle superior to 60° [9]
   d. Use a flexible tip ETT, eg. the Endoflex™ that's capable of distal angulation of tip [10, 11] (Fig. 3.1) or Styletscope™ which adjusts the angle of the ETT tip between 30–90°
   e. Withdraw the stylet slightly, about an inch, and rotate the ETT
   f. "Reverse-loading" of stylet in the opposite direction of the natural curvature of the tracheal tube [9, 12]

Predictive Test for Difficult Intubation Using Videolaryngoscopes

The predictive value of clinical bedside tests for predicting difficult intubation with direct laryngoscopy remains limited. Sensitivity is generally poor in detecting the difficult airway [13]. Factors such as operator experience with the device, patient's poor mandibular advancement, short sternothyroid distance, severe retrognathia as well as various neck pathologies such as post-radiation changes, scarring and masses may indicate possible difficult videolaryngoscopy [7, 14, 15]. One airway assessment tool, the El-Ganzouri index, shows promise when it is used for patients undergoing GlideScope intubation. It comprises seven variables that assesses mouth opening, thyromental distance, neck movement, jaw prognation, body weight, Mallampati score and history of difficult intubation to predict a likely difficult airway [16].

Glidescope®

Overview and Characteristics

The GlideScope® videolaryngoscope (Verathon Inc., Washington, USA) became commercially available in 2001 and is a widely used video laryngoscope. It comes with a 60 degree curved blade with various sizes to facilitate intubations in neonates as small as 1.8 kg and morbidly obese adults. There is a wide angle of view via the metal-oxide semiconductor camera and a light emitting diode (LED) located at the distal tip of the blade. The unit consists of a video monitor which has a resolution of 320 $\times$ 240 pixels. The device switches on with a single button, and the image does not require further adjustment. The 12 V lithium rechargeable battery has an average battery life of 90 min and approximately 500 charge cycles.

Other GlideScope models include the GlideScope advanced video laryngoscope (AVL) suited for difficult airways and comes with optional disposable blades (See Fig. 3.2a, b). The GlideScope® Ranger, designed for portability, also has digital video recording ability. The GlideScope® product range is presented in Table 3.5. The Glidescope Titanium range introduced in 2014 comprises four reusable blades (Macintosh size T3 and T4, and angulated LoPro T3 and T4 blades) which are lightweight, slim and low- profile designs. It promises improved maneuverability and working space in patient's mouths.

Instruction for Use

The GlideScope is first introduced into the midline of the oral pharynx to identify the epiglottis. The GlideScope may be used like a Macintosh laryngoscope to indirectly lift the epiglottis or produce a Miller's lift. After obtaining the best glottic view, the endotracheal tube (ETT), preformed with a generic stylet, or the GlideRite® Rigid Stylet is then guided into position alongside the blade under direct vision. It is only when the distal tip of the ETT disappears from direct view that the monitor is viewed. The tube is gently rotated or angled to redirect as needed and the stylet is removed prior to advancement of the tracheal tube past the vocal cords.

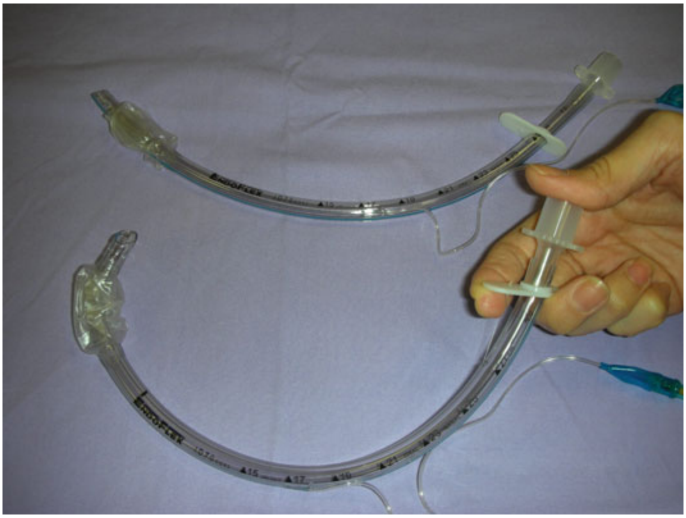

Fig. 3.1 Endoflex tracheal tube. The operator can flex its distal tip by engaging a monofilament built into the *side* of the tube as shown

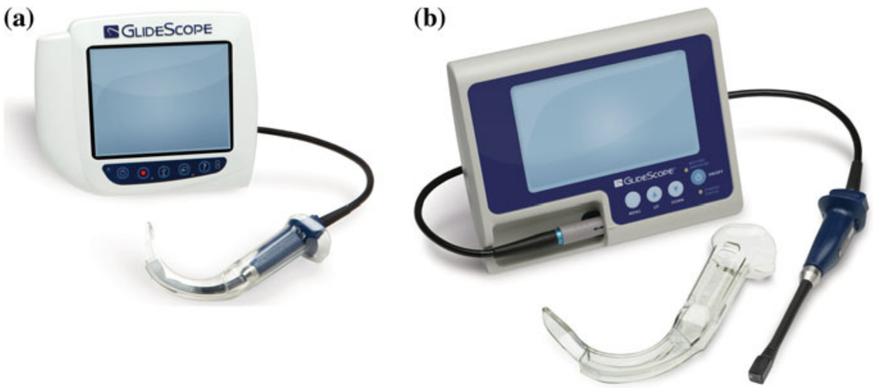

Fig. 3.2 **a** Glidescope Advanced Videolaryngoscopy (AVL) system with single use stat blades, **b** Glidescope GVL system with cobalt GVL stat blades

Clinical Performance

A meta-analysis of first time success intubation rates in 1,076 patients predicted to have a normal airway was 96.4 %, with an overall success rate of 99.8 %. In 213 patients with difficult airways, the first time success rate was 92.3 % with an overall success rate of 85.4 % [17]. Two meta-analyses of literature comparing the GlideScope with direct laryngoscopy found that there was definite improved

Table 3.5 Range of glidescope products

	Glidescope videolaryngoscope (GVL)	Glidescope advanced videolaryngoscope (AVL)			Glidescope ranger	
		Single use	Preterm/ small children	Reusable	Ranger	Single use
Suitable for patient weight	1.8 kg to morbidly obese	500 grams to morbidly obese	500 grams to 28 kg	4 kg to morbidly obese	10 kg to morbidly obese	500 grams to morbidly obese
Blade sizes (#)	GVL® 2, 3, 4, 5	GVL® Stat 0, 1, 2, 2.5, 3, 4	GVL® Stat 0, 1, 2, 2.5	GVL® 2, 3, 4, 5	Ranger® GVL 3, 4	GVL® Stat 0, 1, 2, 2.5, 3, 4
Monitor screen feature	Anti-reflective 7 inch colour monitor 320 × 240 pixel 167 × 207 × 83 mm Weight 1.4 kg	Anti-reflective 6.5 inch colour monitor 640 × 480 pixels 190 × 225 × 80 mm Weight 1 kg			Anti-reflective 3.5 inch colour monitor 320 × 240 pixel 168 × 173 × 49 mm Weight 0.56 kg	

glottic visualization, which was more pronounced in difficult intubations than routine intubations. Novice operators using the Glidescope experienced improved first intubation success rates and shorter intubation times compared to direct laryngoscopy [17, 18] but these findings were not found in experts [18].

Problems and Complications

Although the GlideScope provides an improved view when compared with direct laryngoscopy, this does not necessarily lead to better intubation success [19]. This paradox arises because the camera sited near the distal tip of the GlideScope blade acts as the 'eye' of the operator to obtain a wide angle of view. Superior, indirect view of the glottic can be achieved without the alignment of oral-pharyngeal-laryngeal axes and displacement of pharyngeal tissues to enlarge the retropharyngeal space. However, when tissues are not displaced to create the line of sight, as it is done during direct laryngoscopy (leading some users to perceive that the blade is "bulky" due to the limited oropharyngeal space) no direct path is made for the ETT advancement, In contrast, during direct laryngoscopy, intubation may be possible with adjuncts such as the bougie even in poor glottic view. Reported GlideScope-related injuries include palatopharyngeal, anterior tonsillar pillar or soft palate perforations caused by the tracheal tube, even without apparent force or difficulty during intubation [20]. The operator may be fixated on the monitor screen and fail to observe initial blade or ETT insertion, thus causing trauma.

Keypoints

The GlideScope comes with a wide rage of different models to suit different patient's sizes and needs. It is one of the most popular and researched videolaryngoscope currently on the market. Advancement of the ETT should only be done under direct vision or via the videocamera image to avoid inadvertently traumatizing the pharynx or larynx. The airway should also be examined as the blade is being removed.

McGrath®

Overview and Characteristics

McGrath® Series 5 (Aircraft Medical Limited, Edinburgh, United Kingdom) is a portable videolaryngoscope, weighing just 325 g. The CameraStick™ assembly consists of a light source and a miniature camera and the image is displayed on a

Fig. 3.3 **a** McGrath series 5 videolaryngoscope, **b** McGrath MAC videolaryngoscope

1.7-inch liquid crystal display (LCD) screen mounted on top of the laryngoscope handle. The LCD screen tilts and swivels through a 90° arc to allow the user to operate in a comfortable position whilst maintaining visual contact with the patient, the laryngoscope and during advancement of the ETT. The length of blade can be adjusted to suit patients as young as 5 years old to large adults, thus reducing the hassle of stocking different sized blades in the crash intubation cart. It is powered by a single AA battery and switches on quickly. Infection control can be maintained easily with the sterile single use disposable blades and fully immersible handle (See Fig. 3.3a).

The newer **McGrath MAC** (see Fig. 3.3b) uses a flatter 11.9 mm slim blade, which is similar to the Macintosh. It has a less pronounced curve as compared to the McGrath Series 5. The user can use it like a regular Macintosh for direct laryngoscopy or switch to using it like a McGrath Series 5 to further improve the grade of view by videolaryngoscopy, this combines the advantages of both types of devices to reduce the blind spot during intubation. It features different-sized disposable blades, equivalent to Macintosh sizes 2, 3 and 4. The other advancement from the older McGrath Series 5 is the reinforced steel core alloy chassis capable of withstanding a drop of 2 m. Compatible with the McGrath MAC, the X blade™ is a new blade launched in 2013, with an anterior angulation that is designed for the difficult airway. It is slimmer, less bulky and helps to reduce blind spot by its portrait display.

Instruction for Use

The McGrath series 5 and McGrath X blade is inserted in the midline of the oral cavity, following the base of the tongue to locate the epiglottis. Unlike direct laryngoscopy, sweeping the tongue or aligning the airway axes is not required. The epiglottis is lifted to expose the vocal cords using a gentle pivoting motion. A styleted ETT preformed to a 45–90° curvature or a bougie with a 30° distal curve is recommended by the manufacturer to guide ETT insertion. The entry of the ETT into the pharynx is directly visualized until it is visible on the screen to further advance the ETT under indirect view. Withdrawing the stylet slightly before ETT passage between the vocal cords minimizes the risk of injury. The McGrath MAC blades are used like a normal conventional Macintosh laryngoscope and the patient's tongue needs to be swept aside and displaced anterolaterally to view the vocal cords.

Clinical Performance

Overall success with McGrath in 360 unselected patients was 98–100 % in several series, [8, 21, 22] 100 % in 50 morbidly obese patients, [23] and 91 % in 91 adults in whom direct laryngoscopy failed [24, 25]. In a randomized controlled trial (RCT) comparing McGrath series 5 to Macintosh intubation in 120 uncomplicated tracheal intubations, the authors found that the use of the McGrath took a significantly longer time to intubation 47.0 versus 29.5 s, without an improvement in grade of laryngoscopy view by novice anaesthesologists [22]. In 88 patients with simulated difficult airway, the McGrath series 5 improved the glottic view by 1–3 grades compared with the Macintosh. Tracheal intubation was also successful in all patients using McGrath as compared to a 59 % success rate in the Macintosh group. Stylets were used in all patients, but laryngeal manipulation was not allowed during intubation [26].

In 80 patients with Mallampati grade ≥3, McGrath was able to achieve 90 % grade 1 Cormack and Lehane view as compared to 72 % when a Henderson straight blade was used. However, apart from improving laryngeal view, secondary outcomes such as intubation duration, number of attempts or complications was similar [27]. When compared to the C-MAC in 130 Mallampati grade of ≥3 intubations, time to successful intubation with the McGrath was longer at 67 s versus 50 s in the C-MAC, despite the McGrath videolaryngoscope providing significantly more grade 1 laryngoscopic views. Intubation success, complication rate, and haemodynamic responses between the two videolaryngoscopes were similar [28]. A benefit of the McGrath's slim blade profile is in allowing awake airway evaluation [29]. A recent RCT comparing awake intubation in patients with anticipated difficult airway by experienced anaesthesiologists using a flexible fiberoptic scope or the McGrath found no difference in time to tracheal intubation [30].

Problems and Complications

Users worldwide describe occassional flickering of the screen with the McGrath series 5 that impedes the view. In overcoming this, the manufacturers advocate the sole use of a lithium ion battery, a battery change if flickering is encountered, and cleaning/good maintenance of the battery contact points in the handle (Teoh WH. Personal communication with Aircraft Medical and distributors). Due to its anterior blade angulation, intubation with a pre-styletted ETT is recommended, and as with the Glidescope, palatal perforations have also been reported with the McGrath [31].

Keypoints

The McGrath is a portable and useful device. It improves the laryngeal view in normal and difficult intubations and has a high intubation success rate. More comparative studies with other devices are required for a conclusive evaluation. With the expanding range of blades available, including the McGrath MAC and the X blade, it is versatile in managing difficult airways.

Storz V-MAC®, C-MAC®

Overview and Characteristics

The V-MAC® (Karl Storz, Tuttlingen, Germany) is a videolaryngoscope with a Macintosh blade, launched in 2003. The prototype features the laryngoscope, which houses the camera, as well as a separate LCD screen. It requires a fiber light cord and a camera cable, which connect to the light source and camera control unit, respectively. The monitor may be placed on the patient's chest to allow the operator to attempt intubation and view the patient and the monitor in one axis.

The newer generation C-MAC videolaryngoscope is a portable model, which consists of only the laryngoscope connected to the monitor via one cable (See Fig. 3.4a). The C-MAC differs in the slimmer, closed blade design with no gaps for hygienic traps, as well as better image quality. In contrast to the V-MAC which uses fiberoptic technique with external light source, C-MAC uses a 800 × 480 pixels Complementary Metal Oxide Semiconductor digital camera and a LED, located laterally in the distal third of the blade. There is no need for focusing or white balance. The embedded optical lens provides a wider angle of view of 80° (see Fig. 3.4b).

Karl Storz is now offering the 4th generation of the C-MAC system that is battery operated and allows video or image storage. The D-BLADE (DCI®) is a

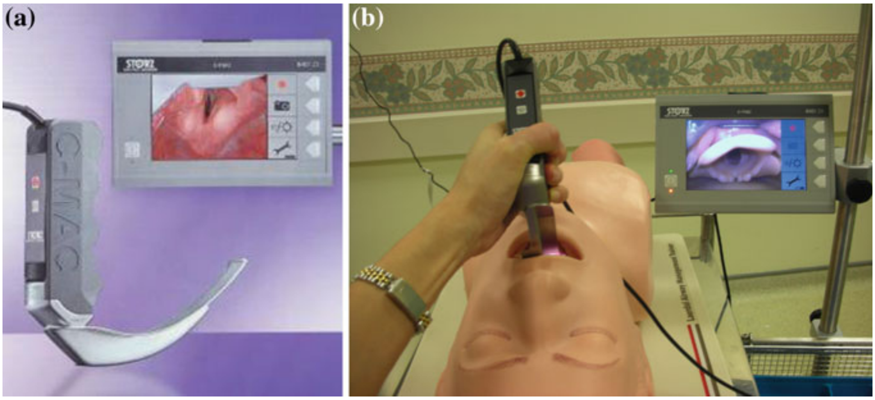

Fig. 3.4 **a** C-MAC videolaryngoscope, **b** C-MAC provides a widened viewing angle to 80° improving glottic views

further extension of the existing system and differs in its pronouncedly curved blade. It is recommended for the subset of patients with difficult airway who cannot be managed with the C-MAC. Experienced anesthesiologists were able to achieve 100 % success intubation in 20 patients with unexpected difficult intubation whilst using the C-Mac D Blade [32].

The C-MAC PM (Pocket Monitor) is a further improvement in portability as its monitor is attached to the top of the laryngoscope handle. The C-MAC S is a single use system, which features a disposable one-piece blade-handle unit to optimize protection against cross contamination of infectious material. See Table 3.6 for a summary of product features.

Instruction for Use

A videolaryngoscope that comes with Macintosh blades combines the dual advantages of direct laryngoscopy and enhanced video view (wider angle) in the one device, thereby improving glottic visualization [33]. There is practically no learning curve and its use is intuitive to all anaesthetists who have grown-up learning to intubate with a standard Macintosh direct laryngoscope by sweeping the tongue anterolaterally. Hence, they need not master new skills to achieve a good view on laryngoscopy. However, delivering the ETT through the vocal cords is a dynamic process that requires some hand-eye coordination, and the authors recommend 20 clinical intubations to gain device-specific proficiency. This is true for all videolaryngoscopes on the market. However, the C-MAC's ease of blade insertion (and laryngoscopy technique) has been ranked easiest and best amongst other videolaryngoscope devices e.g. Glidescope and Pentax AirwayScope [34]. Tracheal tube advancement is also generally simpler than when angulated blades are used, and a bougie or stylet not always necessary.

Table 3.6 List of V-MAC and C-MAC products

V-MAC	Reusable standard Macintosh blade Comes in paediatric and adult sizes Fiberoptic technique with an external light source Separate 8 inch LCD monitor Not portable
C-MAC	Portable Slimmer blade profile (14 mm) with slanted edges to minimize dental trauma Closed blade design with no gaps for hygienic traps Reusable standard Macintosh blades sizes ranging 2–4, and D-Blade. Separate 7 inch LCD monitor with 800 × 480 pixel resolution Lithium rechargeable battery lasting up to 2 h Embedded optical lens has an increased aperture angle of 80° Anti-fog mechanism present
C-MAC® PM	Highest portability and recommended for preclinical use High-resolution 2.4" LED display with 240 × 320 pixels Rechargeable Li-ion battery with one hour operating time Pocket monitor unit can be fully immersed in disinfection solution
C-MAC® S	Single disposable piece consisting of the blade and handle providing protection against infections D-BLADE with short handle MACINTOSH blades which are easily exchanged

Clinical Performance

Systemic review of the V-MAC showed a first time intubation success rate of 87–93 % in unselected airways, overall success rate of 98–100 % in predicted difficult airway and overall success rate of 99–100 % in unselected airways [4]. In 150 morbidly obese patients [23] and 450 patients with normal airways [8], the V-MAC required half the number of attempts for tracheal intubation with the least amount of time or extra adjuncts required as compared to the GlideScope or McGrath. In a preliminary study of 60 unselected patients, a good view and intubation were achieved in all, with a median intubation time of 16 s. Three patients with unexpected difficult laryngoscopy were intubated easily using the straight blade technique [35]. In 100 patients with normal airways, the C-MAC has a high first time success rate of 93 % [34]. In 300 patients with predictors of difficult airway, the C-MAC achieved a better view and first time success (93 vs. 84 %) as compared with the Macintosh amongst a diverse range of operators [36].

Problems and Complications

It is of note that despite a plethora of publications on the use of the VMAC and C-MAC since their introduction into clinical use since 2003 and 2008 respectively, there is no report in the literature regarding any injuries or perforations of pharyngeal structures, compared to the Glidescope (introduced in 2001) and McGrath in 2006. Compared to oher videolaryngoscopes, subtle differences pertaining to the geometry of the C-MAC blade and position of the camera on the blade may account for its safety track record.

Keypoints

There is good evidence in the literature that the V-MAC has a high overall success in subjects at a higher risk of difficulty during direct laryngoscopy. The range of V-MAC and C-MAC products from Storz provide a wide scope of options and versatility. For the majority of anaesthesiologists trained in the use of the Macintosh blade, the ease of switching to the C-MAC system is a benefit. In contrast to other videolaryngoscopes, the C-MAC can obtain both a direct laryngoscopic view and a camera view, which is displayed on the video screen. It is particularly useful during direct laryngoscopy training when the instructor can follow the student's intubation attempts directly to provide real time guidance and to monitor for complications.

PENTAX Airway Scope (AWS)®

Overview and Characteristics

The PENTAX Airway Scope (AWS) videolaryngoscope (Pentax Medical, Tokyo, Japan) is a channeled indirect videolaryngoscope available since 2006. It has a tube guidance system, which assists in directing the ETT into the trachea, eliminating the need for a stylet. It consists of a 2.4 inch LCD screen mounted onto a characteristic orange-coloured handle, which is connected to an anatomically shaped, disposable rigid Pblade (See Fig. 3.5). The light source and camera system is located 3 cm from the tip of the blade. The monitor screen may be adjusted from 0 to 120 degree to facilitate viewing of images from positions relative to the patient's head. The ETT channel, which guides its insertion, fits ETT sizes up to 11 mm in external diameter or even a double-lumen tube [37]. Suctioning of secretions may be performed under direct vision via the PBlade's dedicated built-in channel. The lightweight (430 g), simple design, water resistant and durable construction allows prehospital, inclement weather use. Two AA batteries operate it, which allows an hour of usage. Video documentation of intubation is possible with compatible external monitors or recording devices. An improved version was introduced in 2014 called the Pentax AWS-S200, which is lighter (235 g) and accomodates a wider repertoire of PBlades. In addition to the standard adult PBlade (55 g that houses ETT 8.5–11.0 mm outer diameter), there is now a thinner adult blade (25 g, ETT 7.5–10.0 mm), a neonatal blade (ETT below 5.0 mm) and a pediatric blade (ETT 5.5–7.6 mm).

Fig. 3.5 Pentax airway scope with tracheal tube in its guiding channel

Instruction for Use

Successful laryngoscopy and intubation with the AWS requires an "insertion–rotation–elevation–intubation" technique [38]. Firstly, the AWS is introduced into the patient's mouth in the midline (insertion), its blade advanced into the posterior pharynx with the screen rotated towards the user (rotation) till the glottis is observed on the LCD monitor. The epiglottis is identified and elevated directly with the PBlade tip (elevation).The vocal cords need to be sited within the green target symbol on the monitor, to facilitate intubation by indicating the direction of ETT travel. Once the target mark is aligned with the vocal cords, the preloaded ETT is advanced via the tube channel, and then removed from the groove. Neck extension to align the airway axes is not required to achieve a good glottic view due to its anatomically shaped blade. The use of a bougie prior to the introduction of ETT may further reduce cervical spine movement in patients with spinal pathology [39].

Clinical Performance

Systematic review of AWS shows 97–100 and 99–100 % overall success in patients with predicted difficult airway and unselected airway, respectively [4]. In an initial study of AWS in 320 unselected patients, it was found to have a 96 % first time intubation success and a 100 % overall success rate with a mean intubation time of 20 s. It converted 14 % of the grade 3 and 4 Cormack and Lehane views using the Macintosh to grade 1 or 2 views [40]. Intubation with the AWS by 74 operators on 405 patients found a 100 % glottis visualization and intubation rate [41].

In addition to improving views, its tube guide-facilitated intubation eliminated the problems commonly faced by other videolaryngoscope during ETT insertion. When compared with Macintosh, GlideScope and C-Mac, AWS had the shortest intubation times, best grade 1 laryngeal view (97 %) and best first time intubation success rate of 95 % in a group of 400 patients with normal airways [34]. There was also less postoperative sorethroat with the AWS compared to the Glidescope [42].

In 46 patients with sleep apnea undergoing uvuloplasty, the AWS has been shown to have better first attempt success rate (100 vs. 82.6 %) and faster intubation time (12.9 vs. 29.9 s) than the Macintosh [43]. In 203 patients with restricted neck movements, a grade 1 view and intubation was achieved 100 % with the AWS as compared to the Macintosh, where grade 1–2 views were seen only in 89 % and successful intubation only in 89 % [44]. This study corroborated with a comparative study of 4 airway devices in 120 patients with restricted neck movements, which also found AWS had improved views, ease of intubation and the least haemodynamic disturbance amongst the Macintosh, Truview and Glidescope [45]. In 270 patients with difficult direct laryngoscopy, intubation was achieved in 99.3 % using the AWS [46].

In contrast, one study found the AWS not to be useful. In 105 obese patients randomized to a size 4 Macintosh or AWS found that the time to intubation was longer in the Pentax group with a poorer first time (86 vs. 92 %) and overall success rate (90 vs. 100 %) [47]. It is unclear how the patients in this study were positioned. There is controversy regarding the optimum head and neck placement of patients for AWS intubation, with some advocating the “sniffing morning air position” and others a neutral neck position without a pillow [47].

Numerous reports of awake intubation for difficult airways via oral or nasal routes have been described in literature with the AWS [48]. In patients with airway pathology, it may not be possible to avoid injury with the ETT as it is being advanced over the flexible fiberscope. The AWS is beneficial in this aspect as it allows the course of tracheal intubation to be monitored. Successful intubation with the AWS has also been described in the prone position [49], in mannequins undergoing simulated chest compression (hence its benefit over conventional Macintosh laryngoscopy in resuscitation scenarios) [50], and in the first robotic tracheal intubation in humans [51].

Problems and Complications

The PBlade, which appears somewhat bulky, requires a mouth opening of at least 2.5 cm. Another limitation is the standard adult PBlade’s length of 32.5 cm. Placement of the blade may not be ideal in larger sized patients. In instances where an optimum laryngeal view cannot be obtained due to the inability to lift the epiglottis with the AWS, a jaw thrust maneuver has been described to lift the epiglottis and expose the glottis [52] or using a bougie [53].

Intubation with the AWS appears to have a higher failure rate when the reinforced ETT is used. It is postulated that the ETT channel and target symbol is designed for preformed, curved PVC tubes and when reinforced tubes are used, the reinforced ETT moves posterior to the target symbol. This problem can be resolved by first inserting a bougie into the trachea under direct vision prior to railroading in the reinforced ETT [54].

Keypoints

The AWS improves the laryngeal view, and its strength lies in its unique tube guiding channel which facilitates tracheal intubation under vision, eliminating the use of a bougie or need for stylet. There is good evidence for its role in the management of predicted difficult airway, and increasingly in not only routine airways, but also difficult intubations, prehospital resuscitation and intubation in non-supine positions.

Airtraq®

Overview and Characteristics

The Airtraq® Avant (Prodol Meditec SA, Spain) laryngoscope is an anatomically shaped, optical laryngoscope with a guiding channel which holds and directs the ETT to the glottic opening. It has two viewing systems and either allows the user to look into the airway through the eyecup or through a wireless camera and display recorder.

It consists of 4 components:

(1) The reusable Optics, which contains the optic, electronic and anti-fog system. Each full battery charge allows illumination for up to 90 min and the service life of the optics approximates 50 uses. Battery charge and service life light indicators are included.

(2) The disposable Blades and Eyecup protects the Optics system from patient contact and can be easily assembled with the Optics. The blade comes in a regular size 3 for use with ETT sizes 7.0–8.5 and a small size for use with ETT sizes 6.0–7.5. Both can work with any types of ETTs including double lumen tubes. They require a minimum mouth opening of 18 mm.

(3) The Docking Station, which recharges the battery and displays service life.

(4) The optional Camera that can be attached to any Airtraq model to transmit images wirelessly when used with the Airtraq Wireless Display Recorder monitor.

Fig. 3.6 Airtraqs (single use) in a range of adult, pediatric and neonatal sizes

The Airtraq SP is fully disposable and comes in 2 more models for the adult intubation—the double lumen model that can hold double lumen tubes sizes 28–41 Fr and the adult nasal model. There are 3 models for paediatric use—the paediatric (compatible with size 4.0–5.5 ETTs), the infant (compatible with size 2.5–3.5 ETTs) and the infant nasal model (See Fig. 3.6). Newly launched in 2014 is the Airtraq A360 WiFi camera that sits atop the Airtraq. With a 2-axis flip screen and video recording capability, the image can be transmitted by wifi to PCs, tablets, laptops. Soon, there will be a snap-on connector and App for all smartphones, and integrated adapter to FOB cameras.

Instruction for Use

The Airtraq/ETT assembly is inserted into the oral cavity in the midline and advanced over the tongue with minimal anatomical distortion. The tip of the Airtraq blade is introduced into the vallecula to lift the epiglottis or it may be placed under the epiglottis to expose the glottic opening. The tracheal tube can then be advanced down the channel while the vertical lifting force is maintained. After successful insertion of the ETT into the trachea, the tube is peeled off the guiding channel. A finger placed between the channel and the ETT facilitates the separation of the ETT. The Airtraq is then removed while holding the ETT in place.

Successful tracheal intubation using the Airtraq laryngoscope requires the glottic opening to be centred in the view, and positioning the inter-arytenoid cleft medially below the horizontal line in the centre of the view [55]. In obese patients, the Airtraq may be inserted 180° opposite to that recommended and once in place, rotated into the conventional pharyngeal position [56]. Contrary to manufacturer's instructions, Stott et al. [57] recommends the use of the dominant hand to manipulate the Airtraq. The non-dominant hand may perform a jaw lift maneuver to open the mouth. When an optimal image of the glottis has been obtained, the non-dominant hand can then maintain the Airtraq position whilst the dominant hand advances the ETT.

Clinical Performance

A meta-analysis of 12 RCT including 1061 patients showed a reduced intubation time when the Airtraq was used by experienced anaesthesiologists and novices. The risk of esophageal intubation was significantly reduced, first attempt successful intubation was increased in novices but not experienced operators [58]. It appears that the Airtraq is an effective device for intubation, especially in novice hands [58, 59]. Another systematic review of Airtraq intubation found 89–100 % success in unselected patients, 96–100 % success in patients with a higher risk of difficult direct laryngoscopy and 80–100 % overall success rate of intubation in patients with failed or difficult laryngoscopy [4].

In 90 patients with cervical spine immobilization, the Airtraq demonstrated best performance in terms of ease of intubation, glottic view, need for maneouvers to optimize visualization, as compared to the Macintosh and the C-MAC [60]. In 106 morbidly obese patients, the Airtraq achieves faster intubation (24 vs. 56 s) and was better at preventing arterial oxygen desaturation as compared to the Macintosh [61]. This was supported by another study in which 132 bariatric patients had a faster intubation time (14 vs. 37 s) and better glottic view in the Airtraq group when compared to the Macintosh group. One patient who failed Macintosh intubation was successfully intubated with the Airtraq [62].

In a large prospective study of a difficult airway algorithm involving 12,225 patients, 27 of the 28 who failed Macintosh intubation were intubated successfully with the Airtraq. Of the 27 patients, 3 required a bougie as an adjunct. The single patient who failed Airtraq intubation was a tall and obese man (1.9 m, 40 kg/m^2 BMI) with a floppy epiglottis which could not be lifted to give a good view. He was eventually intubated with an LMA CTrach [63].

In a study of 200 nasal intubations in normal and expected difficult airway, all normal intubations (n = 100) were successful in both the Airtraq and Macintosh groups. In the expected difficult intubation group, the Airtraq proved to be superior to the Macintosh with a better success rate (94 vs. 66 %), superior glottic view, shorter intubation time (45 vs. 77 s), and reduced number of optimizing manoeuvres [64]. The efficacy of nasal intubation with the Airtraq was found to be comparable to that of the C-Mac and GlideScope when a modified Magill forceps was used [65]. For insertion of a double lumen ETT, the Airtraq was comparable to the Macintosh in terms of intubation duration (20.1 vs. 17.5 s), although visualization was improved in the Airtraq group [66].

The Airtraq was shown to be disappointing when used as a first line airway device in the prehospital setting. Out of 212 patients in a RCT, the success rate of the Airtraq was 47 % versus 99 % when compared with the Macintosh. Problems identified with the use of the Airtraq were poor views due to blood or vomitus and handling problems such as poor visualization of the glottis, ETT displacement or cuff damage. Direct laryngoscopy was successful on the first attempt in 54 of the 56 patients who failed Airtraq intubation [67].

Problems and Complications

The attractiveness of the single use Airtraqs is its extreme portability and individual packaging, making it ideal to be stored as the portable videolaryngoscope with negligible maintenance for "grab bags" e.g. resuscitation bags, when an airway code, trauma or need for emergency medical management is called. Its success with novices in decreasing oesophageal intubation is encouraging but needs to be interpreted with caution, due to the Airtraq failures from poor view due to blood and vomitus as described above. Moreover, the tip of the ETT tends to exit lower from the Aitrtraq blade aperture compared to a similarly shaped device e.g. Pentax-AWS, and prior clinical experience is needed to learn subtle manipulations and device handling, so the ETT does not get caught on the inter-arytenoids or enter the oesphagus [7]. The view from the single use Airtraq is also limited (looking down an eyepiece) and less panoramic during regular intubation, making it harder to correct any malposition during laryngoscopy if the device is not maintained in the midline of the mouth. Fogging of the lens can obscure the laryngeal view, particularly when intubation is prolonged. Incidence of fogging in a study of 604 adult and paediatric patients was 12 %. Connecting the circuit to the ETT and activating the oxygen flush valve two to three times rapidly successfully defogged the lens [68]. However, the risk of barotrauma or gastric distension is cautioned.

Keypoints

There is evidence in the literature to show that the Airtraq is comparable to direct laryngoscopy in routine airway management. During difficult intubations in patients who are obese or with immobilized cervical spines, it has been shown to be superior. It is also useful in nasal and double lumen intubation. However, its efficacy in the prehospital setting and paediatric intubations remains to be seen.

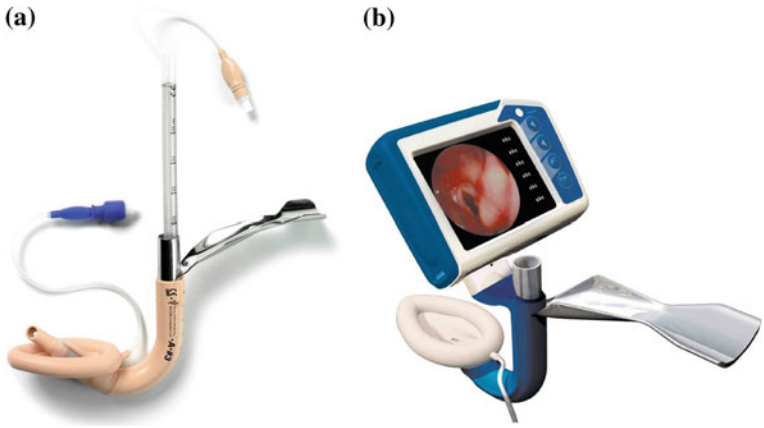

Fig. 3.7 **a** Intubating LMA Fastrach, **b** Intubating LMA C-Trach

Lma Fastrach® and Lma C-Trach®

Overview and Characteristics

The **LMA™ Fastrach** (LMA North America, Inc, San Diego, USA) is an evolution from the classic LMA which is designed to facilitate blind intubation via the LMA while allowing continuous ventilation. The Fastrach includes a rigid, anatomically shaped airway tube that allows the insertion of a size 8.0 ETT which is short enough to facilitate the ETT's passage past the vocal cords. The rigid handle allows single hand insertion, adjustment and removal of the device while freeing the other hand for manual bag ventilation. The mask aperture holds the epiglottic elevating bar, which elevates the epiglottis during ETT insertion. The ETT is also directed centrally and anteriorly to minimize arytenoid trauma or esophageal intubation. It is available in 2 sizes in adults (LMA sizes 4 and 5, both suitable for ETTs up to size 7.5) and 1 size in children (LMA size 3, suitable for ETTs up to size 7.0) (See Fig. 3.7a). The LMA Fastrach™ is available with a LMA Fastrach ETT (sizes 6.0–8.0 mm) and comes in reusable or disposable models [69].

The **LMA™ CTrach** (Teleflex, Buckinghamshire, United Kingdom) is a further modification containing an integrated fibreoptic system, which optimizes the light source and allows uninterrupted image transmission to the operator. A lens sits behind the epiglottis elevator and captures the image from the front of the mask aperture, located over the glottis when the CTrach is positioned. A detachable high resolution (10000 pixel, 3.4 inch) LCD digital viewer displays the captured image. The image is adjusted with a focusing wheel located at the side of the viewer. Light intensity is changed by push buttons. It comes with a charger cradle and rechargeable battery, when charged, allows 30 min of continuous usage. The CTrach is reusable and autoclavable, allowing 20 uses (see Fig. 3.7b).

Instruction for Use

The CTrach is first inserted without the viewer attached. The mask is inflated to optimize ventilation. The viewer is then attached to the magnetic latch connector. When the glottis comes into view, the ETT is passed into the trachea under vision before its placement is confirmed clinically. Both the viewer and the CTrach mask may then be removed.

Clinical Performance

The Intubating LMA Fastrach used to be the difficult airway device advocated in failed intubation algorithms, prior to the prevalent use of videolaryngoscopes. It allows ventilation, that videolaryngoscopes don't [70]. There is a high success rate of LMA insertion in 294 patients with normal airway when the CTrach is used for intubation. First attempt success rate exceeded 93.3 %, overall success rate averaged 98.3 % and average time to intubation ranged from 116 to 166 s. Ventilation was possible in all patients. Failures occurred due to poor views obtained through the LMA where intubation had failed or was not attempted [71–73]. In 104 morbidly obese patients, oxygenation was improved in those managed with the CTrach as compared to direct laryngoscopy. Blind tracheal intubation was mandatory in 17 % of those in the direct laryngoscopy group, while tracheal intubation was observed in all from the CTrach group. However, the duration of tracheal intubation was increased by 57 s in the CTrach group due to LMA placement, without increased incidence of adverse events [74]. Awake intubation in patients with difficult airways has been described using CTrach [75]. Twenty out of 21 intubations were well tolerated and successful: 19 under vision and 1 blindly. In one instance, intubation failed due to undiagnosed lingual tonsil hyperplasia.

Problems and Complications

Associated problems with the CTrach include poor view and airway trauma. Reasons for poor view include poor light intensity and obstruction by the down folding epiglottis, arytenoids or secretions [71, 76]. Adjustment manoeuvres to improve poor views can lead to high rates of successful intubation. Compared with fibreoptic scopes, image quality of the CTrach is poorer. Even though the warranty covers 20 applications, image quality deteriorates with use. Nonetheless, even in poor view or optics failure, the Ctrach can be used as a regular intubating LMA. The size of the ETT used is limited by the size of the CTrach. Only the CTrach ETTs are compatible. Preparation is required before use, which may cause delay

Fig. 3.8 Bonfils rigid fiberscope

due to application of anti-fog solution, lubrication of the assembly, as well as the adjustment of image focus and light intensity.

Keypoints

The CTrach is a unique device that allows continuous ventilation to minimize the likelihood of hypoxia during intubation. It is particularly useful in patients with low functional respiratory reserve, such as those encountered during "cannot intubate-cannot ventilate" scenarios or during cardiopulmonary resuscitation. As an LMA, it may be ideal for prehospital use. It is unknown if the increased duration required to achieve intubation translates to an increased risk of aspiration.

Bonfils®

Overview and Characteristics

The Bonfils Retromolar Intubation Fiberscope (Karl Storz GmbH, Tuttlingen, Germany) is a 40 cm long, straight, rigid intubating stylet with a 40 degree curved tip to facilitate targeted intubation under vision. It has a 110 degree wide angle of view. The eyepiece is mounted on the handle proximally, and is used for direct viewing or may be attached to a camera and video monitor system. A light source or battery pack is attached to the handle (see Fig. 3.8).

Table 3.7 Characteristics, indications and advantages of Bonfils fiberscope

Characteristics	Advantages	Indications
Rigid, straight fiberoptic device with a 40-degree curved tip and 110-degree angle of view	* Facilitates targeted intubation which can be achieved without cervical spine manipulation * Wide angle view allows visual assessment of aberrant anatomy to determine feasibility of intubation * Can maneuver around and displace mobile structures	* Intubation in patients with unstable or fixed cervical spine * Allows intubation in patient with difficult airways, particularly in those with anterior larynx, long floppy epiglottis or mobile airway tumors
Slim profile of 5 mm external diameter allowing intubation via the retromolar approach	Minimal airway trauma, hemodynamic instability	* Intubation in patients with small mouth opening and/or delicate dental work, loose or inconveniently placed teeth which impede intubation * Possible awake oral airway assessment or intubation
No leading edge that must displace tissues prior to viewing the larynx	Minimizes tissue injury	Intubation in patients with a history of traumatic intubation or friable tissues
Lightweight, durable, portable and fast set up	Allows intubation in remote locations	Intubation in pre-hospital settings or “code blue” situations
Available in paediatric sizes with 2 mm or 3.5 mm external diameter	One of the few difficult airway devices available for use in children	Children with congenital airway anomalies

The Bonfils comes in one size for adults, which has a 5 mm outer diameter (fits ETT size 6.0 mm and above), and 2 sizes for children, which have outer diameters of 2 mm (2.5–3.5 mm ETT) or 3.5 mm (4.5–5.5 mm ETT). The adult version has a 1.2 mm working channel within the shaft, which allows local anaesthetic administration into the airway via the distal tip. The Bonfils is designed to be durable, lightweight and portable. The characteristics and advantages are summarized in Table 3.7 [77].

Instruction for Use

The ETT is loaded onto the scope body, and is locked at the proximal end by a detachable ETT holder. The distal end of the Bonfils fiberscope is aligned with the beveled tip of the ETT. Via the tube adaptor, it is possible to insufflate oxygen or suction the airway. Low flow oxygen (less than 3 liters per minute) insufflation minimizes fogging of the lens, and disperses oral secretions from the lens tip. It is imperative to ensure that the attached camera and video monitor system are focused and orientated, as the attachment is not fixed.

In the recommended retromolar intubation technique, the operator's left hand grasps the mandible to expose the laryngeal inlet. The scope is advanced down the right side of patient's mouth, alongside the molars and underneath the epiglottis. The scope is then rotated to view the epiglottis and guided through the vocal cords to identify the tracheal rings. The ETT may then be railroaded using a gentle corkscrew motion after releasing it from the ETT holder. Alternatively, the scope can be advanced midline to the epiglottis. This is easier for novices to locate the laryngeal inlet. Instead of a chin lift maneouvre, direct laryngoscopy may enlarge the retropharyngeal space.

Clinical Performance

Overall successful intubation in "predicted normal airway" patients and "predicted difficult or difficult airway" patients were 96.4 and 95.6 % in a meta-analysis [17]. There are several case series describing the use of the Bonfils in normal airways with contradicting results. Intubation success was 98.3 % with a median intubation time of 33 s in 60 patients by anaesthesiologists unfamiliar with the Bonfils. Based on their experience, the authors recommended a learning curve of 20 intubations [78]. However, in another study of 36 unselected patients, the overall successful intubation rate was only 86 % with a long median intubation time of 80 s. There were 5 failed intubation, due to inability to locate the laryngeal inlet and esophageal intubation [79].

Comparison with Flexible Fiberoptic Bronchoscope

The FOB is the gold standard in difficult airway management and awake intubation, and is a component of the ASA difficult airway algorithm [3]. In a RCT, 116 patients with difficult airways were included to undergo Bonfils—or FOB-aided tracheal intubation. Endoscopic view was better, and the time to intubation shorter in the Bonfils group (160 vs. 229 s). Of the 3 failed intubations with the FOB, intubation was achieved with the Bonfils in 2 patients [80]. Bonfils preparation requires a shorter time, and the ability to observe ETT advancement between the vocal cords lowers the risk of injury. The Bonfils' rigid structure can displace soft tissue or a floppy epiglottis and allows advancement past the obstruction. There is improved endoscopic orientation with the Bonfils. The operator only requires one hand for maneuvering with a better translation of hand-to-scope movements.

Comparison with the Macintosh Laryngoscope

In patients with normal cervical spines, intubation is more successful (100 vs. 91.7 %) and faster with the Macintosh (18.9 vs. 52.1 s) [81]. The Bonfils, however, is more effective for intubation in patients with immobilized cervical spines and limited inter-incisor distance when compared with the Macintosh (success rate of 81.6 vs. 39.5 %) [82]. Cervical spine movement is also less when Bonfils is used (5.5 vs. 22.5°), thus potentially benefitting patients with unstable cervical spine, or those needing a cervical collar [81]. The Bonfils was an effective rescue device after failed direct laryngoscopy and intubation in 25 patients undergoing elective cardiac surgery, achieving intubation in 24 patients. The last patient was eventually intubated nasally with the FOB. Mean intubation time using the Bonfils was 47.5 s without occurrence of adverse event [83].

Other Settings

The successful use of the Bonfils in the prehospital emergency setting [84], awake intubation [85] and in patients with obstructing airway tumors has been described [86]. This success is related to its small shaft diameter and wide angle of view. Unlike laryngoscopes or even videolaryngoscopes, there is no leading edge that must first displace the tissue before viewing the glottis. By shortening the tracheal and the bronchial connectors of double lumen tubes, intubation with DLT using the Bonfils has been described in patients who failed direct laryngoscopy [87].

Problems and Complications

The rigidity of the scope may increase the risk of airway trauma in inexperienced hands and the non-malleable shaft may limit the ability to angle the scope in cases where the larynx is extremely anterior. Other problems encountered are poor views, failure to locate the laryngeal inlet and problems with railroading the ETT. To avoid problems of ETT disengagement from the scope and into the trachea, when loading the ETT onto the Bonfils, beveled end should face left for scope insertion from the right side or the centre of the mouth. Impingement of the ETT tip on the vocal cords should be excluded before rotating the ETT using a twisting motion to slide it off the scope. Readjustment of the scope to prevent leverage on the teeth should be considered. Hand movements to manipulate the scope need to be subtle as slight movements at the handle translate to large movements at the distal end. Counterclockwise wrist movements are performed to direct the Bonfils to the left and vice versa. The handle of the scope is pulled down like a jackpot stick to direct Bonfils tip anteriorly and the opposite is done to direct Bonfils tip posteriorly. A good initial view needs to be established by maintaining a shallow scope insertion to avoid getting lost or seeing “red-out”. If indiscernible pink tissue is seen, the scope should be withdrawn slightly. Perform chin lift to enlarge the retropharyngeal space. One needs to master the subtle hand movements which direct the scope and recognize signposts such as the uvula and the epiglottis.

Keypoints

Bonfils' rigid structure makes it more maneuverable and its slim profile makes it useful in patients with small mouth opening, limited cervical spine movement or narrowed airways. Compared with the flexible fiberoptic scope, endoscopic orientation is improved. It is more robust, portable and easy to set up. Although intubation success rate is high, the use of Bonfils is not intuitive and requires dexterity. Nonetheless it remains an effective tool for difficult airway management after initial training.

Shikani® and Levitan® Optical Stylet

Overview and Characteristics

The Clarus Shikani Optical Stylet (Clarus Medical, Minneapolis, USA) was first described in 1999 [88]. It is a reusable, malleable stylet with a lens at its distal end and a fiberoptic cable within its stainless steel shaft. An eyepiece is located on the handle to allow viewing. Alternatively, images can be captured by a connected camera and displayed on a video monitor. It allows real time airway visualization during intubation. The adult model accommodates ETT sizes from 5.5 to 9.0, while the pediatric version fits ETT sizes 3.5–5.0. The ETT is loaded on the Shikani and kept in place by an 'adjustable tube stop' with an oxygen port which allows oxygen delivery [89]. The stylet and light source are immersible for efficient sterilization. Unlike the fiberscope, the Shikani cannot be orientated in a precise direction. However, it is malleable, portable and cheaper. It may act as a light wand by providing illumination in the neck.

The Clarus Levitan (Clarus Medical, Minneapolis, USA) is similar to the Shikani, except that its shorter length of 30 cm allows an ETT to be fitted without the tube stop. It is can be used to facilitate ETT, LMA or tracheostomy tube placement. Since most videolaryngoscopes work with a stylet, having one which provides fiberoptic visualization capability optimizes the vocal cords view. It comes in one size and fits ETT sizes 5.5–9.0 (See Fig. 3.9).

Fig. 3.9 Clarus shikani and levitan optical stylet

Instruction for Use

The use of the Shikani is similar to that of the Bonfils; laryngoscopy may or may not be used with it for intubation. Neck extension may be more effective than a neutral neck position [90].

Clinical Performance

Initial evaluation of the Shikani is favourable with a 100 % intubation success rate in 2 studies involving 140 surgical patients which included 5 awake intubations [88, 89]. In 12 difficult pediatric airways due to congenital syndromes, airway trauma or tumors, intubation was achieved in 11 patients [91, 92]. The Shikani has also been described to facilitate intubation via the intubating LMA. The operator introduces an ETT loaded onto the Shikani stylet through the airway channel of the LMA to achieve intubation under vision [93].

In 301 intubations with the Levitan, success rate was 99.7 % with a mean intubation time of 23 s [94]. In a crossover trial comparing the Levitan with the Bonfils, both devices showed a good overall success rate of 94 % and similar intubation times (Bonfils 36 s vs. Levitan 44 s) and ease of intubation. However, first time success rate was higher with the Bonfils (73 vs. 57 %) and there were fewer complications such as sore throat and dysphonia [95]. Both devices were equally effective in patients with normal airways when used by trained anaesthesiologists.

Problems and Complications

The Shikani has a limited depth of view, with a focal distance of one centimeter. Other problems are similar to fiberoptic devices such as obscured view by secretions. During advancement its angulated shape may also impinge onto the laryngeal structures or tracheal wall [91].

Keypoints

The Shikani or the Levitan dual functions as the main intubating device or as an intubation adjunct, owing to its feature as an optical malleable stylet. This unique device provides a different approach to securing the airway and is invaluable in that aspect. Due to the limited literature on the Shikani and Levitan, further comparative studies are required to establish its role and efficacy.

Newer Videolaryngoscopes

Newer generations of devices continue to show promise in managing routine and difficult airways, with better, lighter technology, improved optics, and greater affordability. An example of this is the **King Vision®** videolaryngoscope (AMBU Ballerup, Denmark), with its durable reusable video display and size 3 disposable blades for difficult and routine intubations (see Fig. 3.10). In particular, its channeled blade (allows 6.0–8.0 mm ETT) has been shown to facilitate intubation by novice personnel without incidence of esophageal intubation, compared to the Macintosh laryngoscope [96]. Results of more clinical studies are underway, and the launch of the King Vision aBlades in 2014 will herald even greater affordability coupled with high performance visualisation.

The **Venner A.P Advance®** videolaryngoscope (Venner Medical, Switzerland) (see Fig. 3.11) has 3 levels of functionality. It can be used as a traditional stand alone laryngoscope. Connection to the 9 cm viewing screen at the tip of the reusable handle provides the enhanced views of videolaryngoscopy, used in

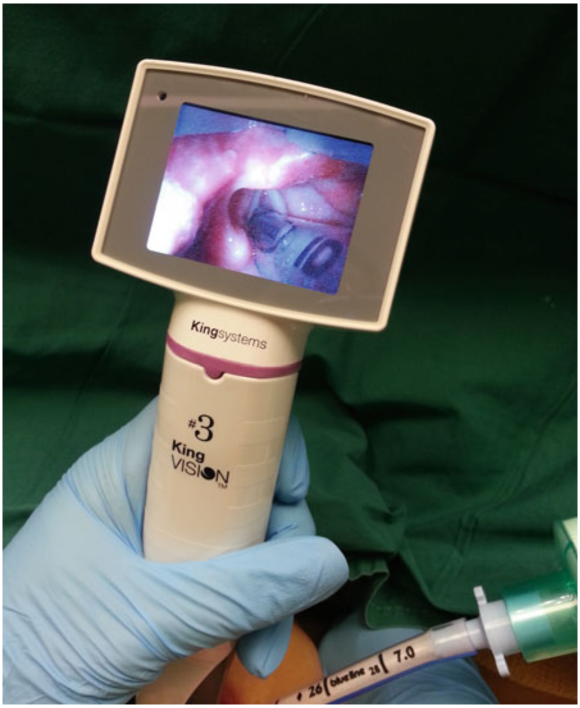

Fig. 3.10 King vision videolaryngoscope

conjunction with the MAC 3 and MAC 4 Macintosh style disposable blades or its Difficult Airway Blade (DAB) which has an upward elevation on the blade tip that allows visualization of anterior larynxes, and intubation without stylet due to a guiding conduit. There are emerging publications of its efficacy in cervical spine cases [97], simulated difficult airways [98] and for base of tongue biopies [99].

Documentation

When documenting laryngoscopy grade, there has been much debate about whether the grades achieved on videolaryngoscopy are comparable to direct laryngoscopy [100]. A simple way is to replace Cormack and Lehane Grade 1 or 2 view with a prefix v1 or v2 for views achieved on videolaryngoscopy [101]. Documenting the type of videolaryngoscope used, the size or type of blade, and need for adjuncts like a bougie, stylet or external laryngeal pressure to successfully intubate provides further comprehensive information for future intubators.

Fig. 3.11 Venner A.P. Advance videolaryngoscope

Conclusion

Videolaryngoscopes and indirect intubating aids provide improved visualization of the larynx with high success rates of intubation. Its incorporation into the revised 2013 ASA Difficult Airway Algorithm lends further weight to the fact that these devices should be embraced as the initial first-line approach to intubate anyone suspected of a difficult airway. This translates to a paradigm shift in how we practice, where routine clinical intubations should be performed with videolaryngoscopy, so that device-specific proficiency is attained. Subtle skills in delivering the ETT through the vocal cords needs to be learnt and practiced, so that when the real difficult airway presents itself, the operator is not performing a videolaryngoscopic intubation for the very first time and getting an improved view of the larynx but then not being able to successfully intubate rapidly.

There are considerable differences between the different products available, resulting in distinct advantages and disadvantages, depending on the airway situation. Clinical research is beginning to provide evidence to prove this premise, although no one device is shown superior, and its true clinical effectiveness also depends on the intubator's skills. Continuing training and familiarity with new devices remain an essential component in maximizing the utility of these devices and minimizing the complications.

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Chapter 4
Perioperative Care of Ambulatory Anaesthesia

Anil Agarwal and Kamal Kishore

Abstract Ambulatory surgery colloquially defined as any surgical procedure or any outpatient intervention where in an outpatient setup the patient is discharged on the same working day is being practiced with the main goals of curtailing economic burden and preventing and family stresses that occur when the hospital stay is prolonged. Nevertheless, it needs all the preoperative care that admitted patient need.

Keywords Preoperative care · Fast track anaesthesia · Surgical procedure

Ambulatory surgery is defined as 'any operation or procedure or any outpatient intervention where the patient is discharged on the same working day'. It gained popularity in 1960 when first unit of ambulatory anaesthesia was established but formal development occurred with the formation of Society for Ambulatory Anaesthesia (SAMBA) in 1984.

The need for day care surgery is expanding with the change in financial situation of the world. Recent advances of anaesthesia, surgery and pain management have resulted in a vast expansion of this modality and resulted in decreased hospitalization [1]. The availability of rapid, short acting anaesthetic, analgesic and muscle relaxant drugs have clearly facilitated the recovery process after surgery and development of minimally invasive surgical procedures have added wings to ambulatory anaesthesia [2]. The facilities of ambulatory anaesthesia can be attached to main hospital or office based which involves the conduct of anaesthesia in a location that is integrated to a physician's office. The advantages of ambulatory anaesthesia are personal attention, care, service, ease of scheduling,

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greater privacy, lower cost, increased efficiency and decreased nosocomial infection. Despite advantages of ambulatory anaesthesia one must remember that it is not for every anaesthesiologist or surgeon nor appropriate neither for every patient nor for every surgical procedure.

As far as the data is concerned National health statistics report USA state that among all surgical procedures more than 60 % of surgeries were conducted on ambulatory basis and less than 0.8 % needed inpatient admission [3]. Although data is not available for India, there is huge potential for ambulatory anaesthesia and surgery in view of large population and massive growth of private sector.

For providing optimal perioperative care during ambulatory surgery and anaesthesia one should always consider patient selection criteria and preoperative assessment, surgical procedures and their duration, preparation, anaesthetic management, recovery, postoperative complications and organization.

Patient Selection

Ambulatory surgery should be accompanied by minimum disturbances in postoperative physiology and uncomplicated recovery [4]. There must be certain criteria for determining patient selection for ambulatory procedures. It is recommended that multidisciplinary approach, with agreed protocols for patient's assessment including inclusion and exclusion criteria for day care surgery, should be agreed locally with anaesthesia department. These should take into account:

- Patient medical status (specific diagnosis, co-morbid conditions and duration of therapy)
- Degree of stability of medical status
- Patient's psychological status
- Patient's support system at home
- Intensity and duration of post-procedural monitoring
- Risk of developing complications (deep vein thrombosis (DVT) and pulmonary embolism (PE))

Mostly patients being treated in ambulatory surgical units belong to ASA physical status I and II but with the improved anaesthesia and surgical techniques, patients with medically stable ASA physical status III and IV are also being allowed with the same low incidence of morbidity [5]. The complications and the duration of stay can be minimized if pre-existing medical conditions are stable for more than three months before scheduled operation [6]. Now a days a full term infant for more than one month; an elderly patient with multiple co-morbidities are acceptable for day care procedures. It is ideal for children because of minimum separation from their parents and risk for hospital acquired infection [7, 8].

There are few contraindications for ambulatory procedures [9]:

1. Potentially life-threatening chronic illnesses
2. Morbid obesity complicated by symptomatic cardio-respiratory problems (e.g., angina, asthma)
3. Multiple chronic centrally active drug therapies or active cocaine abuse
4. Ex-premature infants less than 60 weeks post conceptual age requiring general endotracheal anesthesia
5. No responsible adult at home to care for the patient on the evening after surgery

Preoperative Assessment

Preoperative assessment of outpatients is increasingly important to avoid costly delays or last minute cancellations. The assessment of the medical condition of the patient should be based on recent history, physical examination and laboratory investigations [10]. Although the National Institute of Health and Clinical Excellence (NICE) guidance on pre-operative investigations is widely used, one recent study showed no difference in the outcomes of day surgery patients even when all pre-operative investigations were omitted [11]. The concerned anaesthesiologist should carefully consider the following specific factors while deciding anaesthesia in their ambulatory unit [12]:

a. Abnormalities of major organ systems, and stability and optimization of any medical illness.
b. Difficult airway, morbid obesity and/or obstructive sleep apnea.
c. Previous adverse experience with anesthesia and surgery.
d. Current medications and drug allergies, including latex allergy.
e. Time and nature of the last oral intake.
f. History of alcohol or substance use or abuse.
g. Presence of a adult who assumes responsibility specifically for accompanying the patient from the ambulatory unit.

Perioperative Care

The anaesthesiologist providing patient care in the ambulatory setting should adhere to the standard protocols and guidelines to assure optimal safety and comfort of the patient.

Preoperative Preparation

Optimal preoperative preparations reduce the risks adherent to ambulatory surgery, improve patient outcome and make surgery more safer and acceptable for the patient. Appropriate fasting protocol and medications (to be taken or withheld) before surgery should be ascertained. Measures should be taken to minimize the patient's anxiety.

Intra-operative Care

Appropriate selection and patient preparation is very important for ambulatory surgery. The ideal outpatient anesthetic should have a rapid and smooth onset of action, produce intra-operative amnesia and analgesia, provide optimal surgical conditions and adequate muscle relaxation with a short recovery period, and have no adverse effects in the post discharge period. Standard intra-operative monitoring guidelines for ambulatory surgery should be followed.

The choice of anaesthesia technique depends on surgical and patient factors. Anaesthetic technique should ensure minimum stress and maximum comfort for the patient along with considering the risk and benefit of that technique. The anaesthetic technique in ambulatory anaesthesia can range from local anaesthetic infiltration to sedation to general anaesthesia. Although there is no ideal technique or drug for day care procedures, a knowledge of options available is important for optimal surgical conditions and fast-track recovery [9].

General Anaesthesia

General anaesthesia remains the most widely used anaesthetic technique for ambulatory surgery despite higher incidence of side effects than regional anaesthesia. LMA insertion shows minimal cardiovascular response, better tolerance and less airway complications in lighter plane of anaesthesia than endotracheal intubation. Total intravenous anaesthesia (TIVA) is an advantageous technique in ambulatory anaesthesia using propofol and fentanyl (remifentanyl is preferred if available) utilizing a computer based drug delivery system. It avoids the risk of failure of regional block, residual muscle paralysis and lesser side effects in the form of decreased postoperative nausea vomiting (PONV). Use of newer inhalational agents like sevoflurane and desflurane shows faster emergence than intravenous agents [13, 14].

Regional Anaesthesia

Regional anaesthesia can offer advantages for ambulatory surgery with respect to speed of recovery, decreased nursing care and more effective analgesia in early post operative period [15]. Central neuraxial blocks (spinal and epidural anaesthesia) are offered commonly in day care surgery. Residual blockade in spinal or epidural anaesthesia may cause problem like postural hypotension and urinary retention despite return of sensory or motor function. So it is important to choose the most appropriate local anaesthetic and adjuvant combination so as to avoid prolonged local anaesthetic effect. Suggested criteria before attempting ambulation after neuraxial block include the return of sensation in the perianal area (S4–5), plantar flexion of the foot at preoperative levels of strength and return of proprioception in the big toe [16].

Peripheral Nerve Block

The peripheral nerve blocks like bracheal plexus or femoral sciatic nerve block can provide profound and prolonged anaesthesia to an extremity and are very popular in ambulatory anaesthesia. Use of ultrasound enhances the accuracy of block. Continuous infusion local anaesthetic can decrease the need for intravenous opioid analgesics and enhance the patient satisfaction and mobility [17]. In paediatric patients peripheral nerve block can be performed immediately after general anaesthesia and caudal nerve block is most preferred in this segment of patients.

Local Infiltration

Infiltration of local anaesthetic at the surgical site is the simplest and safest method of post-operative pain relief. Patient comfort can be improved if intravenous sedation and analgesia is used to complement it. It can be used as a sole anaesthesia technique for superficial procedures (inguinal hernia, breast lump, few plastic surgery procedures) [18].

Intravenous Regional Anaesthesia

The intravenous regional anesthetic (IVRA) technique with 0.5 % lidocaine is a simple and reliable technique for short superficial surgical procedures (<60 min) limited to a single extremity. It is more cost effective technique for outpatient hand surgery than general anaesthesia [9].

Post-operative Recovery and Discharge

There are three phases of recovery after ambulatory anaesthesia i.e. early, intermediate and late.

During early recovery phase the patient emerge from anaesthesia, recover their protective reflexes and resume early motor activity. As per the patient's need, the oxygen supplementation, analgesic or antiemetic medications are administered. Modified Aldrete score is commonly used to assess the fitness of patient to shift to recovery area.

During intermediate phase patient start voiding, ambulate, drinks fluid and prepare for discharge. Anaesthesia technique and medications used mainly affect the intermediate phase. Other factors that prolong this phase are female gender, advanced age, prolonged surgery, larger blood loss, post operative pain and nausea and vomiting and spinal anaesthesia [19, 20].

The late recovery phase starts after the discharge of the patient till complete physiological and psychological recovery and patient resumes their normal daily activity. The surgical procedure itself has the highest impact on late recovery.

Another objective discharge criteria has been developed for patient readiness for discharge is called as Post Anaesthesia Discharge Scoring System (PADSS). It is based on five major criteria which include (a) vital signs, including blood pressure, heart rate, respiratory rate, and temperature; (b) ambulation and mental status; (c) pain and post operative nausea and vomiting; (d) surgical bleeding; and

Table 4.1 Modified post anesthesia discharge scoring (PADS) system

Vital signs	
2	Within 20 % of the preoperative value
1	20–40 % of the preoperative value
0	40 % of the preoperative value
Ambulation	
2	Steady gait/no dizziness
1	With assistance
0	No ambulation/dizziness
Nausea and vomiting	
2	Minimal
1	Moderate
0	Severe
Pain	
2	Minimal
1	Moderate
0	Severe
Surgical bleeding	
2	Minimal
1	Moderate
0	Severe

Table 4.2 Factors alleged to delay discharge and lead to unanticipated admissions after ambulatory surgery

Delayed discharge
Preoperative
• Female gender
• Increasing age
• Congestive heart failure
Intraoperative
• Long duration of surgery
• General anesthesia
• Spinal anesthesia
Postoperative
• Postoperative nausea and vomiting
• Moderate-to-severe pain
• Excess drowsiness
• No escort
Unanticipated admissions
Surgical
• Pain
• Bleeding
• Extensive surgery
• Surgical complications
• Abdominal surgery
• Otorhinolaryngology and urology surgery
Anesthesia
• Nausea and vomiting
• Somnolence
• Aspiration
Social
• No escort
Medical
• Diabetes mellitus
• Ischemic heart disease
• Sleep apnea

(e) fluid intake/output. This was later modified by F. Chung et al. who eliminated input and output as a discharge criteria and this resulted in earlier discharge for up to 20 % of the outpatients studied (Table 4.1) [21].

Outcome Measures

The ambulatory surgery continues to grow but ambulatory centres should develop the methods to measure the outcome during early and late postoperative period. The incidence of major morbidity is very low but certain clinical anaesthesia outcome like incision pain, nausea, vomiting preoperative anxiety and pain of intravenous line insertion should be avoided [22].

Delayed discharge and unexpected hospital admission after outpatient surgery are the most commonly identified outcome measures after ambulatory anesthesia (Table 4.2) [23].

Conclusion

Ambulatory anaesthesia is a faster growing subspecialty of anaesthesia. One should be careful about choosing the patients, optimizing them preoperatively, planning optimal anaesthesia technique, using appropriate monitoring system, caring their postoperative complications and discharging them with optimal advice to make it more beneficial for them. In future the ambulatory care will reach people in geographically distant areas as well.

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Chapter 5
The Paediatric Airway: Normal and Abnormal

Ina Ismiarti Shariffuddin and Lucy Chan

Abstract Management of paediatric airway is a great challenge especially for the non-paediatric anaesthesiologist. The children's airway is different from adults and any mishandling of it can lead to airway obstruction and hypoxia. The first part of the chapter aims at providing a basic understanding of anatomy and physiology in paediatric airway, followed by a basic airway evaluation. The second half of this chapter provides simple principles for management of the abnormal paediatric airway.

Keywords Paediatric airways · Anatomy · Physiology · Management · Abnormal airway

Introduction

Managing paediatric airway poses a great challenge to many physicians as the anatomy and physiology of a child's airway is considerably different from an adult [1, 2]. Congenital abnormalities and acquired diseases can complicate the management of the child's airway further. Hence, the objective of this chapter is to enhance the understanding of the normal anatomy and physiology of a child and its clinical implications. The management of basic and abnormal airway in children is also described in this chapter. This will hopefully help the attending physician to manage the children's airway safely.

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Anatomy of the Airway

Airway is defined as the passage whereby oxygen reaches a person's lungs from the environment and for the carbon dioxide to be removed from the lungs back into the environment. This passage extends from the nose or mouth, joining the pharynx, larynx, glottis, trachea, bronchus and bronchioles in the lungs [3].

The anatomy of a child's airway differs from an adult in many ways. Firstly, the size of the airway is smaller, hence making it slightly more difficult to manage. Infants have smaller mouth and larger tongue as compared to adult. They have short and floppy epiglottis with vocal cord that is anterior. The vocal cord is located higher at the level C3 and C4 as compared to C5 and C6 in adult. These characteristics can cause the process of laryngoscopy and intubating a child difficult. A straight blade like Miller's blade would probably be more suitable to intubate a neonate than a curve Macintosh blade. We should lift up the floppy epiglottis in children with a straight blade like Miller's in order to visualize the vocal cord better. Due to the anterior vocal cord, positioning the child's head in the neutral position is the optimal way to view the vocal cord at laryngoscopy. In fact, extreme neck extension can actually obstruct the airway.

In children, the trachea is narrow, short and funnel-shaped with the narrowest part at the level of cricoid cartilage. On the other hand, adult's trachea is cylindrical and the narrowest part at the vocal cord region (Figs. 5.1 and 5.2). Therefore, choosing the right size of endotracheal tube for intubation is important as the narrowest point of the trachea in children is at the subglottic area. A tight fitting endotracheal tube at the vocal cord can cause tracheal oedema, which can lead to laryngeal damage, tracheal damage and subglottic stenosis after extubation.

Children have smaller trachea in comparison to adult. The average diameter of an infant's trachea is 3–4 mm as compared to the average diameter of adult's

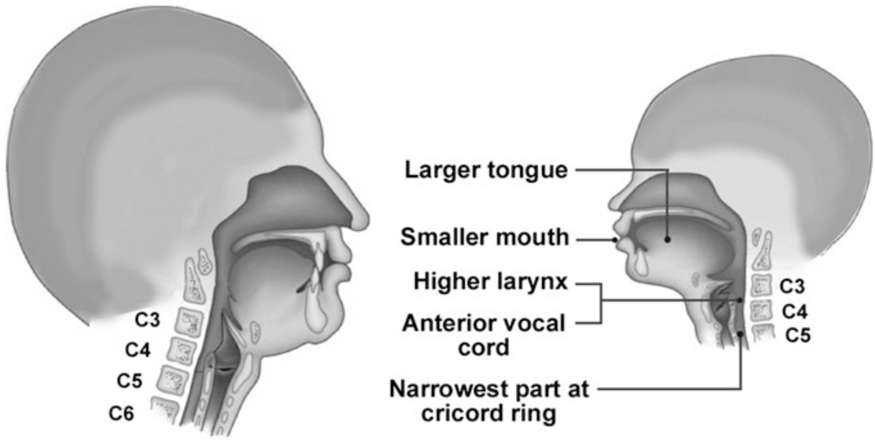

Fig. 5.1 Differences of paediatric and adult airway

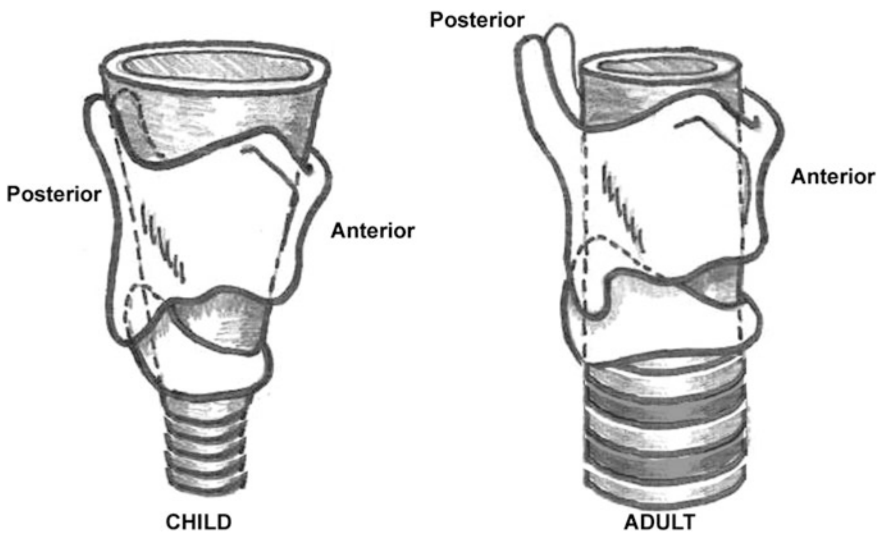

Fig. 5.2 Comparison of larynx of a child and an adult

trachea is 18 to 20 mm [4, 5]. Hence the ratio of the diameter of a neonate's tracheal to adult trachea is about 1:5. The small radius of the trachea in infant has a great impact on the airway resistance. A small change in the airway radius will

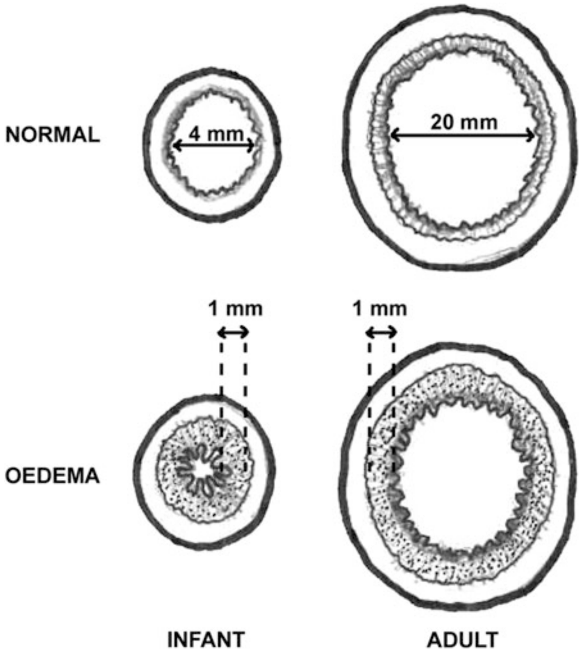

Fig. 5.3 The effect of oedema on the airway resistance of an infant versus an adult

increase the resistance of the airway by the fourth power as shown by the Poiseuille equation and illustrated in Fig. 5.3.

$$R = 8nl/\pi r^4$$

(R = resistance, l = length of the airway and r = radius of the airway n = viscosity of the gas)

Therefore, smaller airways cause them to be more susceptible to obstruction due to oedema.

Poiseuille's law: if the radius of the airway is halved, the resistance will increase by 16x.

Neonate has immature laryngeal, tracheal and bronchial structures. These structures are poorly cartilaged, hence are soft, very compliant and are easily compressed. This can lead to dynamic airway compression especially at the thoracic inlet where the pressure gradient between the atmosphere and the intra tracheal pressure is the greatest. These cartilages are fully developed at the age of 10–12 years [6].

Physiology of the Airway

Newborn infants are obligatory nasal breathers as they are unable to coordinate the movement of their laryngeal structures with respiratory effort. Most of them will be able to coordinate this movement by 3–5 months of age [7]. Their narrow nasal passages can be easily blocked. In fact, the major cause of the airway resistance in infant originates from the nasal passages. As an obligate nasal breather, this can lead to upper airway obstruction in infant [8]. This can be due to congenital causes such as bilateral choanal atresia, acquired such as secretions during upper respiratory tract infection or iatrogenic such as insertion of nasogastric tube.

Infant's ribs are more cartilaginous than adult's ribs. Therefore, their chest wall is more compliance when compared to adults. On the other hand, they have low lung compliance due to the presence of thick-walled alveolar precursors and decreased amounts of elastin. As a consequence, the infant's alveolar are more prone to collapse, resulting in lower resting lung volume. To overcome these problems, infants try to maintain a larger resting lung volumes with a several mechanism such as premature cessation of the expiratory phase (braking) at the laryngeal and diaphragmatic levels and stabilization of the chest wall with increased intercostal tone during exhalation [9]. The lung compliance improves with increasing age of a child [10].

The closing volumes of very young children encroach the functional residual capacity. Closing volume is the lung volume at which terminal airways begin to collapse. Large closing volumes increase dead-space ventilation and can lead to atelectasis and shunting. Children also have lesser number of alveoli in comparison to adult. They only have approximately 10 % of adults' alveoli. The alveoli clusters only develop to adult level over the first 8 years of life. Most importantly, children have higher oxygen consumption when compared to adult. The oxygen consumption of a child is 6 ml/kg/min as compared to adult, 3 ml/kg/min. In order to optimize work of breathing to meet the high oxygen demand, infants breathe at higher respiratory rate rather than a bigger tidal volume. As a result of high oxygen consumption and limited lung reserves, neonates are at higher risk of hypoxia.

Infants depend primarily on diaphragmatic breathing, as their ribs are horizontal preventing the 'bucket handle' action movements like in adult's breathing. This limits the increase in infants' tidal volume. Therefore, their minute ventilation is rate dependant. A normal respiratory rate for a neonate is around 30–50/min. In addition, infants have less of type 1 oxidative muscle fibers in the diaphragm and intercostals muscle that allows repetitive motion without fatigue. Hence, a sustained increase in respiratory rate in infant will lead to muscle fatigue and apnea. The number of this muscle increases in children when they grow over the first year of life.

The control of breathing in a neonate is different compared to adult. Hypoxia causes the neonate to increase the ventilation transiently, before depressing the ventilation. The initial increase in ventilation to hypoxia is due to the stimulation of the peripheral chemoreceptors, mainly the carotid body. The cause of depressed ventilation to hypoxia in the later part in the neonate is not fully under stood, but this could be due to the immature control of respiration located at the medullary respiratory centers [11]. In premature babies this response is exaggerated. The response to hypercarbia is the same as in adults, but is more rapid because of a lower resting carbon dioxide level. The ventilatory response of neonate to hypoxia is affected by temperature, level of arousal and maturity of the neonate.

Anaesthesia affects the control of breathing in neonates in many ways. The respiratory depressant and sedative effects of the anaesthetic drugs and exposure to cold ambient temperature in the operating theatre can blunt the neonate's ventilatory response to hypoxia. Hence, the anaesthetist should use drugs that have better respiratory and sedative recovery profile. It is also important to keep the patient in normothermia perioperatively with active warming devices.

Evaluation of Paediatric Airway

In managing a child's airway, it is utmost important to evaluate and assess the child systematically. A careful medical history, physical examination and a review of relevant investigation should be performed before any decision of intubating the airway is taken. A history should include, history of systemic illness that predisposes a patient to airway problem such as Asthma, history of recent upper respiratory tract infection (URTI) and any previous records of anaesthesia and intubation. In clinical examination, apart from examining the airway, we should also examine the cardiovascular and respiratory system thoroughly. This is because, any problems in these systems can predispose patient to hypoxia during airway manipulation. We should also look for any obvious features of difficult airway such as craniofacial abnormality and related syndromes. Certain congenital syndromes are associated with difficult airway. This will be discussed in the next section.

Child's Airway and Clinical Implications

A neonate with distended acute abdomen is at risk of developing hypoxia. The distended abdomen will lead to splinting of the diaphragm that limits the depth of diaphragmatic movements. The splinting of the diaphragm will also cause alveolar collapsed in the neonate. A combination of a sick neonate with a high oxygen demand, poor lung reserves and limited ventilation rate will render the neonate to desaturate very rapidly.

The Abnormal Paediatric Airway

The paediatric airway is vulnerable to obstruction because of its anatomy, size, and susceptibility to injury and disease. This risk is increased if the airway is abnormal. A heterogenous group of pathological conditions affects the airway. Management depends on the specific disorder. Interventions by clinicians with special skills can adequately manage airway emergencies (obstruction and respiratory failure), ideally in the Operation Theatre (OT) [12].

This chapter does not address the management of the abnormal or obstructed airway inside the OT, that is, the tools and strategies for intubation and intra-operative management.

To understand the individual characteristics of the entire spectrum of abnormal airway disorders, doctors are encouraged to read further. Recognition and management of some specific lesions are highlighted only.

Recognition

Routine evaluation of the airway requires a thorough history and physical examination. Any of the following features from history and physical assessment should alert the clinician to potential problems and further work-up:

A. History

- Snoring, noisy breathing
- Chronic cough, frequent respiratory tract infections
- Sudden onset coughing, choking or foreign body aspiration
- Feeding problems with respiratory distress
- Hoarse voice, stridor, cyanosis

- Previous anaesthetic problems (difficult intubation, extubation or difficult mask ventilation)
- History of congenital syndrome

B. Physical Examination

- Respiratory rate, baseline oxygen saturation
- Retractions of suprasternal, intercostal, subcostal muscles
- Facial expression, nasal flaring, mouth breathing, drooling, colour of mucous membrane
- Mouth opening, size of mandible, location of trachea
- Masses involving oropharynx, face, neck
- Stridor (inspiratory/expiratory)
- Global appearance (congenital disorders)

Additional investigations, apart from a detailed history and physical examination, help in diagnosis and decision making. Radiographs of the upper airway may locate the aetiology and site of airway obstruction. Extra information may be obtained from MRI and CT scan. Biomedical imaging is best undertaken in the presence of skilled personnel with appropriate facilities for airway management. Endotracheal intubation takes priority over radiographic diagnosis when respiratory failure is imminent. Blood gases are useful but performing an arterial puncture on an agitated child may aggravate respiratory distress.

General Management of Airway

A patent airway has to be ensured at all times, preventing hypoxia, respiratory acidosis, aspiration and asphyxia. In the early stage before deterioration sets in, non-invasive airway management for respiratory distress in a sick child with abnormal airway may be managed by oxygen supplementation using nasal prongs, positioning prone or lateral and CPAP devices. Removal of secretions is important and tube feeding may be initiated.

A child with stridor alerts every clinician. Stridor is the sound caused by abnormal airflow during breathing [13]. The cause of stridor can be located in extrathoracic (nose, pharynx, larynx, trachea) or intrathoracic airway (tracheobronchial tree). Stridor may be acute or chronic and may be congenital or acquired. It is a sign and not a diagnosis. The paediatrician has to determine the severity of respiratory compromise and the need for immediate intervention. Referral to an ENT surgeon for an upper and lower airway endoscopy depends on whether a significant lesion is suspected. Collaboration with colleagues from related disciplines for follow-up and subsequent management is often required.

Flexible bronchoscopy is a technique to evaluate, among its many other uses, the functional disorders of the airway. It is relevant particularly to predict the development of subglottic stenosis and tracheomalacia in neonates who receive prolonged ventilation and are oxygen dependent.

A broad classification of the abnormal paediatric airway that focuses on aetiology is: congenital conditions, inflammatory disorders and foreign body in the airway/airway trauma.

Congenital Conditions

Varying degrees of chronic airway obstruction manifest in this group of children. In some, the airway is not the only issue but there are problems with the heart, central nervous system and other body organs. Sleep-disordered breathing syndromes can lead to adverse complications in the cardiovascular system (pulmonary hypertension), neurocognitive function and growth. These syndromes occur more frequently in patients with craniofacial disorders where early recognition and surgical corrections are team-based and highly specialized [14].

Some of the syndromes associated with abnormal airways include the following:

- Congenital neck masses (dermoid cyst, cystic hygroma, lymphangioma, neurofibroma)
- Congenital anomalies of respiratory tract (chonal atresia, tracheomalacia, laryngomalacia, tracheal stenosis, laryngeal web, vascular ring)
- Congenital syndromes (Pierre Robin, Down's syndrome, Goldenhar, Cruzon, Achondroplasia)
- Metabolic disorders (mucopolysaccharidosis)

The biggest challenges for acute airway management in congenital airway disorders are anatomical features associated with hypoplasia of the mandible, hypoplasia of the midface or associated with a large tongue (macroglossia). A multidisciplinary approach is generally needed with referrals to several subspecialiaties including ENT and Anaesthesiology.

An example of congenital condition is Pierre Robin Syndromes (Fig. 5.4). Pierre Robin syndrome represents an abnormal developmental process associated with a cluster of typical clinical features:

- micrognathia, retrognathia
- cleft palate
- glossoptosis (implying a relatively large tongue with risk for upper airway obstruction)

The baby has inspiratory and expiratory airway distress. Obstruction leads to hypoxia, pulmonary hypertension, cor pulmonale or failure to thrive (secondary to difficulty in swallowing and aspiration). Despite the risk for breathing difficulties, the goal of treatment is to optimize growth and adequate nutrition. General

Fig. 5.4 Pierre Robin syndrome

measures such as placing the infant in the prone or lateral position may prevent the tongue falling backwards. Nasogastric or gastrostomy tube feedings may be considered. Respiratory distress may be managed without an operation (either by prone positioning, short term intubation, or placement of a nasopharyngeal airway). Gastroesophageal reflux seems to be more prevalent in these infants. The reflux of acidic contents in the posterior pharynx and upper airway can worsen airway obstruction. Treatment options include upright positioning, small and frequent feedings and pharmacotherapy (such as proton pump inhibitors).

When conservative treatment fails, emergency surgical treatment by an artificial ankyloglossia or glossopexy may prevent recurrent glossoptosis. The technique of tongue fixation below the mandible is a surgical option. The placement of a button helps to prevent the stitches cutting through (Fig. 5.5).

Fig. 5.5 Tongue fixation below the mandible

Fig. 5.6 Laryngoscopy view of swollen epiglottitis

Inflammatory Disorders

Inflammatory disorders of the airway in children usually result in progressive airway obstruction as seen in epiglottitis, croup and diphtheria.

Acute epiglottitis is most common between ages 2–8 years old but can occur at any age [15]. It is an airway emergency and potentially life threatening. Epiglottitis is, in reality, supraglottitis because the inflammatory process frequently involves other structures such as the aryepiglottic folds, the arytenoids and the entire supraglottic area (Fig. 5.6). The most important cause of infection is *Haemophilus influenza* (Type B) for which there is a specific vaccine. Some cases are due to *Streptococcus pneumoniae* and other bacteria. Epiglottitis presents acutely with high fever, anxiety, stridor, drooling and dysphonia. The child looks toxic and prefers to sit and lean forward to avoid the pain caused by the epiglottis touching the posterior pharyngeal wall. Rapid diagnosis and airway intervention are necessary because sudden airway obstruction can occur due to rapid progression of the swelling. Lateral soft tissue radiograph may reveal the classic “thumb sign” of the swollen epiglottis. CT imaging can differentiate other conditions that have similar clinical presentation (such as peritonsillar abscess or retropharyngeal abscess).

If the child deteriorates in the emergency department, rapid intubation has to be performed, bearing in mind the difficult airway and the dangers of laryngospasm and total airway obstruction. If condition of the child permits, joint evaluation and treatment by trained anaesthesiologist and otolaryngologist can ensure optimal management of the airway in a controlled manner with facilities including rigid bronchoscopy, cricothyrotomy and tracheostomy. After the airway is secure, antibiotic therapy is the key to resolution of the infection. Second or third-generation cephalosporin, either alone or in combination with penicillin or ampicillin for streptococcal cover, is suitable.

Foreign Body in the Airway/Airway Trauma

These are acute airway disorders associated airway instability and sudden airway obstruction. Examples are airway burns, accidents with faciomaxillary and oropharyngeal injuries, cervical fracture and dislocation, inhalational injury and post-intubation croup. Rapid assessment is essential. Resuscitative measures are prioritized to airway and circulation in a collapsed child. Urgent biomedical imaging may not be possible.

Foreign body in the airway is not an uncommon problem (Fig. 5.7). A high index of suspicion may be the only clue for a foreign body (FB) in the airway. A history of choking is pertinent. Food items (peanut, bean) are common in infants and toddlers while non-food objects (safety pin, coin) are aspirated in older children. Significant obstruction is indicated by agitation, cyanosis, a weak or absent cry, retractions and stridor. The urgency to establish a patent airway depends on the degree of obstruction and functional impairment. A chest radiograph can confirm the presence and the location of radiolucent objects in the respiratory tract. Retrieval of the FB is the only definitive treatment [16].

Complete airway obstruction may occur on arrival at the emergency department. If this happens, the FB may be located at the larynx or it is in the trachea. In this crisis, the FB is big enough and located strategically to cut-off airflow completely. Direct laryngoscopy can remove the FB above the glottis but if the FB is in the trachea, the FB is purposely pushed into one bronchus with an endotracheal tube. In this partially obstructed condition of the airway, there is some time to transport the patient to the OT for a more controlled bronchoscopic removal of the FB.

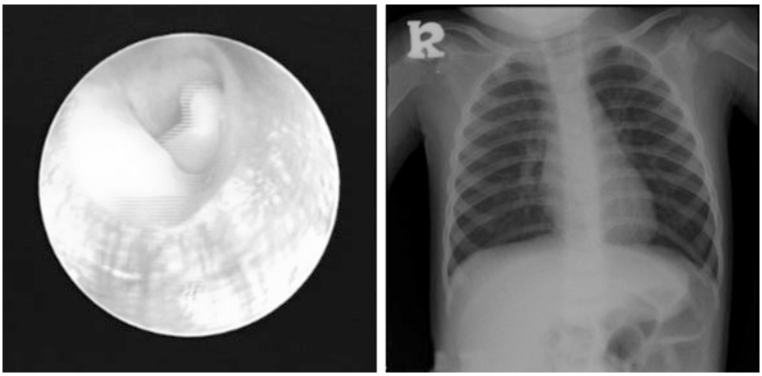

Fig. 5.7 Radio opaque bean in right bronchus

Conclusion

Management of paediatric airway is a great challenge especially for the non-paediatric anaesthesiologist. The children's airway is different from adults and any mishandling of it can lead to airway obstruction and hypoxia. The child with an abnormal airway requires a thorough evaluation and referral to a centre with paediatric expertise in all subspecialities is optimal for integral care.

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Chapter 6
Intubation of the Pediatric Patient

Josef Holzki

Abstract Pediatric intubation is an often occurring practice in pediatric anesthesia. However, this does not mean this procedure to be entirely safe. Despite its long history there are still discussions going on whether the epiglottis should be uploaded with the tip of the blade of the laryngoscope or not. Endoscopic evidence has shown that this uploading can injure the mucosa significantly as well as narrow the entrance to the glottis, impeding the advance of tracheal tube which might injure the vocal cords particularly. With more frequent use of simple optical instruments the already high standard of safety in pediatric intubation could be improved.

Keywords Pediatric intubation · Intubation injuries · Endoscopic control of intubation trauma

Introduction

The intubation of infants and children is a very common procedure in pediatric anesthesia and neonatal/pediatric intensive care—but there are many divergent opinions in the literature about the least traumatic way of intubation. Avoiding trauma to the airway by the intubation procedure and by an inadequate selection of tracheal tubes must be the pivot of our concern when performing our medical duties according to the very old physicians rule of: 'nil nocere'. We simply never would like to harm any patient.

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Basic Rules for Pediatric Tracheal Intubation

Several basic rules which serve as prerequisites for an uncomplicated intubation in adults, which were introduced into clinical practice many years ago [1], are practically the same for infants and children:

- Placing the patient in the "sniffing" position: Backward tilt of the head, the neck bent forward
- Performing the "triple airway maneuver": sniffing position (I), opening of the mouth by a forward shift of the ascending branch of the mandible ("jaw thrust", II), pushing the tip of the mandible down in order to separate lips and teeth (III), thus opening up the pharynx for the passage of air (Fig. 6.1).

These maneuvers are very important (but are often neglected, because they seem to be so simple!) since they prepare the patient for an adequate exposure of the larynx for ventilation with bag and mask and for a full vision of the glottis (Fig. 6.1).

However, positioning the head of the infant and pre-school child needs to be modified from the approach in adults because the large occiput of this age, laid flat on the operating table, places the head automatically in the sniffing position. The occiput should be placed in a doughnut like soft ring to prevent the head from moving unintentionally to the sides. A pad under the neck or the shoulders can be counterproductive for the intubation procedure in infancy and pre-school age. When the neck becomes over-distended by a pad, the exposure of the larynx becomes more difficult because the larynx moves anteriorly.

The triple airway maneuver, popularized by Safar [1] since 1973, appears to be difficult for the beginner but can be learnt even in self-training [2].

Paucity of Data Supporting Current Practices of Pediatric Intubation

Many details and variations of pediatric intubation have been published in the past and have found their place in well acknowledged international textbooks of pediatric anesthesia [3, 4]. However, there is a paucity of scientific data supporting the common practices of pediatric intubation, leading to controversies till today between pediatric anesthesiologists and neonatologists/pediatricians. The best technical approach to the larynx for intubation has still to be established scientifically.

Despite the long tradition of pediatric intubation by anesthesiologists, neonatologists, intensivists and emergency personnel in ambulances, there is no opinion prevailing whether a straight or a curved laryngoscope blade should be used for intubating infants and children. Under the same token there is no agreement between those who intubate children whether the epiglottis should be uploaded by the tip of the laryngoscope blade or not in this important procedure. The background for this surprising controversy is based on assertions rather than scientific data.

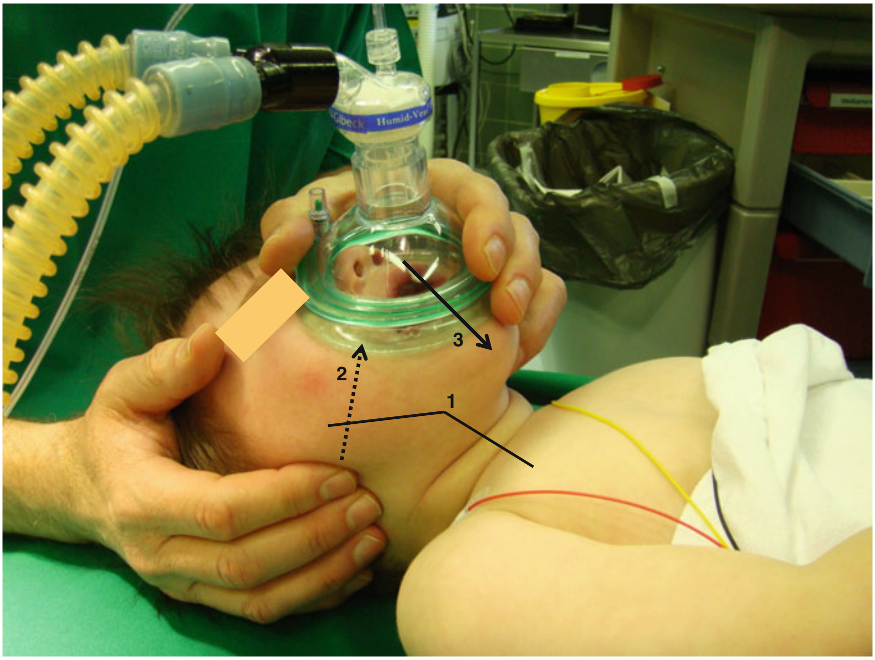


Fig. 6.1 Adequate position of the head in order to perform a quick and smooth intubation: the neck is slightly bent forward, the head is reclining (1 = sniffing position), the ascending branch of the mandible is gently forwarded (2, *dotted arrow*), the mouth is opened by depressing the tip of the mandible (3). 1–3 = triple airway maneuver

All discussions about intubation techniques should aim at avoiding trauma to the pediatric airway. In the present time with the availability of video-laryngoscopes and small optical instruments like the Hopkins rod lens (Fig. 6.2) it is easy to observe and even film the intubation procedure with different blades. This enables us to control the effects of our intubation procedure on the mucosa (ulcers) and the function (e. g. vocal cord paralysis) of larynx and trachea immediately and provide an early treatment in case there is a major irritation of the affected organs.

Importance of Airway Endoscopy to Control for Side Effects of Intubation

If we really want to make progress in airway care and avoid intubation injuries, we have to observe and document side effects of intubation with optical instruments. Seeing with the own eyes the damage we possibly could have done to the patient means evidence in the true sense of the word in every single case.

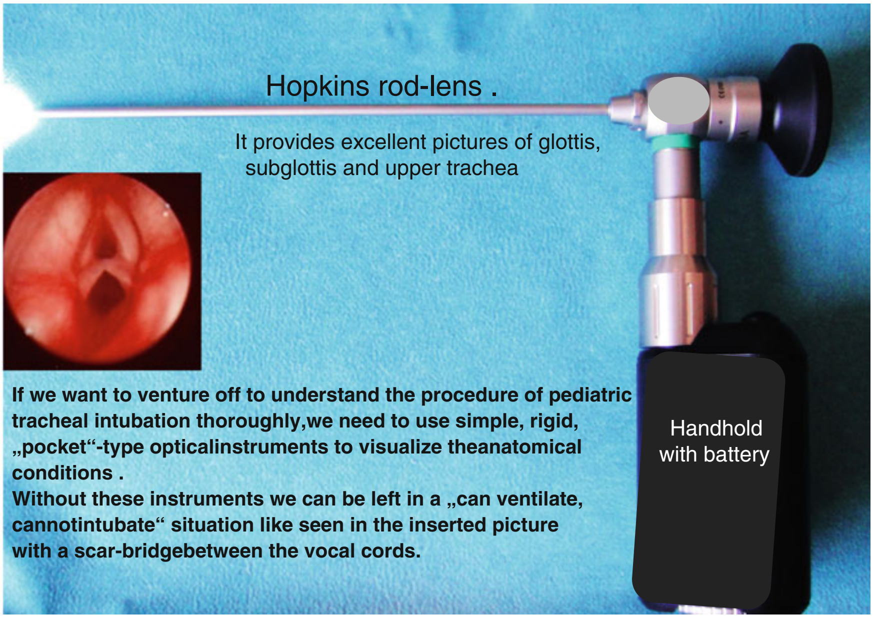


Fig. 6.2 Hopkins rod-lens provides excellent pictures of glottis, subglottis and upper trachea

Using endoscopic instruments enables us to decide which mode of intubation might be the best for the single user. Also we get informed about malformations or old scars dating back to previous traumatic intubations and can adapt our intubation technique to the real situation (Fig. 6.2, inserted picture).

It is obvious that studies in this field are necessary but they can give conclusive answers only, when they are performed under endoscopic control.

What Do We Really Know About Pediatric Intubation Technology Today?

A striking anatomical characteristic in infancy for exposing the larynx for intubation is the large and posteriorly positioned base of the tongue. The most secure and least traumatic approach to the larynx consists in lifting up the base of the tongue with an appropriately curved blade (Fig. 6.3). However, only in recent times attempts have been made to define what an "appropriately curved" blade means [5, 6].

Practically all pediatric laryngoscope blades which are not enough bent at the tip and are not placed into the vallecula make it difficult to lift the base of the tongue properly and thus expose the glottis of a normally positioned larynx adequately (Fig. 6.4).

Straight blades push the tongue mainly forward, thus hiding the larynx rather than exposing it (see Fig. 6.3a). The difference of the effect of a curved blade,

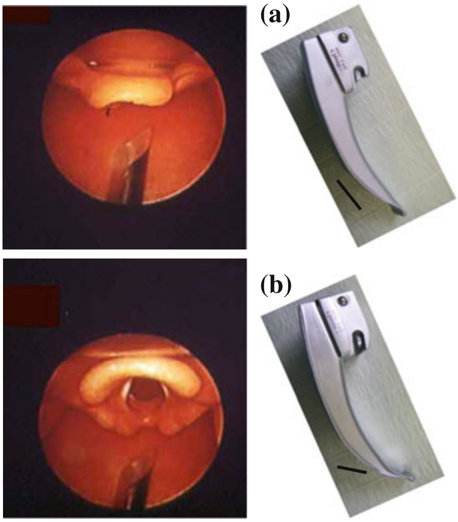


Fig. 6.3 **a** Attempt at exposing the vocal cords with a conventional Mackintosh blade. The vocal cords cannot be visualized because the blade is too straight and cannot lift up the base of the tongue despite having the tip of the blade in the vallecula. **b** The same procedure with the same blade, however, with a more pronounced angle of the tip of blade. The unfolding the entrance of the larynx is easily accomplished now. The effect of this modified blade can be demonstrated in every single normal or slightly difficult intubation!

positioned in the vallecula and a straight blade, loading up the epiglottis can easily be observed in every intubation with a well lighted laryngoscope (Fig. 6.5).

The endoscopic experience of decades of pediatric intubation of the author of this chapter and his group [7, 8] has proven over the past 35 years that a curved blade with a pronounced bending of the tip (30–40°), placed into the vallecula, provides the best general view of the entrance of the larynx. This almost wide angled view offers a good chance for placing a tracheal tube through the larynx into the trachea of infants and children in the least traumatic way (see Fig. 6.3). Lifting up the base of the tongue, instead of loading up the epiglottis by the tip of the blade, is not only the most effective mode of unfolding the entrance of the larynx, but also the best mode of preventing trauma to the mucosa of epiglottis and vocal cords (see Fig. 6.5a). In addition, the narrowing of the entrance of the glottis, a frequent occurrence when the epiglottis is uploaded, can be prevented (see Fig. 6.5b). Both ways, the uploading of the epiglottis and the partly occlusion of the glottis, lead regularly to injury of the mucosa by the tip of the blade (Fig. 6.6). In contrast, when the base of the tongue is lifted up by an adequately curved blade, the tip positioned in the vallecula, a full view of the entrance of the larynx is provided, permitting an easy introduction of the tracheal tube under vision (see Fig. 6.5a).

One pitfall in pediatric intubation consists in the use of pediatric laryngoscope blades with barrel-like conduits for directing tracheal tubes through the glottis into the trachea (Fig. 6.7). The tracheal tube, splinted by the barrel, gets very stiff and

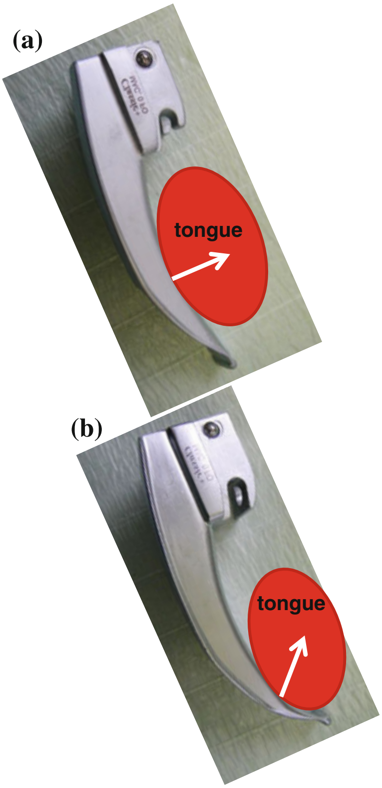


Fig. 6.4 **a** A straight blade, even this moderately curved Macintosh blade, is inadequate for lifting up the base of the tongue which is mainly pushed forward, not upward. Therefore the unfolding of the entrance of the larynx is prevented and uploading of the epiglottis becomes necessary. Uploading of the epiglottis always injures the mucosa of the epiglottis. **b** If the tip of a Mackintosh-type of blade is bent at the tip more than normal and positioned into the vallecula, it is rather easy to lift up the base of the tongue, unfolding the entrance of the larynx and preventing injury to the epiglottis (see Fig. 6.3b)

enables the tip of the tube to injure vocal cords and mucosa easily. Since the vision of the glottis is lost as soon as the tube enters the barrel-like conduit, the tip of the tube is advanced without control of vision.

This danger becomes more obvious if the epiglottis is uploaded and the entrance of the glottis is partly occluded (see Fig. 6.5b).

All this can be prevented by using a curved blade with a pronounced bending of the tip, being inserted into the vallecula (Figs. 6.3 and 6.4), resulting in lifting up the base of the tongue which provides good visibility of the entrance of the larynx.

Is Scientific Support of Intubation Techniques Generally Possible?

In other words, can this everyday experience by pediatric anesthesiologists who are used to control their intubation procedures endoscopically, be supported scientifically?

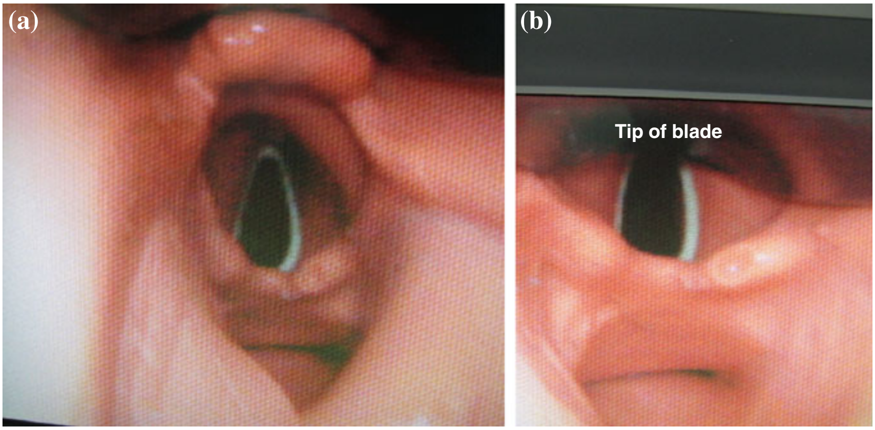
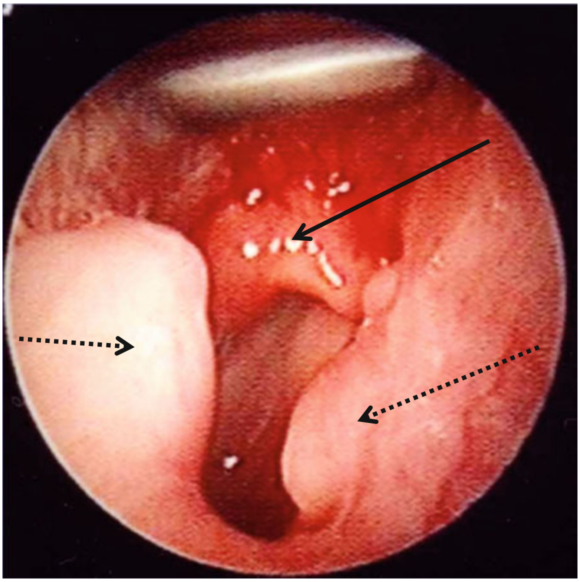


Fig. 6.5 **a** The tip of a blade in the vallecula, lifting up the base of the tongue. A perfect view of the glottis is provided, permitting an atraumatic intubation. **b** The epiglottis is uploaded by the blade of a laryngoscope, narrowing the glottic opening. This impedes the advancement of a tracheal tube, causing damage of vocal cords and the surrounding mucosa (not visible in this position before the intubation)

Fig. 6.6 Swollen and bleeding epiglottis after several attempts at loading up the epiglottis with a straight blade (*arrow*). In the presence of enlarged tonsils and adenoids (*dotted arrows*), the swelling of the epiglottis can end up in a dangerous airway obstruction



This question can be answered positively because in the own practice control of intubation problems with optical instruments is carried out since 1983 in close cooperation with pediatric ENT-surgeons. Every photo of an untoward situation during or after intubation is evidence in itself:

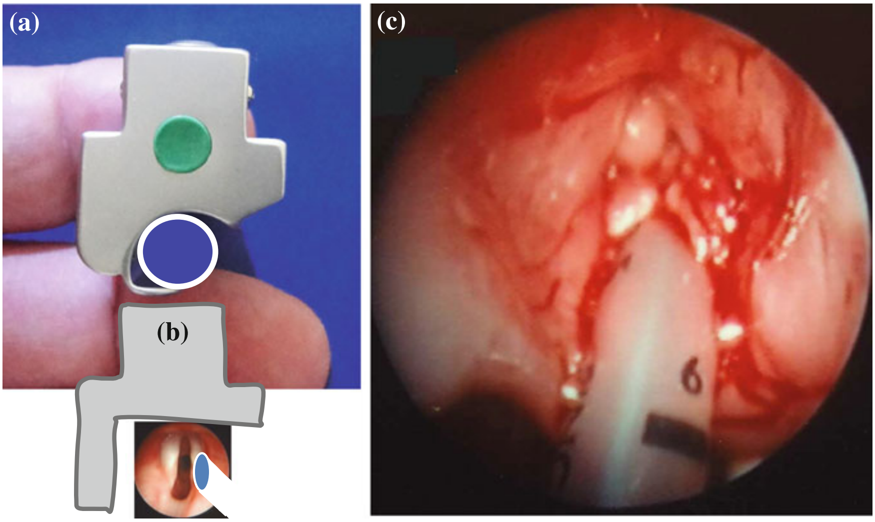


Fig. 6.7 **a** The barrel-like form of the blade acts as a conduit for the tracheal tube. By pushing the tube toward the glottis, it gets splinted and rigid, obstructing the view to the glottis with chances to injure it. **b** A blade which provides free space for introducing a tracheal tube along the blade allows visualization of the vocal cords and a smooth intubation procedure. **c** Significant injury, typical after blind attempts at intubation with a splinted tube

- It is possible for every pediatric anesthesiologist/intensivist to visualize the exposure of the larynx with different blades by using strongly lighted laryngoscopes, at best video-laryngoscopes, or very simple optical instruments like the Hopkins lens (Fig. 6.2) during every single intubation. It is important to see with the own eyes what happens to the vocal cords and the mucosa of the airway with different intubation techniques and then modify the own technique when necessary.

However, to visualize the larynx below the vocal cords and the advancement of the tracheal tube beyond the glottis, a small Hopkins rod lens (Fig. 6.2) is necessary to document injuries or malformations in this area [7, 8]. In case of suspecting an injury, the mucosa of the upper airway can be controlled during and immediately after extubation. A large number of major injuries can be detected only with optical instruments. Particularly ulcers after extubation are frequently overlooked since they never produce the symptom of stridor which needs an obstruction of more than 50 % of the lumen to become audible. Therefore stridor is an entirely insufficient outcome measure in studies which are investigating airway trauma [8]. However, ulcers may become infected and cause airway obstruction weeks or months after intubation when nobody thinks of a relation to the intubation.

The above mentioned instruments are easy to handle, the learning curve is very steep, the observation time for detecting injuries very short, 10–15 s.

This has been practiced in the own hospital and other places since more than 25 years, leading to early treatment when the injuries were detected early.

- One enlightening review article, published in 2009, about the best use of different laryngoscope blades, reports about the most effective curvature at the tip of the blades, comes to similar results like the own group, based on observations, endoscopic investigations and a comprehensive review of the literature [7].

Why Could Fundamentally Conflicting Opinions About Pediatric Intubation Arise over the Past Decades?

The most probable reason is the lack of applying technologies of visualization (airway endoscopy) when describing the intubation procedures or controlling for side effects.

Till today few pediatric anesthesia centers use airway endoscopy regularly for investigating side effects of this important and frequently used procedure. This is regrettable since airway endoscopy provides us with vitally important information for preventing airway injury and "cannot intubate" situations (see Fig. 6.2).

Another reason for conflicting arguments might be the inadequate knowledge of the intricate anatomy of the pediatric larynx by many anesthesiologists, as proven in clinical practice [7, 8]. This can also be observed in many discussions during workshops where a common teaching is: "aim with the tip of the tube at the dark triangle between the vocal cords and push the tracheal tube into it and you are safe". This might be correct in the adult patient, but not in the child where the particular anatomy of the larynx begins *below* the vocal cords. Since this inadequate teaching can perpetually be observed in pediatric airway workshops, it might be of value to outline in a draft the most important landmarks of the pediatric larynx.

History of Detecting the Particularities of the Pediatric Airway

The basic anatomical findings of the pediatric larynx go back to Bayeux who made moulds of the larynx of autopsy specimen of deceased pediatric patients in 1897 [9] and found out, that the larynx of children is funnel shaped on a lateral view after an anterior-posterior cut through the organ (Fig. 6.8).

This was forgotten for many years till Eckenhoff re-discovered these findings and published them in 1951 [10] with his own observations, e. g. the reclining of the lamina of the cricoid ring. The V-shaped posterior part of the entrance of the cricoid ring, being a predilection point of airway injury by too large tubes (see Fig. 6.10), was described by Tucker et al. in 1977 [11]. Due to the arch of the

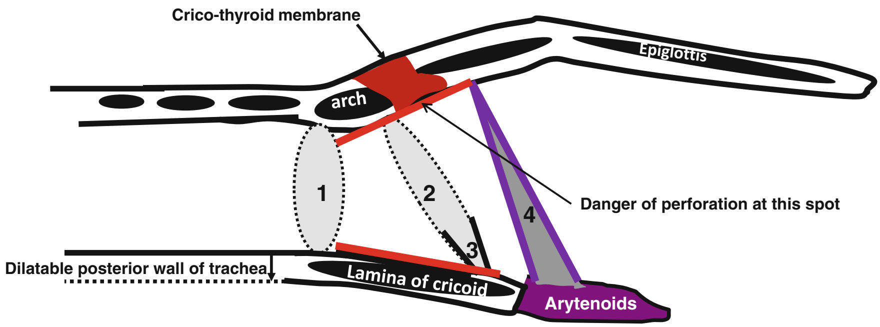


Fig. 6.8 The narrowest part of the upper airway is the almost circular outlet of the cricoid ring (*1*) whereas the entrance of the cricoid is ovally shaped (*2*), including the V-shaped posterior part (*3*) which was described in 1977. The vocal cords are slanting towards the anterior commissure, forming a "*dark triangle*" at laryngoscopy (*4*). Due to the arch of the cricoid ring being relatively close to the lamina, the crico-thyroid membrane is forced to face the vocal cords, thus fixing the larynx in a funnel shaped lumen (*red bars*). The crico-thyroid membrane can be seen in every intubation by strongly lighted laryngoscopes or by a Hopkins lens. This is a very important landmark since the advancing tube can perforate at this spot, ending mostly fatally

cricoid ring being closer to the lamina in infancy and small children, the crico-thyroid membrane is forced to face the vocal cords, thus fixing the larynx in a funnel shaped lumen.

If a tracheal tube is placed through the larynx into the trachea it is easy to understand that an adequately selected tube, according to the outer diameter, doesńt need a cuff for occluding the upper airway since the pediatric larynx is predestined to be intubated with an uncuffed tube, providing a seal at the outlet of the cricoid ring (Fig. 6.9). The leak never occurs "around" the tube because the tube lies in a curved position in larynx and trachea, occluding always the posterior and lateral parts of the larynx. Since the leak occurs only anteriorly, air escapes with every inspiratory positive pressure cycle like a jet-stream, cleaning the larynx from saliva and liquid food which regularly collects at the vocal cords, thus preventing aspiration.

The crico-thyroid membrane can be seen in every intubation by a strongly lighted laryngoscope or better by a Hopkins lens which often shows considerable irritation of the mucosa (Fig. 6.10).

The anatomical structure of the larynx, as described above, led to the general use of uncuffed tubes in infants and children till about the eigth year of age because a seal for ventilation could be made within the larynx at the outlet of the cricoid ring (see Fig. 6.9).

The use of uncuffed tubes have proved to be accompanied by a remarkably low incidence of airway trauma by the procedure of intubation itself [8] since Eckenhoffś publication in 1951. This means, they have been used for good reason [12].

The described anatomical details of the pediatric larynx originate not only from own observations but also from a combination of endoscopic investigations, autopsy studies and findings during laryngeal surgery.

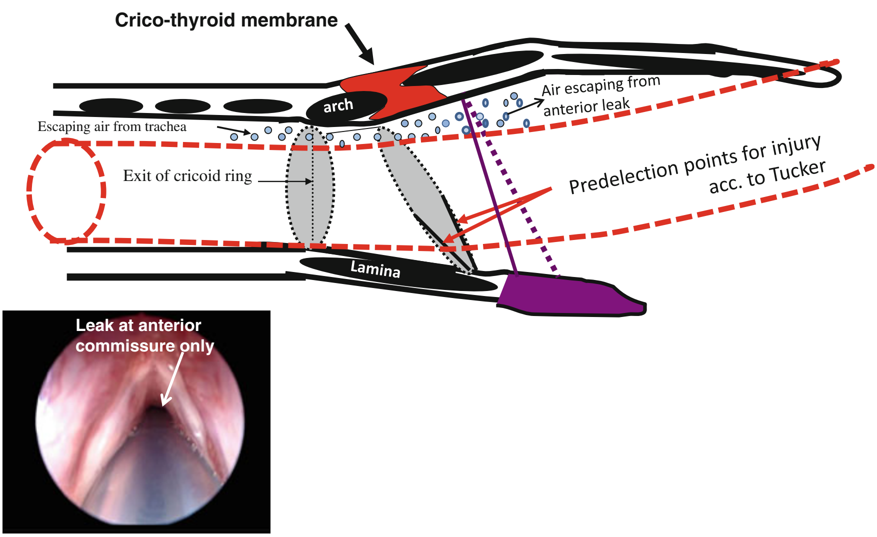


Fig. 6.9 The uncuffed tracheal tube fits well into the pediatric larynx when carefully selected according to the outer diameter of the tube. There never exists a leak "around" the tube but an anterior leak at the forwardly bent tube which occludes the posterior and lateral part of the larynx. The anterior leak is well audible and ejects fluids which are collecting above the vocal cords with every positive pressure cycle (inserted picture)

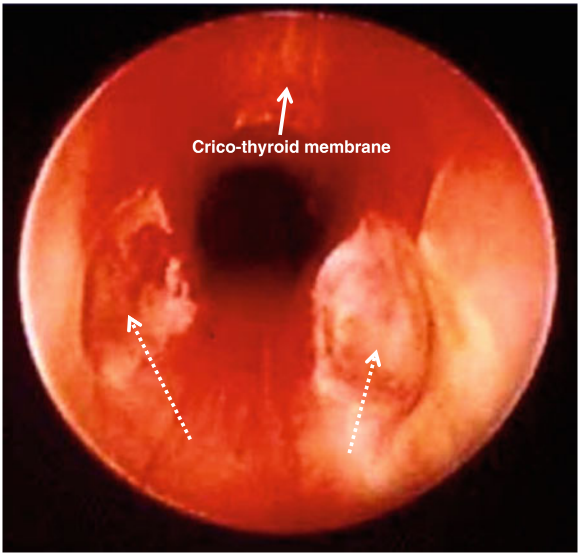


Fig. 6.10 The crico-thyroid membrane appears like a whitish triangle (*arrow*). Deep symmetrical ulcers can be seen at the V-shaped posterior part of the ovally shaped entrance of the cricoid ring, caused by a too large tracheal tube (*dotted arrows*)

The most convincing description of the pediatric larynx was published by the pediatric ENT-surgeons Holinger et al. in 1997 [13].

New Investigations Concerning the Anatomy of the Pediatric Larynx

Two articles in recent years have brought some confusion into the community of pediatric anesthesiologists. These bring up the message that not the cricoid ring, but the level of the vocal cords presents the narrowest part of the pediatric upper airway when the patient is paralysed or deeply sedated. The first article [14] measured the lumen of the vocal cords and the cricoid ring by MRI-imaging and the second [15] by area-measurements in square mm by a special device. This entirely erroneous assertion is astounding since both articles compare the very flexible vocal cords, getting always into the so called "semi-cadaveric" parallel position under muscle paralysis, almost touching each other, with a rigid cartilagineous ring, the cricoid. Both structures are not comparable. The vocal cords, acting like a closed curtain when paralysed, can be pushed to the sides easily when a tracheal tube enters. This is well known since the onset of pediatric intubation. The external form of tracheal tubes is based on this knowledge: they have a bevel just for this reason, to push the vocal cords to the sides when being inserted into larynx and trachea. Both mentioned papers have not contributed anything helpful to the commonly practiced intubation technique but caused some irritation in some anesthesiologists who wanted to make a seal for ventilating children within the vocal cord level which, of course, is not viable.

New Visualizing Technology for Difficult Intubations

Visualizing technology is applied more and more in all fields of medicine to find out what occurs inside of (mostly hollow) organs. It is an attempt to see with the own eyes what in the past was based on theories only. This makes it absolutely necessary, wherever possible, to introduce endoscopic technology into controlling the pediatric airway when the suspicion of untoward effects due to intubation arises. Before intubation it is important to check for malformations and scars of old injuries. More importantly, after extubation when stridor occurs or other signs of airway injury are suspected (e. g. pain at swallowing), endoscopy ought to be carried out under quiet conditions in the recovery room or a special endoscopy unit.

Patients with a large tongue or hemangiomas/lymphomas within the tongue which fill the pharynx almost entirely, can be intubated with a blade with a movable tip. There are several instruments with this type of blade on the market. To use a laryngoscope with a movable tip needs some experience to handle it

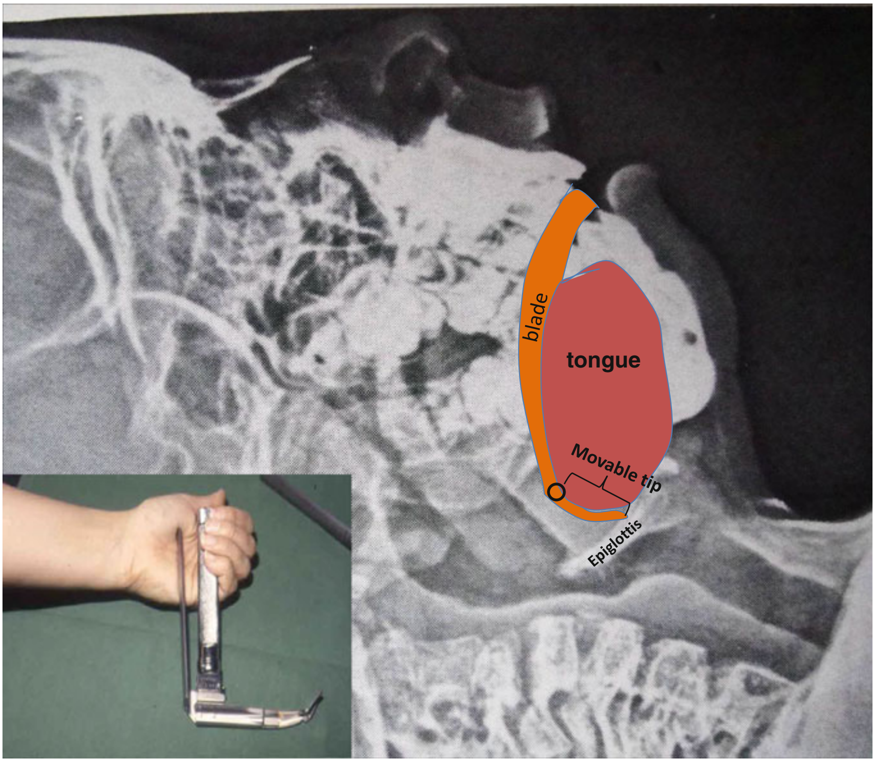


Fig. 6.11 The blade with a movable tip (McCoy-type). This is helpful when there are large masses in the pharynx, i.e., a very large tongue or a lymphoma. However, this blade is difficult to handle since two movements have to be carried out at the same time (see inserted picture)

because two movements have to be made at the same time, moving the handle of the laryngoscope and the movable tip of the blade with an extra lever (Fig. 6.11).

A recently produced instrument for intubation of infants and small children with a "full" pharynx (by tonsils and copious lymphatic tissue) is very helpful in addition to intubate the moderately difficult airway. This is the rigid, curved, fiberoptic lens according to Bonfils [1]. The angle of the bent tip amounts to 30–40° to get around a large mass at the base of the tongue and can also be used as a diagnostic tool as well as an intubation guide by pulling a tube over the instrument and advancing it under excellent vision into the trachea (Fig. 6.12).[1]

It is easy to handle and has a very steep learning curve [16]. An oxygen supply tube helps to prolong the time for intubation. The advantage of this simple instrument is its pocket size and being able to be battery powered. This makes the instrument available within seconds in emergency situations.

[1] Bonfils rigid, curved fiberoptic instrument, baby version. Only producer: Karl Storz GmbH & CO-KG. Mittelstr. 8. D-78532 Tuttlingen, Germany.

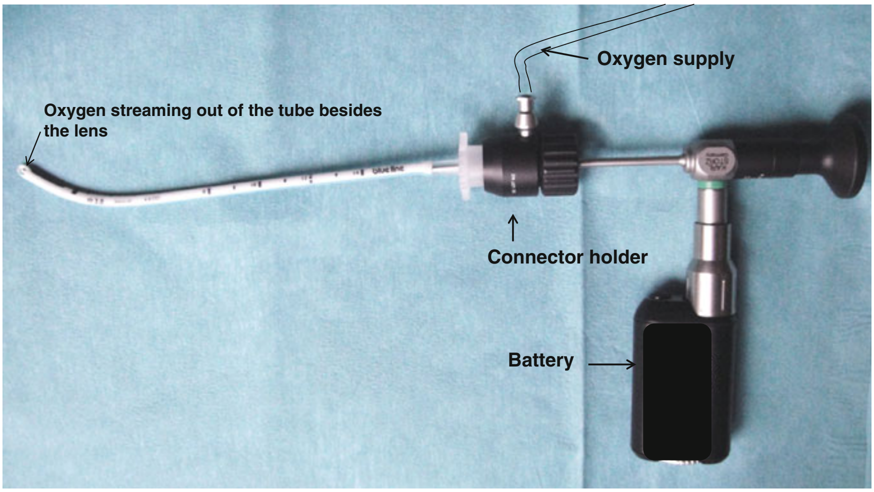


Fig. 6.12 Smallest version of Bonfils lens (for neonates and infants), a rigid, bent fiberoptic instrument. Outer diameter of the lens 2.0 mm. Tubes of 2.5 mm internal diameter can be pulled over it for being introduced into the glottis under full vision of larynx and upper trachea

Altogether, the intubating procedure in infants and children needs skilled and sensitive hands, good knowledge of the anatomy of the upper airway and insight into the effects and side-effects of the different intubation tools. More endoscopy controlled scientific studies are needed to improve current intubation techniques.

Conclusions

The old and very common procedure of pediatric intubation still needs some improvement because trauma to the airway continues to occur. Different techniques should be compared in comparative studies with the help of simple but practical optical instruments. The aims of all anesthesiologists ought to be ‘nil nocere‘, never to do damage to the airway of children. This can be accomplished by regular, personal visualization of what might have happened to the mucosa of the upper airway or to the vocal cords.

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Chapter 7
The Difficult Pediatric Airway: Management Options

Mahesh Vakamudi

Abstract The management of difficult airway in the pediatric population is more challenging than in the adult. Although unanticipated difficult intubation is uncommon in children, securing the airway awake is usually not an option, except in a co-operative adolescent. Many devices designed for adult airway management have been downsized to be used in the pediatric age group. Invasive access options are fraught with complications. A proper preoperative planning, an awareness of available options and experience in handling these fragile, small airways form the cornerstone of management.

Keywords Difficult airway · Pediatrics · Preoperative planning

Introduction

A leading cause of perioperative mortality and morbidity in children is hypoxia [1, 2], the incidence being higher in children of younger age [3], and a common cause of hypoxia is a failure to recognize and manage airway problems. Mortality from difficulties in pediatric airway management is a catastrophic but rarely reported event. The incidence of difficult laryngoscopy (Cormack Lehane grade III and IV) is 1.35 % [4] to 3 % [5] and is higher in infants than in older children (4.7 versus 0.7 %) [4].

The pediatric difficult airway presents a unique set of challenges not usually seen with adult airway management. Awake approaches cannot be applied to children because of inadequate co-operation. Most intubations have to be performed only under general anesthesia except for the occasional neonate or a co-operative

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Table 7.1 Classification of the child with a difficult airway [7]

Unexpected difficult normal pediatric airway	• Anatomical obstruction • Functional obstruction
Impaired normal pediatric airway	• Inflammation • Foreign body • Allergy • Trauma
Real difficult pediatric airway	• Head, neck, airway anomalies Congenital, associated with syndromes Acquired (burns, scars) • Tumor and other masses • Subglottic and tracheal disorders • Anterior mediastinal mass syndrome

teenager. Also, children have higher rates of oxygen consumption with lower oxygen reserves, leading to rapid desaturation following even short periods of apnea. Fortunately, most of the difficult pediatric airways are predictable preoperatively based on anatomic findings and it is only under rare circumstances that we find ourselves in an unanticipated difficult airway situation in children. So, in most instances, the difficult intubation scenario in pediatric practice is a "well predicted, well planned and hopefully well executed procedure [6].

Classification of a Child with a Difficult Airway

Airway problems can occur with a normal airway, an impaired normal airway and a known or expected difficult pediatric airway [7] (Table 7.1). The airway issues in an unexpected normal pediatric airway are anatomical and functional airway obstruction; anatomical obstruction can easily be overcome with head positioning, chin lift, jaw thrust, use of oropharyngeal and nasopharyngeal airways, two-hand and two-person bag and mask ventilation or with a supraglottic airway device; functional airway obstruction can be overcome with deepening anesthesia and muscle relaxation. The impaired normal pediatric airway refers to airway involvement by inflammation (epiglottitis), foreign body, allergy or trauma. The anesthetic approach depends on the site of the lesion and the time left before an intervention is required. The known difficult (real abnormal) pediatric airway could be due to congenital or acquired problems involving the bony components (maxillary or mandibular hypoplasia, temporomandibular joint ankylosis, cervical vertebral fusion etc.) or the soft tissue components (macroglossia, mucopolysaccharide or fat deposition in the oropharyngeal tissues, larynx and trachea etc.) of the airway [8, 9]. There has to be a proper plan in place for the management of these abnormal airways.

Approach to the Pediatric Difficult Airway

It is important to have a stepwise approach, customized according to the local resources and expertise available. Recently, an algorithm to manage the pediatric difficult airway has been published by the Difficult Airway Society [10]. There are also several recent reviews about current practices and management [6, 7, 11–13].

Preoperative Planning

The anesthesia plan should be discussed with the parents, including the possibility of tracheostomy, which may be required either as an emergency procedure or as a planned procedure after the airway has been secured.

It is important to plan ahead and have a “bottom line plan”, that is what to do if things do not go as per the plan. Are we going to wake up the child or proceed with a surgical airway? All the plans should be charted out in a step wise logical sequence.

Premedication

The use of sedative premedicants in a child with an obstructed airway could be dangerous. However, if it is not an obstructed, compromised airway, considering the individual situation, sedative premedication with midazolam would allow induction in a calm atmosphere with all monitoring in place. Antisialogogues like atropine and glycopyrrolate are given to dry secretions and thus enhance visualization.

Equipment

There should be a dedicated pediatric difficult intubation trolley with all adjuncts and alternatives to laryngoscopy and supraglottic airway devices and kits for invasive access. Having everything in one place would prevent running around for things when the need arises, as all steps in a difficult airway scenario are time critical.

Similarly, besides equipment, it is also important to have ready good assistance in the operating room before induction of a difficult pediatric airway.

Fig. 7.1 The retromolar, paraglossal or lateral approach to rigid laryngoscopy using a straight blade

Devices Available

Conventional Laryngoscopes with Modified Blades or Modified Techniques

The choice of laryngoscope blade is important depending on the situation; for e.g., a curved Macintosh blade is very helpful in macroglossia but will often prove disappointing in a patient with micrognathia. On the other hand, a paraglossal intubation using a straight blade can often be helpful in micrognathia [14]. The head is turned to the left and the laryngoscope blade is advanced in the space between the tongue and the lateral pharyngeal wall (Fig. 7.1). This technique bypasses the tongue and shortens the distance to access the larynx. The endotracheal tube can be made "hockey stick" shaped to aid intubation [15]. An assistant can retract the right angle of the mouth to increase the available space. Other names for this approach include the retromolar approach, the far lateral approach and the right molar approach.

The McCoy levering laryngoscope is another option, which comes in pediatric sizes with the Seward blade sizes 1 and 2 (Fig. 7.2) [16].

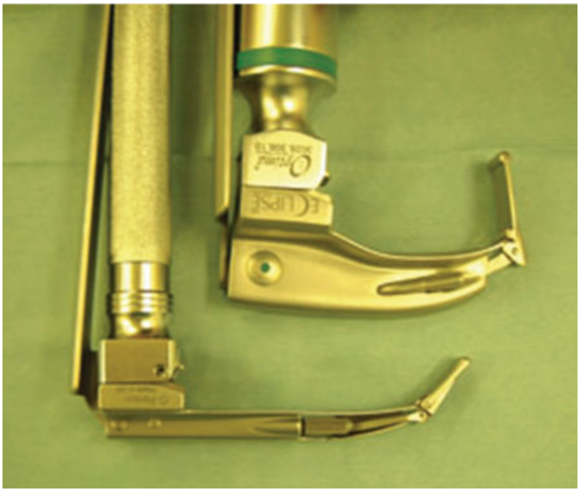


Fig. 7.2 The Seward and Macintosh McCoy levering laryngoscopes [16]

Alternatives to Direct Laryngoscopy

Fiberoptic Bronchoscopes (FOB)

This is the gold standard for intubation when direct laryngoscopy is not possible. After inhalational induction and maintaining spontaneous respiration, a nasopharyngeal airway can be used to continue administration of inhalational agent and oxygen [17], while the FOB can be introduced through the other nostril or orally. FOB can also be introduced through an laryngeal mask airway (LMA) [18, 19]. In larger scopes, a guidewire can be inserted through the suction channel and then used as a guide to railroad the endotracheal tube. Instead of the endotracheal tube, an airway exchange catheter can be loaded over the FOB and once the airway exchange catheter (AEC) is inside the trachea, it can be used to railroad the endotracheal tube (ETT) [20, 21].

It is also important to provide adequate vasoconstriction of the nostril to avoid bleeding that may later obscure the view and use antisialogogues to reduce secretions which again could obscure the view. Besides the anticholinergics, dexmedetomidine has been shown to have an antisialogogue effect, which along with its sedative effect, makes it a useful adjunct to fiberoptic intubation.

The difficulties in anesthetized pediatric fiberoptic intubation include airway collapse due to loss of pharyngeal tone decreasing the airspace available to advance the scope. Some manoeuvres available to open the space include jaw thrust and pulling the tongue forward. Considerable skill and expertise is required to master this technique.

The disadvantages of FOB intubation in children are a steep learning curve, the expense of the instrument and the need for a field devoid of blood and secretions for good visualization and hence intubation, especially when there is no suction channel in the FOB (as is the case with ultra thin scopes). It is also difficult to navigate ultra thin 2.2 mm and 2.8 mm pediatric bronchoscopes when the larynx is anterior.

Rigid Scopes

Bonfils Rigid Fiberoptic Scope

It is a rigid device comprising a curved non malleable shaft that has a 40° anterior curve that houses a fiberoptic channel. It has an eye piece mounted on the handle. The pediatric size can accommodate a 2.5 mm inner diameter endotracheal tube. A retromolar approach to intubation is recommended with this device by the manufacturer. It also has a port through which oxygen can be insufflated during intubation attempts. The manufacturer recommends a flow of oxygen of < 3 L/min to minimize secretions on the optical lens. However, it is better to avoid using this port for insufflation in neonates and infants because of the risk of pneumothorax if there is no path for egress of the gas when the stylet is in the trachea [16].

Special skill is needed to use the pediatric Bonfils and practice is needed in normal airway before using it in difficult airways and special maneuvers may be needed [22]. There are several successful reports of its use in difficult pediatric airway, even in neonates and infants [23–25].

Nasendoscope

A rigid nasendoscope with a 70° view connected to a video camera can be used to indirectly visualize the glottis and then an endotracheal tube can be guided into the glottis looking at the monitor [26].

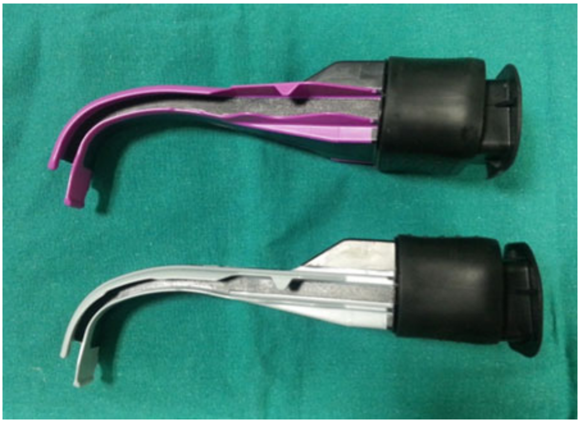
Videolaryngoscopes/Optical Laryngoscopes

These devices have been designed to “look around corners”. Less force needs to be applied to intubate with these devices, with lesser neck movement and hemodynamic response. Some of them incorporate a video camera or coherent fiberoptic bundle mounted on a fixed or malleable intubating blade while others use as series of prisms or mirrors. The image of the larynx is displayed on a monitor screen or is seen through the proximal end (viewfinder) of the device.

Airtraq Disposable Optical Laryngoscope

This is a portable, light weight, laryngoscope that is meant for single use. It has an optical blade with a side channel that guides the endotracheal tube towards the

Fig. 7.3 Airtraq videolaryngoscope pediatric sizes



glottis. The heat from the lamp serves as an anti-fogging mechanism that requires a 30–45 s warm-up time. The rubber eye piece may be used or it can be attached to a light weight camera and used along use with a wireless monitor (Fig. 7.3). The image of the larynx from the distal tip of the device is transmitted to a proximal viewfinder by using a series of prisms and mirrors.

The Airtraq comes in two pediatric sizes (Fig. 7.4). Size 0 is infant size that is color coded gray and accommodates tube size 2.5–3.5 mm and size 1 is the pediatric size that is color coded purple and accommodates tube size 3.5–5.5 mm. A mouth opening of atleast 12 - 13mm is needed for the insertion of these laryngoscopes. The size three is color coded green and is used for older children and accommodates tube size 6–7.5 mm.

Fig. 7.4 C MAC video laryngoscope

Table 7.2 Paediatric blade sizes of the Glidescope videolaryngoscope

GVL blade size	0	1	2	2.5
Weight of child	<1.5 kg	1.5–3.6 kg	1.8–10 kg	10–28 kg
Length of blade (mm)	36	44	56	63

During insertion, the Airtraq is inserted in the midline of the mouth and advanced towards the vallecula and placed there or alternatively, it may be used to lift the epiglottis. On insertion, the tongue, uvula, tongue base, epiglottis and glottis opening are visualized in succession with proper advancement. When the glottis is visualized, the lubricated endotracheal tube is slowly advanced through the guide channel. If the endotracheal tube advances posteriorly towards the oesophagus, the device has to be repositioned by lifting it. The use of a malleable stylet helps direct the tube more anteriorly, but increases the risk of airway injuries[27].

The limitations with the Airtraq videolaryngoscope are that some mouth opening is required, the quality of optics is poorer than the other videolaryngoscopes and the smaller viewing area. However, it provides a clear enough view of the glottis for successful intubation [28] at a lower price compared to the other videolaryngoscopes.

The Glidescope Video Laryngoscope

The Glidescope was the first commercially available videolaryngoscope. It integrates a high resolution video camera into the tip of a plastic laryngoscope blade. The Glidescope Cobalt is the third version of the pediatric Glidescope. It has a video baton which can be reused and laryngoscopy blades (called stats) that are meant for single use. These blades come in four sizes (Table 7.2) and have a 70° angulation, facilitating visualization the glottis on the monitor screen. It has an inbuilt antifogging mechanism that resists lens clouding and secretions.

Studies have shown that the glidescope provides a better view than direct laryngoscopy in children with normal airways [29, 30].

The Storz DCI Video Laryngoscope

This device incorporates fiber optics and a video lens within two slim Miller like laryngoscope blades, size 0 and 1. A camera attached to the blade transmits the picture of the glottis on a monitor screen. The video lens is located within the light source, close to the tip of the blade, with an 80° view angle. It does not have inbuilt antifogging mechanism.

Insertion of the blade is easier compared to other videolaryngoscopes, as the blade is like a conventional Miller blade. The height of the blade is only 5 mm,

Fig. 7.5 Truview video laryngoscope

allowing its use even in small infants with limited mouth opening. Curved Macintosh blades are available (Fig. 7.4) for older children. The CMAC videolaryngoscope has an inbuilt antifogging mechanism and comes with a D blade in addition to the Macintosh and Miller blades. This D blade has an enhanced anterior angulation, but is not available in pediatric sizes. The CMAC S blade has been designed for single use.

Truview PCD Infant (Truphatek)

It is a rigid laryngoscope with a tip that is angulated to provide a view of the glottis at a 46° anterior refracted angle (Fig. 7.5). It uses a series of prisms to transmit the image of the glottis from the distal tip to the eyepiece. A camera can be attached to the eyepiece to view the glottis on a monitor screen. It has an adapter for insufflations of oxygen that also serves as an anti-fogging mechanism. The height of the blade is only 8 mm, which allows it to be used in neonates.

A summary of the available devices and features is given in Table 7.3.

Videolaryngoscopy is an attractive modality for difficult intubation because of its similarity to intubation with a standard laryngoscope. However, it is not a panacea for difficult airway management, as it does have limitations. Some mouth opening is required to insert these devices, they cannot be used for nasotracheal intubation, there can be an excellent view of the glottic opening, but there could be difficulty with endotracheal tube placement, there can be trauma to the upper airway structures related to blind passage of the styletted tube into the pharynx and lastly, there could be poor visualization due to blood and secretions. Visualization of the tube insertion into the pharynx reduces the chance of injury to the pharyngeal mucosa from a misguided tube that is blindly inserted.

Table 7.3 Comparison of 4 different videolaryngoscopes [27]

Features	Airtraq	Glidescope Cobalt	Storz VL	Truview PCD
Size (height of laryngoscope blade) mm	12	10	5	8
Field of vision when laryngoscope is in optimal position	Glottis and near surroundings	Full view of glottis and surroundings	Only glottis	Only glottis
Portability	+++ (without video)	++ (device is mounted on a mobile stand)	+ (trolley required)	+++ (without video)
Anti fog mechanism	Yes[a]	Yes[a]	No	Yes[b]
Laryngoscope can be used without a stylet in the endotracheal tube	Yes	No	No (yes[c])	No
Can be used without camera/monitor	Yes	No	No	Yes
Disposability	Single-use	Single-use blades	Reusable	Reusable
Advantages	Easy to obtain good view of glottis	Easier to direct ETT because of larger field of vision	1. High quality view on monitor 2. Operational with smallest mouth opening	Oxygen insufflations prolongs time before desaturation occurs
Drawbacks	Bulky, difficult to position ETT in narrow airways		1. Anti fogging solution necessary 2. Not ergonomic; occasionally disassembles during use	

[a] Anti-fogging is facilitated by the heat from the device's lamp
[b] Anti-fogging is facilitated by oxygen flow
[c] The device may be used without stylet, when sliding the ETT in the groove of the laryngoscope blade reproduced with permission [27]

To minimize the risk of trauma with videolaryngoscopy, Dr. Rolf Holm-Knudsen has proposed a four-step technique, [27].

Step 1: Looking in the mouth. The laryngoscope is inserted into the mouth and gently advanced toward the root of the tongue.
Step 2: Looking at the screen. The position of the laryngoscope is optimized
Step 3: Looking in the mouth. The endotracheal tube with the stylet is inserted gently and placed as close to the tip of the laryngoscope as possible
Step 4: Looking at the screen. The endotracheal tube is directed toward the glottis and between the vocal cords.

Adjuncts to Direct Laryngoscopy

This includes light wands, optical stylets, bougies and intubating introducers.

Optical Stylets

Optical stylets combine a lighted stylet with the optics of a flexible fiberoptic bronchoscope. Since they are rigid, it is easy to control their tip. The advantage that optical stylets have over flexible fiberoptic intubation is that the passage of the tip of the tracheal tube through the vocal cords can be visualized with optical stylets; but this step is managed blindly with a fiberoptic intubation.

The Shikani optical stylet is malleable stylet that is J shaped. It has a central optical channel that ends in an eye piece. The eyepiece can be attached to a video camera to display the image of the glottis on a monitor screen. For intubation, the stylet is placed inside the endotracheal tube of appropriate size and held in the dominant hand of the operator. The nondominant hand of the operator is used to provide jaw thrust and the tip of the stylet is placed along the curvature of the tongue in the midline. Once the vocal cords are visualized, the stylet can be advanced under direct vision past the vocal cords and then the endotracheal tube is advanced into the trachea, under direct vision [16].

Extraglottic Airway Devices (EGA)

The extraglottic airways now have a very important role in the management of the difficult pediatric airway and a recent review highlights its use and misuse [31, 32]. The use of an EGA appears as the first or second step in many difficult airway algorithms. It can usually overcome a difficult mask ventilation that is due to a poor mask seal or supraglottic obstruction.

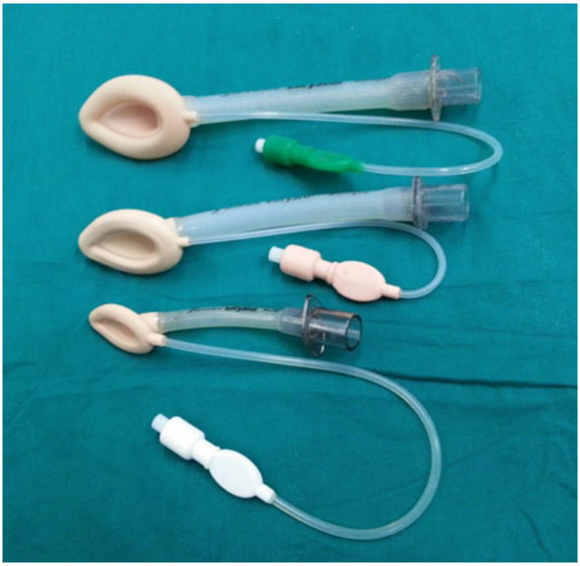


Fig. 7.6 Laryngeal mask airways

The laryngeal mask airway (LMA) is the most ubiquitous extraglottic airway device (Fig. 7.6). Firstly, it can be used as an alternative to endotracheal intubation for short cases. Second, it can be used as a rescue device during a failed intubation to maintain oxygenation and anesthesia. Third, it can also be used as a conduit to facilitate fiberoptic intubation. Blind intubation through a supraglottic device may fail as the glottis orifice may not be exactly aligned against the aperture of the device and fiberoptic intubation increases the success of an attempted intubation through an EGA [31].

The proseal LMA (Fig. 7.7) is a modified LMA with an esophageal drain to reduce gastric distension and is the extraglottic airway of choice in full stomach scenarios. The igel is a cuffless extraglottic airway that is made of a thermoplastic elastomer and incorporates a gastric drain tube and an integral bite block.

The intubating LMA (Fastrach) (Fig. 7.8) is specifically designed as a conduit for endotracheal intubation, but it is available only for children weighing >30 kg (size 3).

The air-Q intubating laryngeal airway is a curved laryngeal mask airway (Fig. 7.9) with a wider airway tube of a shorter length to facilitate fiberoptic intubation with cuffed endotracheal tubes in infants and neonates [33]. The wide airway tube allows accommodation of the pilot balloon of standard endotracheal tubes (unlike the classic LMA) and the shorter length facilitates removal of the air-Q after tracheal intubation (like an ILMA). The 15 mm adapter on the airway tube is detachable, thereby facilitating fiberoptic intubation through the device (Fig. 7.10). It has been successfully used in conjunction with fiberoptic guidance for children weighing as low as 7 kg. Size 1 is recommended for children weighing <7 kg, size 1.5 for children weighing 7–17 kg and size 2 for children weighing 17–30 kg.

Fig. 7.7 Pediatric Proseal Laryngeal Mask Airway

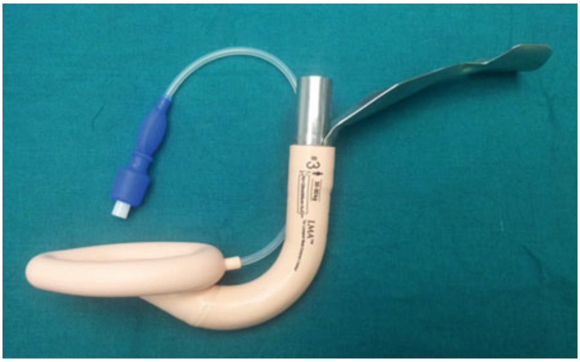


Fig. 7.8 Intubating Laryngeal Mask Airway Size 3

Unanticipated Difficult Airway

When there is an unanticipated difficult airway, it is important to weigh further intubation attempts against the potential for iatrogenic injuries, particularly supraglottic edema and bleeding, which can occur even with the gentlest instrumentation and can convert a "cannot intubate, can ventilate" situation into a "cannot intubate, cannot ventilate" situation. No single method or device has been found to be successful in all situations. A stepwise approach should be formally established in all sites and protocols should be in place to handle such a situation,

Fig. 7.9 The air-Q intubating laryngeal airway

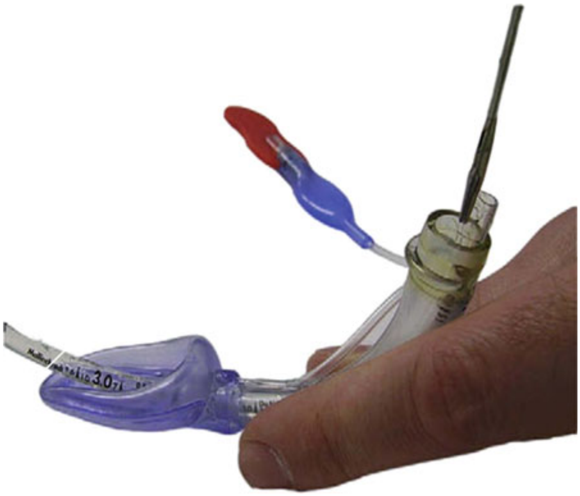


Fig. 7.10 Intubation through an air Q LMA

depending on the local resources and expertise available. It is important not to get obsessed with intubation, as failure to intubation does not kill, but failure to oxygenate does.

Invasive Airway Access

The management of infants and children who cannot be ventilated or intubated is very challenging as rescue options are very limited. The anatomic features of a pediatric airway (smaller, moveable, difficult to localize, elastic and more

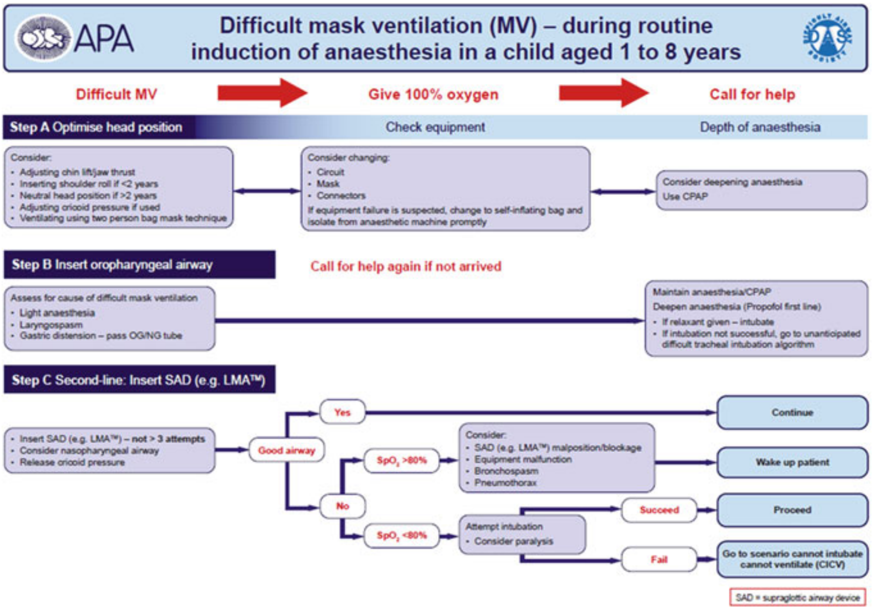


Fig. 7.11 DAS algorithm for difficult mask ventilation during routine induction of anesthesia in a child aged 1 to 8 years [10]

compressible pediatric trachea) makes transtracheal catheter placement more difficult, more time consuming and hence more risky [34], especially in children under 5–6 years of age. The size of the cricothyroid membrane (mean length of 2.6 ± 0.7 mm and mean width of 3 ± 0.63 mm) limits the size of the trans-tracheal device. Due to these reasons, a surgical tracheostomy inserted by an experienced surgeon may be preferred over cricothyrotomy, if acceptable oxygenation can be maintained by two hand-two person mask ventilation with oro-pharyngeal airway or a nasopharyngeal airway with the mouth and the other nostril closed. Several readymade cricothyrotomy kits are available for use in older children.

Algorithms

The difficult airway society has come up with the "Paediatric Airway Guidelines 2012". There are three guidelines that relate to the management of the unanticipated difficult airway in children aged 1–8 years. These include

(A) Difficult mask ventilation during routine induction of anesthesia in a child aged 1–8 years (Fig. 7.11).
(B) Unanticipated difficult tracheal intubation during routine induction of anesthesia in a child aged 1–8 years (Fig. 7.12).

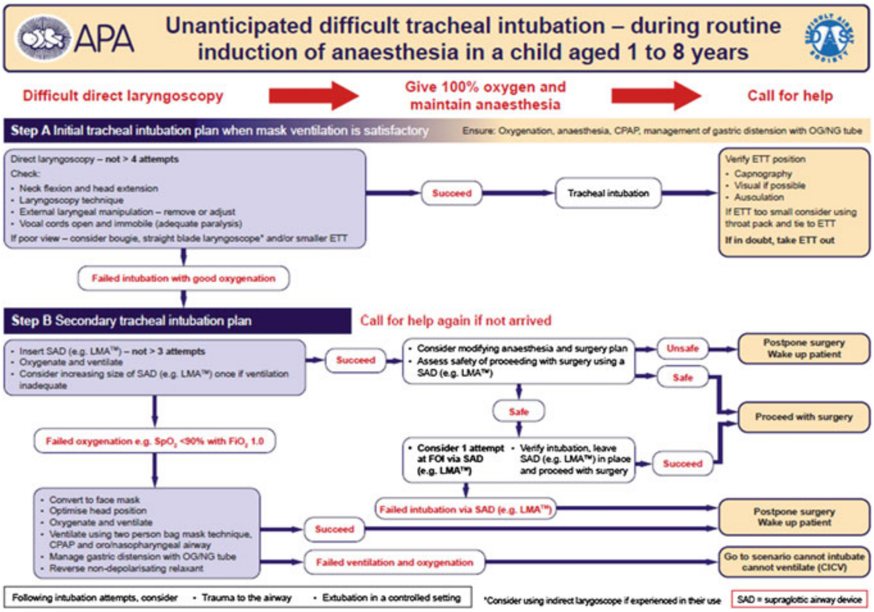


Fig. 7.12 DAS algorithm for management of unanticipated difficult intubation in children aged 1 to 8 years [10]

(C) Cannot intubate and cannot ventilate (CICV) in a paralysed anesthetised child aged 1–8 years (Fig. 7.13).

Extubation of a Difficult Airway

A difficult airway situation may remain so, even at the end of the surgical procedure and the circumstances surrounding extubation, in most instances, may be more unfavorable than during induction and intubation. The DAS has now come up with guidelines for extubation also. It is important to remember that all the necessary equipment and expert personnel and assistance and plans available during intubation should be continued through extubation. Airway exchange catheters are available (Fig. 7.14) in pediatric sizes for rescue reintubation, but should be used judiciously to avoid airway trauma. Extubation of a difficult airway should only be done when the child is fully awake, and a team of providers with advanced airway skills are available for reintubation, if it is needed.

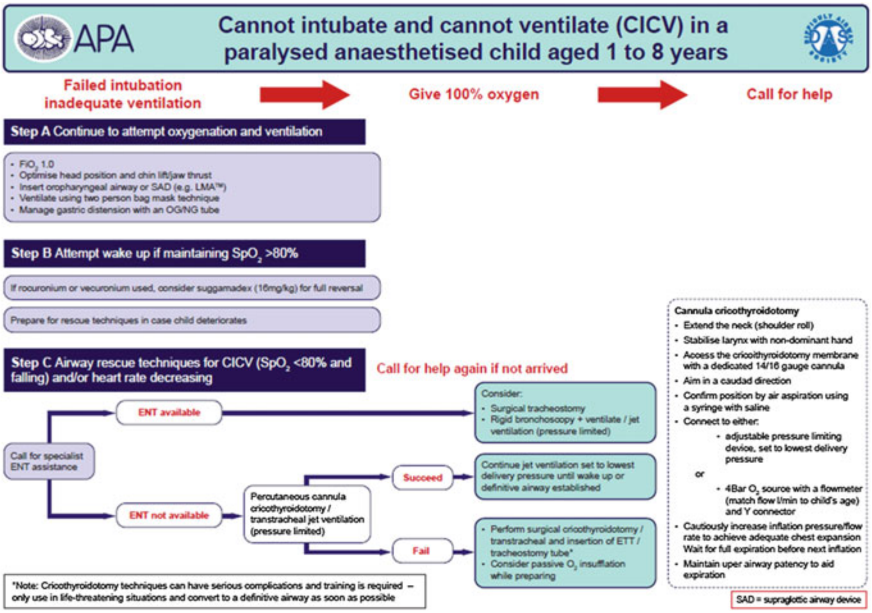


Fig. 7.13 The DAS algorithm for management of Cannot Intubate and Cannot Ventilate situation in children aged 1 to 8 years [10]

Fig. 7.14 Pediatric airway exchange catheter

Conclusion

The difficult pediatric airway can be a challenging scenario even for a trained pediatric anesthesiologist. Proper planning and having alternate plans and an ultimate "bottom-line" plan is an essential step towards averting mishaps. It is important to procure essential equipment, equip ourselves with adequate skills and practice in non emergent scenarios so that we are not found wanting when the need to manage a difficult paediatric airway arises. There are a lot of equipment available on the market. It is important to choose a few that we are comfortable with and train ourselves in it.

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Chapter 8
Perioperative Management of Obstructive Sleep Apnea

Karen Mak and Edwin Seet

Abstract Obstructive sleep apnea is the most common type of sleep-disordered breathing. This disease entity is also associated with multiple comorbidities and poses a risk of various perioperative and postoperative complications. Many patients with OSA present preoperatively undiagnosed; thus, it is important that these patients are identified via screening tools and optimized. In addition, there are various perioperative risk mitigation strategies for OSA patients in order to reduce the incidence of complications. This article provides a brief introduction of OSA, screening, diagnosis and risk stratification of high risk groups, as well as peri- and post-operative management of this vulnerable group of patients.

Keywords Obstructive sleep apnea · Perioperative risk · Postoperative management

Introduction

Obstructive sleep apnea (OSA) is the most prevalent sleep-disordered breathing [1]. The estimated prevalence in the general population for mild OSA is 1 in 4 males and 1 in 10 females [2]; and for moderate OSA 1 in 9 males and 1 in 20 females [3, 4]. OSA is defined as a sleep disorder with recurrent episodes of transient apnea of at least 10 or more seconds, and is characterized by partial or complete airway obstructions caused by an exaggerated depression in pharyngeal

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muscle tone, particularly during sleep and anesthesia [5]. Patients commonly present clinically with repeated nocturnal airway obstruction and arousal during sleep, daytime somnolence, increased sympathetic output, loss of memory and executive and psychomotor dysfunction [6].

Diagnostic Criteria

Frequently, patients present pre-operatively for elective surgery with undiagnosed OSA [7]. Evidence has shown that OSA is associated with an increased risk of postoperative complications. In addition, the perioperative management of patients with OSA is challenging and special considerations and advanced planning needs to be instituted. Thus, it is imperative to identify this group of patients with undiagnosed OSA.

The gold standard for the diagnosis of OSA has classically been an overnight sleep study incorporating an in-laboratory polysomnography (PSG). The diagnosis and severity of OSA is based on the Apnea-Hypopnea Index (AHI), which is defined as the average number of abnormal breathing events per hour of sleep. An apneic episode is defined as the cessation of airflow for at least 10 s; and hypopnea refers to desaturation of more than 4 % as a result of reduced airflow [8].

The diagnostic criteria for OSA varies according to different guidelines. The American Academy of Sleep Medicine (AASM) recommends that a diagnosis of OSA is made if the AHI on PSG exceeds 15; or in patients with symptoms an AHI greater than 5. Symptoms include unintentional sleep episodes during wakefulness, daytime somnolence, poor sleep quality, fatigue, insomnia, breath holding and sleep arousal, gasping, choking and snoring with interruption of sleep. A Respiratory Disturbance Index (RDI) is also obtained and OSA severity has been defined as mild for RDI ≥ 5 and < 15, moderate for RDI ≥ 15 and ≤ 30, severe for RDI > 30 [9].

The Canadian Thoracic Society guidelines for the diagnosis of OSA requires an AHI of 5 or more on PSG with either (1) daytime somnolence or (2) at least 2 other OSA symptoms as above. Similarly, severity has been defined as mild OSA for AHI $\geq$ 5–15, moderate for AHI 15–30 and severe for AHI > 30 [10].

Comorbidities Associated with OSA

OSA has been associated with a myriad of medical comorbidities of the various organ systems and has been known to be an independent risk factor for serious cardiovascular, neuro-cognitive and endocrine conditions which can lead to increased morbidity and mortality in all age groups. Organ systems affected include cardiovascular (myocardial ischemia, heart failure, brady and tachyarrhythmias, hypertension), central nervous system (cerebrovascular disease, neurocognitive impairment, psychiatric issues such as depression), Endocrine (impaired glucose tolerance and diabetes, metabolic syndrome, dyslipidemia, obesity), gastrointestinal (esophageal reflux) etc. Various other factors also predispose to OSA. Pathophysiological factors include anatomic abnormalities such as craniofacial deformities, macroglossia, micrognathia etc. which can predispose to airway obstruction secondary to mechanical reduction in the airway diameter. Endocrine diseases (Cushing's disease and hypothyroidism) and connective tissue disorders such as Marfan syndrome can also predispose to OSA. Other non-specific predisposing factors include the male gender, age greater than 50 years, neck circumference greater than 40 cm as well as lifestyle factors such as alcohol consumption and smoking [11].

Etiology and Pathophysiology

In OSA, upper airway obstruction occurs when the negative pressure generated by inspiratory muscles exceeds the intrinsic ability of the dilatory muscles of the pharynx to maintain airway patency, thus leading to airway collapse [12]. Medical conditions such as obesity which causes fatty deposition in the upper airways, as well as structural abnormalities in the airway anatomy (retrognathia, macroglossia, enlarged tonsils, craniofacial deformities) as mentioned above can thus reduce airway caliber and increase the risk of airway of episodic airway obstruction.

Particular concern during the perioperative period stems from the fact that many pharmacologic agents such as opioids, muscle relaxants, inhalational anaesthetic agents and sedatives are used intraoperatively and these have the propensity to impair upper airway muscle contraction and cause a loss of consciousness and hypoventilation. The confluence of these factors further predisposes to airway collapse and airflow obstruction [13, 14].

Anaesthetic agents and sedatives cause a dose dependent depression in muscle tone and activity. Inhalational induction agents cause respiratory center depression and hence suppress the diaphragmatic and intercostal muscles [15]. Intravenous induction agents such as propofol inhibits the action of the genioglossus muscle and thus increases the risk of airway collapse [16]. Benzodiazepines such as Midazolam can cause obstructive episodes by increasing supraglottic airway resistance [17]. Opioids are known to cause respiratory depression and depress respiratory drive with a decreased ventilatory response to hypercapnia and hypoxia, thus they can cause impaired respiration and lead to airway obstruction [18, 19].

Postoperative Complications in Patients with OSA

If left untreated, chronic OSA can lead to various multi-systemic adverse complications as mentioned above, and predispose to increased morbidity and mortality in the perioperative period. The susceptibility of the airway to collapse also predisposes the surgical OSA patient to an increased risk of serious airway complications both peri- and postoperatively. Various studies have shown an increase in serious postoperative complications associated with OSA such as unplanned admission to Intensive Care Unit (ICU), reintubation, cardiac events, pneumonia, requirement for non-invasive ventilation, postoperative hypoxemia, prolonged hospitalization and postoperative delirium. There has been an increasing body of evidence which suggest an increase in adverse perioperative and postoperative outcomes in OSA patients; hence precautions should be taken to reduce the incidence of complications in this susceptible group.

Clinical Pathways and Principles of Perioperative Management

In view of the need to improve the perioperative care and postoperative outcomes for OSA patients, several clinicians have come up with a variety of guidelines, protocols and clinical pathways. Preoperatively, various centers have adopted a wide range of sensitive clinical criteria to identify and perform risk stratification of pre-operative patients who potentially have OSA. Very often, the clinician can be alerted to the possibility of undiagnosed OSA by clinical history and physical examination alone. Researchers from the Mayo Clinic used the Flemons Prediction Model [20] to generate a Sleep Apnea Clinical Score (SACS) which utilizes a combination of various clinical variables such as neck circumference greater than 43 cm, snoring, and disturbed breathing during sleep, daytime somnolence, obesity and hypertension to screen for OSA risk. Other screening systems include the American Society of Anesthesiologists (ASA) checklist [21], which comprises of 3 categories (physical characteristics, OSA symptoms and somnolence) with a total of 16 items. A scoring system is then utilized to predict the patient's perioperative risk for OSA by taking into account OSA severity, invasiveness of surgical procedure, as well as expected postoperative opioid requirement. Other recent review articles have proposed the use of various questionnaire—based screening tools to predict the probability and severity of OSA in patients. High-risk patients detected on screening should then undergo formal evaluation with diagnostic PSG and Positive Airway Pressure (PAP) implemented prior to surgery if deemed necessary.

Intraoperatively, focus should be on predicting and managing difficult airways, ways to reduce gastric aspiration as well as the careful titration of pharmacological agents such as opioids in order to minimize the risk of postoperative complications such as over-sedation and respiratory depression [22–24]. Close monitoring and early detection and intervention of postoperative complications are extremely crucial in the immediate postoperative period. The American Sleep Society proposes that patients with OSA should be monitored in the post anesthesia care unit

(PACU) for 3 h more than non-OSA patients and 7 h in patients with respiratory complications if they were to be discharged to an unmonitored facility [22]. Adesanya et al. proposes that patients identified to be at high risk for or diagnosed with OSA should be monitored in PACU for at least 2 h and PAP implemented should desaturation occur [22].

Postoperatively, patients should receive continuous oxygen saturation monitoring and PAP should be considered early in patients who were previously already on PAP treatment, non-compliant patients, as well as high-risk patients.

Preoperative Evaluation of the Patient with Diagnosed OSA

As with all medical conditions, it is essential that a thorough history is taken and physical examination performed. The patient should be asked targeted questions which focus on eliciting OSA symptoms and PSG results if available should be reviewed to confirm diagnosis and ascertain severity of OSA.

In patients with long-standing chronic OSA, they may present with a variety of signs and symptoms which may suggest systemic complications of the disease as mentioned above; for example hypoxemia, hypercarbia, polycythemia and cor pulmonale. The physician should also look out for associated significant comorbidities such as morbid obesity, uncontrolled hypertension, arrhythmias, cerebrovascular disease, heart failure, and metabolic syndrome.

In particular, pulmonary hypertension can occur in 15–20 % of patients with OSA and is of importance as intraoperatively, pulmonary artery pressures may be further raised by various physiological derangements and care should be taken to avoid this complication [25]. Although the American College of Chest Physicians does not recommend the routine evaluation for pulmonary hypertension in patients with OSA, [26] the physician should anticipate the possibility of intraoperative triggers (e.g. prolonged duration high risk procedures) which could acutely elevate pulmonary artery pressures and a preoperative transthoracic echocardiogram may be considered for evaluation and risk stratification [22].

Other complications as stated above may be screened by simple non-invasive bedside investigations conducted in the preoperative evaluation clinic, for e.g. a baseline oximetry reading of 94 % or less on room air may suggest severe long-standing OSA (provided all other causes for hypoxemia have been excluded).

Very often, patients with diagnosed OSA may already be on treatment with PAP devices. Such devices include Continuous Positive Airway Pressure (CPAP), Bilevel Positive Airway Pressure (BiPAP), and Automatically Adjusting Positive Airway Pressure (APAP) machines. CPAP machines deliver a single continuous level of pressure; BiPAP machines deliver a higher inspiratory pressure and a lower expiratory pressure; APAP machines deliver varying pressures for respiratory assistance based on airflow measurements, pressure fluctuations and airway resistance [27]. For patients already on PAP therapy, it is important to obtain the patient's updated PAP therapy settings, as well as ascertain level of compliance.

Defaulters should be advised to restart PAP therapy pre-operatively, and in selected individuals (non-compliant patients, recent exacerbation of symptoms, patients who have already undergone surgical intervention for OSA), re-evaluation by a sleep medicine physician may be indicated.

Interestingly, to date, there is still insufficient evidence to prove conclusively that pre-operative PAP therapy is beneficial; and there have been no recommendations with regards to the duration of pre-operative PAP therapy to effectively reduce perioperative complications. Liao et al. [28] conducted a retrospective matched cohort study which suggested that PAP therapy preoperatively may be beneficial, based on the observation that there was a lower complication rate in OSA patients commenced on home PAP therapy pre-operatively compared to untreated OSA patients.

Currently, guidelines generally recommend that OSA patients who are already on PAP therapy should continue treatment preoperatively. The anesthesia team should be informed regarding the patient early in advance in order to plan ahead the intraoperative management of the patient.

The Busselton Health Cohort Study [29] found that mild OSA was not an independent risk factor for higher mortality in the general population. Extrapolating this observation, the perioperative use of PAP in this patient group may not be indicated as mild OSA in itself may not be a significant disease entity for surgery and anesthesia. Figure 8.1 proposes an algorithm for the preoperative evaluation and management of patients either suspected of or already diagnosed with OSA.

Methods for Perioperative Screening for OSA

Although PSG is the gold standard test for the diagnosis of OSA, the need for specialized equipment and special technical expertise renders it costly and resource-demanding, and therefore not suitable for routine screening. There is thus a need for simple, cost-effective, rapid and sensitive screening tests to detect patients with suspected OSA. Over the years, various screening tools have been developed. Examples of such tools include the Epworth Sleepiness Scale [30], the Berlin Questionnaire [31], the ASA checklist [21], the Sleep Apnea Clinical Score [20], the P-SAP score [32], the STOP and the STOP-Bang Questionnaires [33].

The STOP-Bang Questionnaire (Table 8.1) was originally developed for the surgical population but has since been extrapolated for use and validated in other various patient populations [33, 34]. The STOP-Bang Questionnaire is useful in the preoperative setting to predict OSA severity, exclude OSA, and triage patients who require further investigations for diagnosis confirmation. It is a concise, validated and easy-to-use scoring system which incorporates Body-mass-index (BMI), age, neck circumference and gender and comprises of 8 simple questions framed within the acronym STOP-Bang (Table 8.2). The patient either answers a “yes” or “no” to each question and a score is calculated accordingly.

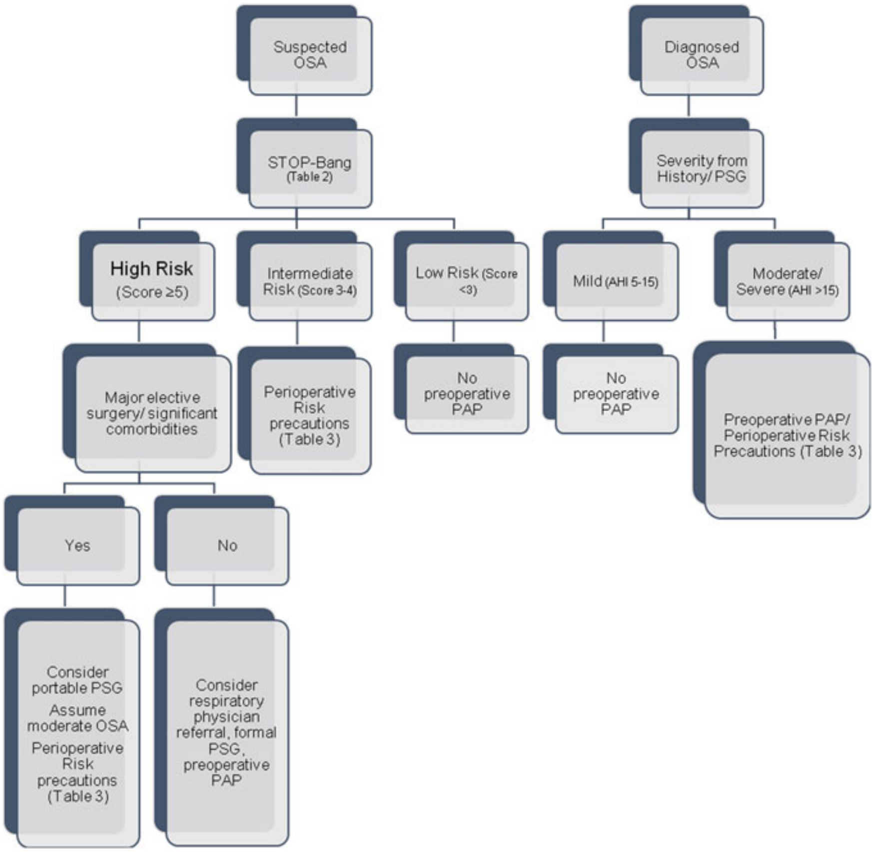

Fig. 8.1 Preoperative evaluation of a patient with known or suspected OSA

The ideal screening test should have a high sensitivity (low false-negative) and high negative predictive value. The STOP-Bang Questionnaire satisfies this criterion, especially in patients with moderate to severe OSA [36]. A STOP-Bang score of less than 3 would mean that the patient is unlikely to have moderate to severe OSA. The sensitivity of the STOP-Bang Questionnaire for moderate OSA (AHI > 15) is 93 % whereas that for severe OSA (AHI > 30) is 100 %; the specificity for moderate OSA is 43 % whereas that for severe OSA is 37 % [36]. At higher cut-off values, the specificity for severe OSA increases significantly: For STOP-Bang scores of 5, 6 and 7, the specificity increases to 74, 88 and 95 % respectively [37]. Patients with a score of 0–2 thus may be considered low risk; 3–4 intermediate risk and 5 or more high risk of having OSA [33, 35].

Table 8.1 Obstructive sleep apnea screening questionnaire: STOP-Bang questionnaire

STOP questionnaire			
S	Snoring: Do you snore loud enough to be heard behind closed doors?	Yes	No
T	Tiredness: Do you feel tired or sleepy during the daytime?	Yes	No
O	Observed: Has anyone observed that you stop breathing during sleep?	Yes	No
P	Pressure: Do you have or are being treated for High Blood Pressure?	Yes	No
B	BMI: > 35 kg/m [2]?	Yes	No
A	Age: > 50 years?	Yes	No
N	Neck circumference: > 40 cm?	Yes	No
G	Gender: Are you male?	Yes	No

Low risk of OSA Yes to less than 3 questions
Moderate risk of OSA Yes to 3–4 questions
High risk of OSA Yes to 5 or more questions

Table 8.2 Perioperative precautions and risk mitigation strategies for OSA patients

Perioperative precautions and risk mitigation for OSA patients	
Anesthetic concern	Principles of management
Premedication	• Avoid sedatives • Consider α_2-adrenergic agonists
Potential difficult airway	• Optimal positioning • Adequate preoxygenation (CPAP) • 2-handed mask ventilation • Anticipate difficult airway: airway adjuncts, difficult-airway algorithm
Gastroesophageal reflux disease	• Pharmacological: proton pump inhibitors, H_2-antagonists, antacids • Rapid sequence induction (RSI)
Opioid-related respiratory depression	• Avoid opioids • Opioid-sparing analgesia (multimodal) • Use short-acting agents (e.g. remifentanyl) • Local/regional anesthesia
Sedative effects of anesthetic agents	• Use short-acting agents (e.g. propofol, desflurane) • Regional anesthesia
Oversedation in monitored anesthesia care	• Use of capnography
Post-extubation airway obstruction	• Ensure complete reversal of neuromuscular blockade • Extubate fully awake • Non-supine posture post-extubation • Restart PAP therapy

Preoperative Evaluation of the Patient with Suspected OSA

In patients with suspected OSA, it is crucial that a thorough history be taken and a clinical examination performed to elicit the important signs and symptoms of OSA. Figure 8.1 is a simple algorithm which can be adopted in evaluating a patient suspected of having OSA [23]. Using the STOP-Bang Questionnaire, if the patient is deemed to be at high risk of OSA, the next step would be to ascertain the urgency of surgery. If the surgery planned is a non-urgent, elective surgery, the subsequent management hinges upon (1) Surgical risk (2) Presence of co-morbidities associated with chronic OSA for example uncontrolled hypertension, heart failure, pulmonary hypertension, cerebrovascular disease. For patients with a STOP-Bang score of 5 or more who are planned for a major surgery and present with comorbidities associated with OSA, a referral to the sleep medicine physician may be warranted for a more detailed pre-operative assessment, and a PSG may be considered in order to confirm the diagnosis and determine the severity of the disease for risk stratification. If diagnosed with OSA, it is important that they be started on PAP therapy prior to surgery and sufficient time allowed for planning of intraoperative and postoperative management [21]. Elective surgeries may need to be postponed for optimization of patients with suspected severe OSA. For patients with a STOP-Bang score of 5 or more, who have no significant co-morbidities associated with chronic OSA, the physician may consider further evaluation with a portable PSG or may proceed with surgery on the presumptive diagnosis of significant OSA and take the necessary perioperative OSA precautions in order to mitigate the risk involved. Ultimately, the decision lies with the physician based on his/her clinical judgment, taking into account the logistic, surgical—related and patient-related issues.

Patients who have a STOP-Bang score of 3–4 or deemed to be at intermediate risk of OSA may proceed with surgery, with the physician taking the necessary perioperative precautions. These patients at intermediate risk of OSA may present with difficult airways [38] or may pose a problems of airway obstruction and desaturation [39] in PACU, and these may warrant a referral to a sleep medicine physician and a PSG postoperatively.

Screening tests for OSA generally have a high negative predictive value (low false-negative rate); thus patients with a score lower than 3 are very unlikely to have OSA and may proceed with surgery with routine perioperative management.

Portable Polysomnography and Overnight Oximetry

Although the standard overnight in-laboratory PSG has been the gold standard for the diagnosis of OSA, it is time consuming and requires specialized equipment and expertise. A possible, more practical alternative to the in-laboratory PSG in a certain subgroup of patients would be home sleep testing, or better known as portable PSG [40]. It can be classified into different levels: level 2 being full PSG with 7 channels; level 3 being devices with 4 to 7 channels and level 4 being devices with 1–2 channels, including nocturnal oximetry. Portable PSG allows patients to be assessed in the comfort of their own homes and has the advantages of accessibility, user-friendly and possibly affordability. Portable PSG has been shown to successfully identify OSA in 82 % of adult surgical patients [41].

Perioperatively, level 2 PSG has been shown to be as accurate as a full in-laboratory PSG in diagnosing OSA [42], whereas nocturnal oximetry has been found to be both sensitive and specific for detecting OSA in patients with a high STOP-Bang score [43]. The AHI obtained from PSG has also been shown to correlate well with the Oxygen Saturation Index obtained from nocturnal oximetry [43].

The Portable Monitoring Task Force of the American Academy of Sleep Medicine (AASM) recommends portable devices for the diagnosis of OSA in certain cases with a high likelihood of moderate to severe OSA but no associated comorbidities [44]. The Canadian Thoracic Society suggests that levels 2, 3 and 4 portable PSG can be used to confirm the diagnosis of OSA, provided that guidelines are adhered when performing the test and during interpretation [45]. Portable PSG and overnight oximetry are particularly useful alternatives to a full formal PSG for preoperative OSA detection and diagnosis, especially if facilities for a standard in-laboratory PSG are not available. These portable devices may also be of value in risk stratification and thus may help to expedite the preoperative diagnosis and implementation of PAP therapy in selected cases, reducing the perioperative and postoperative risks.

Preoperative and Intraoperative Risk-Mitigation Strategies for Patients

There are a variety of strategies which may be adopted to mitigate the risk of adverse perioperative and postoperative complications in patients with OSA. These are summarized in Table 8.2.

Preoperatively, medications with sedative effects should be avoided if possible [46]; and other analgesic adjuvants such as α_2—adrenergic agonists (Clonidine, Dexmedetomidine) may have opioid-sparing effects and reduce requirements for anesthetics intraoperatively, [47] and may be considered.

It is important to anticipate the various problems and complications which a patient with OSA may present with, and take the necessary precautions to avoid adverse effects as far as possible. Intraoperatively, the OSA patient may frequently pose the problem of having a difficult airway, as explored earlier. OSA is an independent predictor for difficult mask ventilation [48] and it has been found that difficult laryngoscopy and tracheal intubations occur 8 times more frequently in patients with OSA compared to those without OSA [49]. In addition, it has also been found that the prevalence of difficult intubation in patients with severe OSA (with a higher AHI) was higher than in the lower AHI group [50]. Thus, it is essential that the anesthesiologist anticipates a difficult airway and practices advanced planning of airway management in concordance with difficult airway algorithms. A thorough history should also be taken with regards to previous surgeries and anesthesia, and complications if any. Old anesthetic records, if available should also be reviewed and any documented history of difficult mask ventilation or intubation noted. There should be experienced and skilled personnel, as well as the necessary equipment including a variety of airway adjuncts readily available prior induction and intubation [51]. The anesthetic team involved should be familiar with difficult airway algorithms such as the American Society of Anesthesiologist (ASA) Task force on management of difficult airway practice guidelines [52]. Some measures have been shown to be useful, for example, pre-oxygenation with continuous PAP of 10 cm H_2O at 100 % oxygen for 3 to 5 min with a 25° head-up tilt to increase end-tidal oxygen has been shown to prolong the time to desaturation [53, 54]. Some other techniques include two-handed mask ventilation to achieve adequate ventilation, as well as optimum positioning of obese patients in the head elevated laryngoscopy position (HELP) to align adequately to facilitate direct laryngoscopy and endotracheal intubation [55]. This position can be achieved by simply stacking multiple towels or blankets, or using special devices designed for this purpose, such as the Troop Elevation Pillow.

Another consideration would be the presence of Gastroesophageal Reflex Disease (GERD) which is commonly seen among patients with OSA. This is secondary to hypotonia of the lower esophageal sphincter and can pose a risk of gastric acid aspiration [56]. Management can be either pharmacological or non-pharmacological. Pharmacological management would include administering pre-operative proton-pump inhibitors, H_2—antagonists or antacids. Non-pharmacological management would include maneuvers such as Rapid Sequence Induction (RSI) and Cricoid pressure, although the use of cricoid pressure may interfere with mask ventilation and tracheal intubation [57].

Another important consideration would be the risk of sedation from the various anesthetic agents, as well as the risk of respiratory depression with the use of opioids. Due to the propensity for airway collapse, sleep deprivation and a reduced response to hypoxia and hypercarbia, patients with OSA are especially sensitive to the respiratory depressant effects of the many pharmacological agents used during anesthesia such as sedatives, anxiolytics, opioids, and inhaled anesthetics. Long-acting agents should be avoided when possible, and instead, short-acting pharmacological agents should be used, for example, Propofol for induction or maintenance of anesthesia, Desflurane for maintenance, and Remifentanil for analgesia. The anesthesiologist should consider the intraoperative use of opioid-sparing agents and a multi-modal approach to analgesia so as to minimize postoperative opioid use. Opioid-sparing analgesics that can be used include Non-Steroidal Anti-inflammatory Drugs (NSAIDs), Cyclooxygenase-2 Inhibitors, Paracetamol, Tramadol, and other adjuvants such as anticonvulsants (Gabapentin, Pregabalin). One report has shown that in OSA patients administered opioids, desaturation was 12-14 times more likely to occur than OSA patients who received opioid-sparing analgesia [58]. Recent developments has revealed various opioid-sparing novel adjuvants such as corticosteroids (e.g. Dexamethasone), N-methyl-$_D$-aspartate receptor antagonist (e.g. Ketamine), [59] α_2—agonists (Clonidine, Dexmedetomidine) [60] and Melatonin [61].

Towards the end of surgery, neuromuscular blockade if given should be fully reversed. The extent of residual neuromuscular blockade should be assessed and can be objectively done with the use of a peripheral nerve stimulator e.g. train-of-four. Murphy et al. found that there was an increase in the risk of aspiration, airway obstruction, hypoventilation, hypoxia and re-intubation with even minute amounts of residual neuromuscular blockade, [62] and these complications may be amplified in a patient with OSA. Patients should be carefully assessed and only extubated when fully awake and consciously obeying commands. Post-extubation, patients should be nursed in a non-supine position, either semi-upright or lateral [21].

Pulmonary hypertension is a known complication of OSA and thus care should be taken to avoid the triggers for elevation of pulmonary artery pressures such as hypercarbia, hypoxemia, hypothermia, and acidosis.

Postoperatively, patients who were previously on PAP therapy pre-operatively should be restarted on PAP devices after surgery [21].

Where feasible, depending on the nature of surgery, alternative techniques to general anesthesia such as local anesthesia and regional anesthesia should be considered in order to minimize manipulation of the airway and minimize the use of sedating, anesthetic and analgesic medications which can predispose to respiratory depression and airway collapse.

For patients undergoing procedures done under monitored anesthesia care, it is recommended that there is continuous capnography monitoring for detection of respiratory depression. Patients already on PAP therapy preoperatively should be continued on PAP therapy if mild to moderate sedation is required [63].

Postoperative Management Strategies of suspected and known OSA patients after General Anesthesia.

There are 3 main components which determine the disposition of the postoperative OSA patient: (1) Severity of OSA (2) Postoperative opioid requirement (3) Nature and extent of surgery as illustrated in Fig. 8.2. As a general guide, a patient with severe OSA who has undergone major surgery requiring high-dose opioids is more likely to require prolonged continuous monitoring. Ultimately, the decision regarding the extent of monitoring lies on the discretion of the attending anesthesiologist.

The ASA Guidelines based on expert opinion recommends that patients with OSA be observed for at least 7 h in PACU should complications such as airway obstruction occur. However, this may not be possible logistically in some centers and thus, alternative algorithms and guidelines have emerged. As illustrated in Fig. 8.2, all patients with diagnosed or suspected OSA should receive extended continuous monitoring with oximetry in the Postanesthesia Care Unit (PACU) for an additional 60 min after the modified Aldrete criteria for discharge has been satisfied [23, 64]. For both arms, (suspected and diagnosed OSA) the occurrence of recurrent PACU respiratory events warrants continuous postoperative monitoring in a monitored environment (e.g. Intensive Care Unit, Step-down unit, or remote pulse oximetry with telemetry in a Surgical Ward) with continuous oximetry and/or PAP therapy [63]. PACU respiratory events refers to: (1) Apneic episodes of 10 s or more (2) Bradypnea of less than 8 breaths per minute (3) high pain and sedation scores concurrently (4) repeated desaturations to less than 90 %. Any of the above events occurring in separate 30-minute intervals is considered recurrent. Other

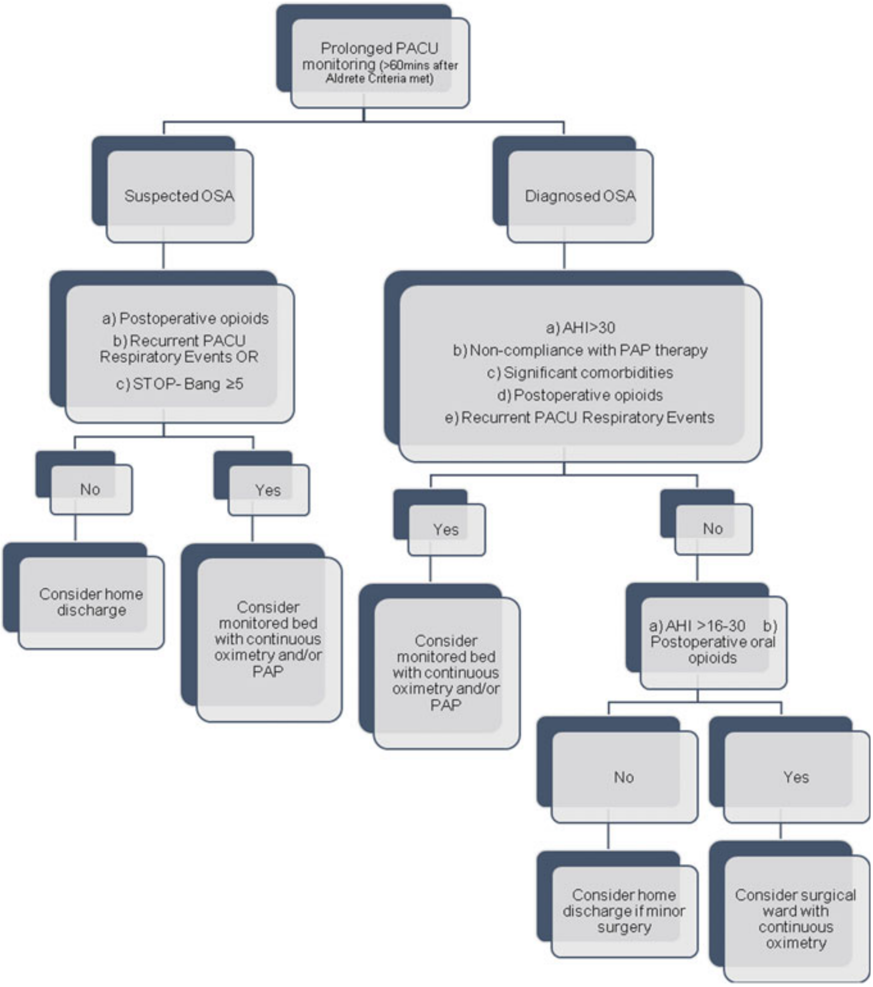

Fig. 8.2 Postoperative management (post General Anesthetic) of the patient with known or suspected OSA

scenarios whereby continuous postoperative monitoring should be considered include: (a) Known OSA patients with severe OSA, non-compliant to PAP therapy, patients with significant co-morbidities, or who have received postoperative parenteral opioids (b) Suspected OSA patients who have received postoperative parenteral opioids, or who have a STOP-Bang of 5 or more. Recent advances in technology has improved the sensitivity of monitoring equipment, enhancing the quality of postoperative care and monitoring of OSA patients [65, 66]. Patients who were previously on PAP therapy preoperatively should be restarted on PAP devices postoperatively.

When possible, postoperative opioids should be avoided, and a multi-modal approach to pain management should be practiced. Alternatives to opioids include pharmacologic therapy (oral or systemic opioid-sparing drugs as mentioned previously), local anesthetic wound infiltration, regional anesthetic (e.g. Epidural catheter, peripheral nerve block or catheter) etc. If postoperative opioids are unavoidable, a patient—controlled analgesia (PCA) is preferred over a basal infusion of opioid. These patients should be given supplemental oxygen and if possible ventilation monitored with e.g. a capnography.

Ambulatory Surgery and the OSA Patient

The 2006 ASA Guidelines on the perioperative management of OSA patients recommend that minor and superficial surgeries, as well as surgeries done under local or regional anesthesia can be performed as day cases [21].

Recently, the Society for Ambulatory Anesthesia (SAMBA) released guidelines regarding the selection of suitable OSA patients for ambulatory surgery. It is recommended that known OSA with well-controlled comorbidities may be considered for ambulatory surgery, provided they are compliant with postoperative PAP therapy, which will be required minimally for several days postoperatively. Patients with suspected OSA with optimized comorbidities, with no recurrent PACU respiratory events, and do not require postoperative opioids may also be considered for ambulatory surgery [67].

All OSA patients should have an accompanying adult to escort home and patient and caregivers should be educated regarding postdischarge care. With advances in technology, careful preoperative optimization, intraoperative risk mitigation and strict discharge criteria, it might be possible for safe ambulatory surgery for a subset of OSA patients.

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Chapter 9
Airway Management in Traumatic Brain Injury (TBI)

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Abstract Traumatic brain injury has become the leading cause of morbidity and mortality all over the world. Early establishment and maintenance of airway is critical as mortality increases in patients who suffer hypoxia. This review discusses the prehospital and intraoperative management of airway in these patients. The current practices and controversies regarding the use of tracheal tubes versus other means of maintaining the airway in prehospital management, indications of tracheal intubation, choice of anaesthetic drugs for induction, hemodynamic response to laryngoscopy and intubation, role of tracheostomy, as well as principles of extubation are discussed.

Keywords Intubation tracheal · Traumatic brain injury · Head trauma · Head injury · Prehospital care · Airway · Tracheostomy · Extubation · Hemodynamic response

Introduction

TBI is currently the leading cause of death and disability in high income countries and is predicted to be the major cause of death and disability worldwide by the year 2020 [1]. Head injury affects more than one million Americans annually [2]. In United Kingdom 11,000 people per year sustain TBI [3]. TBI is also becoming the leading cause of morbidity and mortality in Asia as many low and middle income countries are undergoing rapid urbanisation. Although data from this continent is limited, a paper on Global Burden of Disease Study has compared available data between China, India and the rest of Asia. In this region, India appears to have the highest incidence of TBI due to road traffic accidents, falls, and violence [4]. It is estimated that in India nearly 6 million individuals sustain TBI annually [5].

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Airway control is crucial in these patients in order to prevent secondary brain injury due to effects of hypoxia, hypoventilation and hypercarbia on cerebrovascular physiology or secondary effects of aspiration. Both hypoxia and hypercarbia lead to cerebral vasodilatation and a rise in Intra Cranial Pressure (ICP). The Brain Trauma Foundation Guidelines recommend an oxygen saturation value of more than 90 % and a Systolic Arterial Pressure of more than 90 mm of Hg in patients with severe TBI [6]. These patients may require airway management either in the pre hospital period, in the emergency room, before radiological investigation, in the operating room or in critical care areas.

This topic review is based on Medline literature search from 2009 until 2013. The literature was reviewed using medical subject headings “traumatic brain injury, head injury, head trauma, airway, intubation tracheal, hemodynamic response, extubation, tracheostomy, prehospital care” and various combinations of these terms. Selected references were also accessed. This review will not cover cervical spine trauma as it will be covered elsewhere in the book.

Pre Hospital Airway Management

Hypoxemia and hypercarbia both lead to cerebral vasodilatation, increase in intracranial pressure and worsen outcome in TBI. Early establishment and maintenance of a clear airway is therefore a basic requirement. The first step is to administer high flow oxygen and use of basic airway adjuvant if needed e.g. the oropharyngeal airway. International Brain Trauma Foundation Guidelines recommended pre hospital tracheal intubation in all patients with TBI with GCS less than 8 [6]. Mortality is increased twofold in patients who suffer one hypoxic episode of SpO_2 less than 92 % during transfer to hospital compared to those who do not suffer from hypoxia [7].

Several studies are available primarily from USA, which deal with pre hospital airway management. Patients with impending respiratory arrest or with low GCS will need immediate intubation. The commonly accepted indications for intubation are given in Table 9.1 [8].

There is still controversy as to whether intubation improves outcome [9]. Management at this stage is usually done by non-physicians and hence inexperience or lack of practice in specially tracheal intubation can lead to a high rate of complications [9]. In a retrospective review of Los Angeles County Trauma System Database, Bukar et al. evaluated the role of pre hospital intubation in an urban trauma setting, 2,549 patients were analyzed. After adjusting for confounding

Table 9.1 Indications for tracheal intubation

• Failure to oxygenate
• Failure to ventilate
• Failure to protect the airway
• Anticipated neurological decline
• Anticipated cardiopulmonary decline

factors they concluded that pre hospital intubation in isolated moderate to severe TBI was associated with a fivefold increase in mortality (AOR5, 95 % CI: 1.7–13.7, p = 0.004) [10]. Rapid sequence tracheal intubation (RSI) is recommended when attempting to intubate patients with GCS more than 3 [9, 11].

Laryngeal mask airway (LMA) is being increasingly used in prehospital settings, mainly because of its ease of insertion and at the same time also providing reasonable airway protection [3]. Training and maintenance of skills with LMA is a lot more easier compared to tracheal intubation. The newer version LMA Proseal, now provides a conduit for drainage of stomach contents and hence provides added protection of the airway.

Tracheal Intubation on the Hospital Premises

Preintubated Patients

Patients with acute head injury and GCS less than 8 will probably come to the operating room with their trachea intubated. The position of tracheal tube should always be checked as migration or endobronchial intubation may occur during transport [12].

Tracheal Intubation in the Hospital

Patients with GCS more than 8 or those with extradural hematoma may be conscious. A rapid baseline neurological assessments should be conducted and documented prior to airway management. This should include the level of arousal; muscle tone, reflexes, seizure activity and cervical spine stability [8].

Two groups of patients should be identified; patients with clinical signs of raised ICP and those without any evidence of raised ICP. The later group of patients do not require any specific measures except for adhering to the fundamental principles of neuroanaesthesia. Patients with raised ICP for urgent surgery must be considered as full stomach. Preoxygenation is mandatory and RSI with cricoid pressure is indicated. If the airway is uncomplicated a modified rapid sequence induction with predetermined doses of induction agent, with a short acting opioid and a depolarising muscle relaxant is used [13]. If the patients oxygen saturation decreases during the induction period, gentle IPPV with a bag and mask maybe required keeping the cricoid pressure in place. In case of suspected difficult airway a backup plan for airway management is mandatory.

If cervical spine injury cannot be ruled out then special precautions like the Manual Inline Stabilization should be taken. If the patient comes with a cervical collar the front part of the collar can be removed to allow for better mouth opening [12].

Principles of Tracheal Intubation in TBI

The aim of airway control in TBI is to decrease the chances of secondary brain injury [11]. Goals of tracheal intubation are to prevent hypoxia, hypercarbia, hypo and hypertension, pulmonary aspiration and to avoid any further damage to cervical spine [14].

Choice of Induction Agents to Facilitate Tracheal Intubation

There is no consensus on choice of anesthetic drugs for decreasing ICP at the time of induction.

Induction Agents

Both thiopentone and propofol decrease intracranial pressure and cerebral metabolic rate of oxygen consumption ($CMRO_2$) but also decrease BP specially in hypovolemic patients [15]. A fall in mean arterial pressure (MAP) may lead to a fall in cerebral perfusion pressure (CPP) in patients where cerebral blood flow (CBF) is already low. Etomidate has been used in head injured patients [12] and does decrease ICP and $CMRO_2$ with no fall in BP. However use of even a single dose has been associated with adrenal insufficiency [16] which has led to a delayed fall in BP. Some authors recommend an additional dose of induction agents just prior to intubation [14].

Ketamine is relatively contraindicated for induction [17]. This concern is based on its use in studies from 1970s. Ketamine is now frequently being used in emergency services in out of hospital environment. Level 2 evidence is now emerging that ketamine can be used in traumatic head injury in absence of obstruction of CSF pathway [18]. It has been used in critical care unit to prevent the intracranial pressure elevations during tracheal tube suctioning in patients with severe brain injury [19].

Muscle Relaxants

Use of succinylcholine causes muscle fasciculation and is associated with a temporary increase in ICP. This observation is mainly based on animal studies. One small study in humans has shown no effect [20]. The exact clinical significance of this fasciculation induced rise in ICP has therefore been questioned. This rise can be prevented by a single defasciculating dose of a non-depolarizing muscle relaxant but high quality evidence of this practice is still lacking [21]. An adequate dose of thiopentone or use of propofol and lignocaine also minimize this effect.

If difficult intubation is anticipated succinylcholine can be used. Rocuronium can be chosen as an alternative where difficult intubation is not a concern. Availability of sugammadex in some countries has allowed rocuronium to be used as an alternative agent in situations where succinylcholine is contraindicated.

Narcotics

For inhospital intubation it is routine practice to include a short acting opioid in the induction sequence.

Sympatho Adrenal Response to Tracheal Intubation in TBI

The acutely injured brain is very sensitive to hemodynamic changes. Even brief episodes of hemodynamic derangements can worsen outcome [22]. Few studies have addressed this response in this particular group of patients. Catecholamine surges related to laryngoscopy and tracheal intubation, increase both heart rate and blood pressure which can increase cerebral blood volume and hence ICP [23].

The auto regulation curve is disturbed in TBI hence even a small rise in blood pressure can be detrimental and can cause a further increase in ICP as well as cerebral edema and risk of hematoma enlargement [24]. Perkins et al. conducted an observational study on intubation response in head injury [25]. Seventy nine percent of the patients had a clinically significant hypertensive response. There was 100 % increase in MAP and SAP in every one in 10 patients. In another retrospective study of 97 patients the same author found that this response was not attenuated with increasing head injury severity and recommended that the need to attenuate the response should be assessed independent of severity of injury. However analgesic and anaesthetic drugs were not standardized in this study [26].

In a recent Cochrane Systematic Review on pharmacological treatment for preventing morbidity and mortality associated with this response, the authors looked at the incidence of arrhythmia and myocardial ischemia in pooled data of 72 studies [27]. Only two included studies in neurosurgical patients observed the effects of IV fentanyl and IV hydralazine. A recent publications recommends using either IV fentanyl 2–3 ugs/kg, esmolol 1–2 mg/kg and lidocaine 1.5 mg/kg IV prior to induction to obtund this response [8].

Role of Anesthetic Technique

If the patient is not hypotensive Reverse Trendelenburg position should be considered prior to induction in order to lower ICP. Degree of airway manipulation also affects the hemodynamic response due to prolonged and more forceful laryngoscopy. If duration of laryngoscopy is kept less than 45 s it has a minimum hemodynamic effect [28]. One should also aim for a smooth, gentle and controlled intubation avoiding multiple attempts.

Other non-pharmacological methods are also important. Ensuring adequate muscle relaxation will prevent patient movement on laryngoscopy and intubation. Use of neuromuscular monitoring allows a better judgement of depth of neuromuscular blockade and prevention of bucking or coughing at the time of intubation. Both these raise intrathoracic pressure, decrease venous return from head and neck area and secondarily increase ICP.

While securing the tracheal tube care should be taken to avoid any pressure on the neck veins so that venous return from the head is not obstructed. A tape is therefore preferred to a cloth tie. In a conscious patient with beard, permission should be sought for shaving part of the beard for fixation of tape, as shaving of facial hair may have religious connotations.

Hypotension should be avoided during induction and following intubation in patients with TBI. Aim to keep Mean Arterial Pressure of 80–100 mm of Hg. Also hyperventilation after intubation should be avoided as it worsens brain ischemia [29]. The Brain Trauma Foundation recommends to maintain normocapnia in these patients. Quantitative end tidal carbon dioxide should be monitored during induction, intubation sequence.

Route of Intubation

Oral intubation is the standard specially if rapid control of airway is a requirement. Nasal intubation should be avoided in fractures of the base of skull, severe facial injury or in the presence of bleeding tendency [21].

Extubation of Trachea

Clinical trials on approaches to extubating neurologically impaired patients are lacking. Current evidence supports that early extubation is associated with less complications like Ventilator Associated Pneumonia (VAP), length of hospital stay, and mortality [30, 31].

Routine weaning parameters like tidal volume, respiratory rate etc. cannot reliably predict extubation failure in neurosurgical patients [32]. The general principles of extubation are similar to patients without TBI. Patients with GCS less than 8 should not be extubated and the patients will need tracheostomy. In patients with GCS more than 8 patient's ability to clear secretions and to maintain an unobstructed airway must be evaluated before extubation [10]. A weak cough and copious secretions are associated with an unsatisfactory airway and higher incidence of extubation failure [33]. Any neurological deterioration following extubation is an indication for reintubation. Using neurological status gives predictable results. A GCS score of more than 7 and ability to follow commands correlates with and is associated with successful extubation [34].

Karanjia et al. conducted a retrospective review of 1,265 patients with primary brain injury admitted to the neurocritical care over a 5 year period. This review included patients with TBI, subarachnoid hemorrhage, intracranial hemorrhage and brain tumors. Ten percent patients were re-intubated. The commonest cause was respiratory distress due to altered mental status in 63 % patients. Other causes were pneumonia, herniation, aspiration, stridor, pulmonary edema, seizures etc. The authors were of opinion that this group of patients may benefit from techniques of noninvasive ventilation like BiPAP or CPAP [35].

Tracheostomy in TBI

Urgent tracheostomy may be required as an emergency measure in patients with head injury associated with additional injuries like facial trauma or burns.

The indications of tracheostomy in hospitalised patients with TBI are different from those critically ill patients who do not suffer from head injury. Patients with severe TBI may require a tracheostomy mainly for airway protection and pulmonary toilet rather than prolonged ventilation. There is still no consensus on timing of tracheostomy and both early and late tracheostomy have been recommended. Studies have compared tracheostomy with prolonged tracheal intubation [36] as well as early versus late tracheostomy [37]. The ideal time for performing a tracheostomy is debatable [38]. Early tracheostomy has been shown to decrease the incidence of ventilator associated pneumonia (VAP), length of ICU stay and decrease in mortality.

In a recent systematic review of 3,104 patients over 15 years on prospectively kept data, early tracheostomy group (tracheostomy performed between 1–7 days) was more functionally independent at discharge and had a shorter length of stay [39]. Other studies have shown that early tracheostomy does not improve outcome [40].

Shamim et al. in a retrospective chart review identified predictors of tracheostomy in patients with isolated traumatic brain injury. It is important to study these predictors in order to better utilise resources like operating room time and critical care beds in resource poor countries. They identified age group 31–50 years, pre-existing medical comorbidity, delay in arrival in hospital of more than 1.5 h, abnormal pupillary response, and preoperative neurological worsening during hospital stay, as independent predictors for tracheostomy. They recommended larger prospective studies to validate these results [41].

Use of Alternative Airway Devices

Airway devices other than an ETT may be used as a temporary alternative to tracheal tube or an aid to difficult intubation. Use of LMA which requires a lower level of skill and training has been recommended in emergency airway provider training in pre hospital settings [42].

Use of lighted stylet or fibre-optic laryngoscope still results in a reflex sympathetic response comparable to direct laryngoscopy. Literature on use of video laryngoscopes in TBI is rare. Video laryngoscopy may be theoretically useful in difficult intubations and Glidescope has been used in trauma patients but may intubation may take longer time [43].

Key points

- Prehospital tracheal intubation is recommended in all patients with GCS less than 8
- There is still controversy whether prehospital tracheal intubation improves outcome
- LMA is being increasingly used for prehospital airway management
- Patients with raised ICP should be considered full stomach
- There is no consensus on the choice of anaesthetic agents at the time of induction prior to intubation but their effects on ICP, $CMRO_2$, and CPP should be kept in mind
- Patients with TBI exhibit a clinically significant hemodynamic response to intubation and this response is independent to the severity of injury
- Early extubation of trachea is associated with less complications. Patients with GCS less than 8 will require tracheostomy
- Both early and late tracheostomy has been recommended. Evidence is emerging that early tracheostomy maybe better in terms of complications

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Chapter 10
Airway Management in Cervical Spine Injured Patients

Srikanth Sridhar and Carin A. Hagberg

Abstract Cervical spine injury (CSI) creates a special problem in airway management. The cervical spine is comprised of seven vertebrae that are uniquely configured and house the spinal cord at the center. The configuration of the cervical spine allows specific movements of the head and neck in a limited fashion. Cervical instability is a serious concern and occurs when movement in the spine is greater than normal, possibly placing the spinal cord at risk. Spinal cord injury is the primary concern when considering CSI, and can occur in a number of scenarios and pathologies, the most worrisome of which are direct injury and spinal cord compression. Evaluation and initial management of CSI should include radiographic assessment in patients at particular risk, early cervical immobilization, and potentially elective intubation. Recognition of CSI in association with other traumatic injuries is critical. When approaching the airway of a CSI patient, recognition of injury and timely intubation are critical. Direct laryngoscopy with manual in-line stabilization (MILS) is the most commonly practiced technique and is considered safe; other options for intubation include flexible fiberoptic intubation, video laryngoscopy, laryngeal mask airway (LMA) use, and nasal intubation. Regardless of the modality used, airway management must be conducted with regard for securing the airway as quickly and safely as possible while maintaining cervical immobilization.

Keywords Cervical spine injury · Difficult airway · Spinal cord injury · Trauma

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Introduction

Airway management in patients with cervical spine injury (CSI) and instability presents unique challenges. These patients often require airway intervention and special care must be taken to avoid excessive movement of the spine to prevent secondary injury when securing their airway [1, 2]. Additionally, CSI patients also frequently present with concurrent injuries, further complicating the decision making process. The practitioner is often required to secure the airway as quickly and safely as possible in a patient at risk for neurologic injury. This chapter discusses the anatomy of the cervical spine, elements that contribute to its stability, common cervical spine pathology and injury, evaluation and management of cervical spine injuries, and recommendations for airway management in patients with known cervical instability.

Cervical Spine Anatomy and Stability

The adult cervical spine is comprised of seven vertebrae. The first and second cervical vertebrae (C1 and C2, atlas and axis, respectively) have special configurations. C1 is distinct from other vertebrae and has an anterior and posterior arch, without a significant vertebral body. C2 is also unique; it has a vertebral body called the odontoid process that extends superiorly and rests adjacent and immediately posterior to the anterior arch of C1, within the spinal canal. The atlanto-occipital and atlanto-axial joints play special roles in rotation of the head on the neck and flexion and extension of the head on the neck. Limitation of movement is provided by the transverse, alar, and apical ligaments at this level. The remaining cervical vertebrae, C3 through C7, have a more typical configuration as the remainder of the spine. They are made of a vertebral body, pedicles, transverse processes, laminae, and spinous processes that all encase a central spinal canal where the spinal cord resides. The vertebral bodies are supported and cushioned by intervertebral discs, as well as anterior and posterior longitudinal ligaments. These structures may be referred to as the anterior column of the cervical spine. The spinous processes are supported anteriorly by the ligamentum flavum and posteriorly by the supraspinous ligament. Interspinous ligaments lie between the spinous processes and provide additional support. The vertebrae are joined together by superior and inferior facet joints, which allow for slight flexion and extension with minimal rotation of the vertebrae. These structures together comprise the posterior column of the cervical spine. Unique to the cervical vertebrae are canals within the transverse processes where both vertebral arteries traverse and are protected by the bony transverse processes. The spinal canal lies in the space formed by the vertebrae and encases the spinal cord. In the upper cervical spine, the dens occupies one-third of the space in the spinal canal causing some restriction in the space available for the cord. In the lower cervical spine, at the C6 level, the spinal cord is enlarged to fill approximately 75 % of the spinal canal, leaving little "extra" space in the canal [3]. Throughout its length, the spinal cord is cushioned by the cerebrospinal fluid which provides extra space in the event of cord enlargement or encroachment by injured vertebrae.

Flexion and extension are the most important movement of the cervical spine. The upper cervical spine, namely the atlanto-occipital and atlanto-axial joints provide 24 degrees of flexion and extension. The lower cervical spine, mainly C5-7, similarly provides another 66 degrees of movement [4]. The stability in the upper spine is provided mostly at the atlanto-axial joint and intervening ligaments. The ligaments provide up to 3 mm of displacement between C1 and C2, and disruption of the ligaments can lead to up to 10 mm displacement and significant narrowing of the spinal canal [1]. In the lower cervical spine, the anterior and posterior columns each provide elements of stability. Up to 3 mm of displacement and 10° angular displacement of one vertebra on another is generally considered physiologic [5]. Any greater movement may be classified as instability and result in spinal canal narrowing and neurologic injury.

Cervical Spine Pathology and Injury

The primary concern regarding CSI is the stability of the derangement. Stability indicates a tendency to prevent excessive displacement of vertebrae and related structures by physiologic loads and prevent damage or compromise of the spinal cord and nerve roots [6]. As previously mentioned, there are limitations to spine movement in the noninjured state that are expected with physiologic loads. Instability, therefore, implies that there is enough disruption in the normal spine to allow movement to a degree that places neural structures at risk of damage [7]. Considering the anterior and posterior columns separately related to normal movement and injury uncovers some distinct patterns. The anterior column provides stability during neck extension, and the posterior column provides most of the stability during flexion. Stable rotation of the neck requires both columns to be intact and work as a unit. This knowledge gives a clue as to what areas of the spine may be injured in different scenarios and will be further discussed. The primary concern regarding cervical spine stability is potential narrowing of the spinal canal and/or neural foramina. A far more common scenario for spinal canal narrowing and neural damage involves nontraumatic cervical pathology.

Nontraumatic cervical spine pathology can assume many forms, and all are generally considered "stable" from the standpoint that normal physiologic movement will not result in neurologic injury. All are common, however, in that if untreated, they will potentially result in spinal canal narrowing and manifest symptoms of cord damage. Spondylosis and degenerative disc disease are by far the most common pathological entities and can lead to very limited ability of the patient to perform neck flexion or extension. This can lead to difficult intubation when airway management is encountered [8]. Two relatively common diseases, rheumatoid arthritis and ankylosing spondylitis, can lead to difficulty with intubation [9]. Rheumatoid arthritis, in particular, can cause atlanto-axial joint instability, cricoarytenoid arthritis, and temporomandibular joint arthritis, all of which combine to make airway management potentially very difficult [10]. Additionally, patients with spondylosis and degenerative disease may have severe positional intolerance and if maintained in poor position (usually extension) for long (e.g. under general anesthesia), neurologic injury can occur [11, 12].

On the other hand, nontraumatic disc herniation tends to cause patients pain but does not typically interfere with airway management. When an intervertebral disc herniates into the neural foramina, nerve root impingement can be severe and even small movements can injure the nerves. Posterior herniation into the spinal canal can cause long term cord compression that can also lead to detrimental effects. These patients often have very limited neck mobility, but the limitation is primarily due to the pain associated with nerve root impingement and irritation. Cervical stenosis is another commonly seen cervical spine pathology that involves narrowing of the spinal canal and potential compression of the spinal cord on a long term basis. There is the possibility of neurologic damage; however, symptoms are usually experienced by patients long before the onset of irreversible spinal cord damage [12–14]. There is typically no relation to cervical stenosis with difficult intubation due to the fact that the limitation in movement is mostly functional and related to pain. Positional intolerance often occurs with this pathology, thus poor neck positioning and even minor changes from neutral spine position can result in neurologic symptoms and potentially spinal cord injury [12–14].

Finally, age-related changes frequently occur and can lead to cervical spine pathology. These changes typically involve osteophytes or ossification of supporting ligaments that leads to limitation in vertebral movement, positional intolerance, and cervical stenosis [15]. Difficult intubation is a possibility in this population as the vertebrae are not as likely to align properly with such limited neck mobility. These age-related changes are comparable to spondylitic and degenerative changes in the cervical spine.

Traumatic cervical spine pathology is a far more worrisome phenomenon than the previously discussed nontraumatic pathologies in terms of airway management. Whereas time is usually not of the essence with nontraumatic cervical spine pathology, this is usually not the case in situations involving cervical spine trauma. CSI can be very common in the acute trauma situation, and the patient's airway may be lost or the patient may sustain permanent neurologic injury. Of all trauma patients, approximately 0.9–3 % will sustain CSI [16, 17]. There is a strong association of CSI with head injury as well; 2–10 % of head injured patients also have CSI, and of patients with CSI, 25–50 % also have concomitant head injury [18]. Only 20 % patients with CSI have an isolated injury [18].

Traumatic cervical injuries can manifest in many forms. The most practical classification is categorization into stable and unstable injuries. There is a finite list of cervical injuries that are always considered "stable", including isolated spinous process fractures, compression fractures with <25 % loss of vertebral body height, isolated avulsion fractures, osteophyte fractures, isolated transverse process fractures, type 1 dens fractures (involves only the tip of odontoid process), end-plate fractures, and trabecular fractures [17, 19]. These are almost always not clinically significant or associated with neurologic injury/compromise. All other CSIs must be considered unstable until proven otherwise, and this consideration mandates timely evaluation in an attempt to prevent irreversible spinal cord injury. Unstable injuries can be further classified as to their mechanism of injury. Cervical injury may be caused by excessive motion in any of its axes—hyperflexion, hyperextension, or hyperrotation—or excessive movement of one vertebra on another such as burst fractures or distraction injuries. Each injury has a specific effect on the anterior or posterior column and disrupts one or more of the elements that provide stability. Hyperflexion injuries usually have detrimental effects on the posterior column, hyperextension injuries on the anterior column, and rotational injuries on both columns [3]. Hyperextension injuries can often affect both anterior and posterior columns and, as such, create the most instability and propensity for spinal cord injury.

Alternatively, cervical trauma can be classified according to the location of injury. Fractures and dislocations of bones must be considered unstable until proven otherwise, except for the specific injuries previously outlined. Unstable ligamentous injuries have a high incidence of associated spinal cord injury, often because the injury is unrecognized and progresses to neurologic injury [20, 21]. It is rare, however, to have spinal cord injury in the setting of ligamentous injury without concomitant bony injury (fracture or dislocation of facet joint or subluxation). Nonetheless, there are patients who have a spinal cord injury without radiographic abnormality (SCIWORA). These patients have a ligamentous injury, but no radiographic changes and present a special dilemma, as these patients have a very high incidence of requiring intubation in the early stages after trauma (approximately one-third to half of patients) [22]. Careful evaluation for focal neurologic deficits will be the primary mode of diagnosis of SCIWORA, as well as a high index of suspicion after all appropriate radiographic imaging.

Damage to the cervical spinal cord and subsequent neurologic dysfunction is perhaps the most worrisome aspect of CSI. After all, the construct of bones and ligaments serves its primary function protecting the spinal cord, and loss of function of the cervical spinal cord can have disastrous consequences. Damage to the spinal cord can occur in several ways: (1) direct damage to the spinal cord, (2) cord compression and spinal canal narrowing, (3) hypoperfusion and tissue hypoxia, and, finally (4) secondary neurologic injury.

First, and likely, most destructive, is direct spinal cord injury. There are various mechanisms for direct damage, namely shear injury, avulsive injury, ballistic injury, and distraction injury [23]. All of these will cause tearing or stretching of the neural tissue, cell injury and death. In this manner, the functions of the spinal cord and residing neuronal tissue are disrupted. Typically, direct damage injury will be irreversible and almost instantaneous, thus patients present immediately with neurologic deficits corresponding to the section of spinal cord that was injured.

Second, and possibly most important and most common is compressive injury from spinal canal narrowing. This may include actual spinal canal narrowing from a bone fragment or foreign object or functional canal narrowing due to edema of the cord or surrounding tissues, reducing the space available for the spinal cord in the canal. Cord compression is considered to be the primary mode of spinal cord injury in both the traumatic and nontraumatic setting [24]. Compression must be sustained for at least 1 h and possibly up to 6 h before irreversible injury to the tissues ensues, so there is a time period in which the insult to the spinal cord may be relieved before excessive damage occurs [24, 25]. While common practice dictates that early decompression of the spinal cord will result in better outcomes for patients, there is evidence that patients may have adverse neurologic outcomes, even with decompression [26, 27]. Therefore, although conservative management remains a viable option, surgical decompression may be preferable in settings of incomplete spinal cord injury secondary to compression if the time from injury is not excessive [26, 27].

Third, spinal cord hypoperfusion and tissue hypoxia can cause neurologic injury in the setting of cervical spine trauma. While thought to be a less common cause of spinal cord injury, it is recognized in the setting of vascular trauma/compromise or in the setting of systemic hypotension, severe anemia, or shock, which often occur in severe polytrauma patients [28]. Given that CSI is far more common in patients with other systemic trauma, spinal cord injury must be considered in a patient with severe traumatic injuries and who may not be able to communicate and provide an adequate neurologic exam. Cell damage and death can occur quickly with devitalization (or relative devitalization due to hypoperfusion), thus timely recognition of the injury and its treatment are critical.

Finally, the phenomenon of secondary neurologic injury is a key concept in any discussion on CSI. Secondary neurologic injury refers to spinal cord injury that is not initially evident after injury but manifests at a later time. It can also refer to extension of a spinal cord injury above the initial level at the time of acute injury. The time course may be in the first several days up to 4 weeks after the initial insult and can extend the neurologic injury up to 4 cord levels. There is an association of secondary injury with poor initial management of cervical injury, but there is a 2–10 % incidence even when appropriate immobilization and realignment are utilized [29, 30]. Most often, secondary injury is not precipitated by a second insult to the spinal cord, but as a natural progression of disease resulting from initial traumatic injury. In such cases, spinal cord edema, intrathecal hemorrhage, vascular thrombosis, vascular compromise or damage, or inflammation are thought to have a role in progression of the injury. However, a secondary insult causing a new or extended spinal cord injury may occur in the course of treatment of cervical injury. Immobilization and fracture reduction have been implicated as the cause, as well as surgery, intubation, placement of axial traction on the spine, or sepsis [31, 32]. It is unclear if intubation actually causes neurologic deterioration or if rapid deterioration necessitated airway intervention; the confusion is partly due to the fact that airway management studies have shown almost no incidence of secondary spinal cord injury with intubation. Nonetheless, all of the above maneuvers necessitate some movement of an injured cervical spine, and as such, have the potential of inciting secondary spinal cord injury.

Evaluation and Management of CSI

Clinical management of patients with CSI is fraught with peril. Given that there is such a high correlation with cervical injury and polytrauma (namely head injury) the management of the patient's acute post-traumatic physiology can be very challenging. Moreover, identifying all of a patient's injuries when he is critically ill and often unable to participate in the examination process provides an even loftier challenge. Most disturbing is the fact that, in the case of CSI and other injuries, failure to recognize and treat the CSI in a timely fashion can lead to disastrous consequences [33]. There is a 10–30 % incidence of secondary neurologic injury, meaning that the risk of deterioration with failure to treat is tripled from the population who are managed appropriately [20, 21]. Because the incidence of CSI is so high in trauma patients and the incidence of neurologic injury is so high in undiagnosed CSI patients, evaluation for cervical injury is necessary in all patients sustaining systemic trauma, especially those sustaining head injury. A high index of suspicion should mandate the most thorough evaluation in a risk based fashion; those with highest risk for CSI undergo the most rigorous evaluation, and those unlikely to have sustained CSI may undergo a more basic evaluation.

There are many modalities available for evaluation of CSI. First is physical examination of the patients. In patients who are fully alert and able to participate in their examination, this is a good first step. A thorough neurologic exam will uncover any focal deficits, and the presence of a focal deficit should immediately prompt further radiographic assessment for CSI. Additionally, a patient who meets proper criteria may be clinically evaluated and "cleared" from CSI without any radiographic assessment [34]. In the United States, the National Emergency X-Radiography Utilization Study (NEXUS) has developed criteria that determine a very low likelihood of injury, and these criteria are listed in Table 10.1 [35, 36]. These criteria showed 99 % sensitivity for CSI, and combined with assessment of full range of motion of the neck, will likely exclude any possibility of unstable cervical injury. There is debate, however, on the appropriateness of defining "distracting injury" and "intoxication". NEXUS defined distracting injuries as including long bone fractures, visceral injury, large burns, lacerations, soft tissue damage, or injuries that limit the patient's ability to actively participate in the evaluation process [35]. These encompass a large proportion of associated injuries, but the degree of distraction from neck injury may be debated, as well as the degree of intoxication necessary to prevent adequate evaluation.

Radiographic assessment of the cervical spine is a mainstay in most trauma centers because very few trauma patients at risk for CSI will meet the above criteria for clinical clearance. The most basic form of radiographic assessment is plain film x-ray. The most thorough x-ray evaluation is performed by a three film series—lateral, anteroposterior, and open-mouth odontoid view. Performing only a lateral x-ray allows up to 15 % of significant injuries to be missed. Thus, it is recommended that all three performed. A complete cervical spine series has a

Table 10.1 NEXUS criteria for clearing patients with low-risk for CSI [35]

Patients may be excluded from radiographic imaging of the cervical spine after traumatic injury if they meet all of the following criteria:
1. Normal level of alertness
2. No posterior tenderness over the cervical spine
3. No focal neurologic deficits
4. No evidence of intoxication
5. No other painful distracting injuries

sensitivity of 90 % for all cervical injuries, and will likely only miss 1 % of clinically significant injuries [36–38]. While plain film x-rays are entirely adequate for low risk patients, moderate to high risk patients often need further evaluation. In these cases, computed tomography (CT) scanning is an excellent adjunct to cervical spine assessment. CT provides detailed views in multiple planes of all vertebrae and joints, but has somewhat limited utility in evaluating for ligamentous injury. It has a higher sensitivity and specificity than plain film x-ray, and when used in conjunction with a full cervical plain film series, the sensitivity is >99 % for all bony injuries [36–38]. CT scan is an ideal evaluation modality for patients that arrive in the trauma suite obtunded or otherwise unable to participate in their examination, as it is a rapid and very clinically useful imaging technique. It does cost significantly more to perform than plain film x-rays, so it is impractical for use in every patient.

A final modality for cervical spine imaging is magnetic resonance imaging (MRI). MRI is performed in many centers as an adjunct when a patient has neck pain despite normal plain film x-rays and CT imaging of the neck. The utility of MRI in these patients is questionable, as at least one study has demonstrated that MRI continues to be negative in this population as well [39]. Another study has shown that even if ligament injury is present, it is generally limited to one column and not considered unstable [40]. Moreover, no patients developed neurologic injury. CT is generally considered an adequate modality for assessing unstable ligamentous injury as the incidence of unstable injury despite normal CT scan is extremely low. MRI may have more clinical utility in patients with persistent neurologic symptoms or deficits despite normal plain x-rays or CT imaging; in this situation, additional high resolution imaging may delineate a missed injury.

Clinical management of patients with potential or proven CSI is multifactorial, but the initial and most important maneuver of all is early immobilization of the spine [41]. This is done almost universally in trauma settings as a first step of patient care; it is most often initiated in the prehospital setting by emergency medical personnel acting as first responders. Immobilization is such an early first step because failure to do so at an early stage after injury has been shown to predispose patients to neurologic injury. There have been numerous studies showing poor immobilization or complete lack of it as a cause of adverse neurologic outcome prior to hospital admission in trauma patients [20, 21, 33]. There is some concern, however, that the manipulation required for placing a patient in cervical immobilization may in itself contribute to excessive vertebral motion and spinal cord injury in a patient with a very unstable cervical injury [42]. Despite this concern, early immobilization remains a uniform recommendation among experts with expeditious evaluation to either rule out injury or begin definitive treatment for an existing injury that would prevent further spinal instability. In addition to immobilization, restoration of normal spinal alignment with preservation of spinal cord function and pathways are a primary goal in management of CSI [43, 44]. This action is typically taken by a specialist providing definitive care of the injury after thorough evaluation of the nature of the injury and its neurologic sequelae.

Initial immobilization is accomplished in a number of ways, but the most common are external cervical collars, which come in several varieties. The aim with the use of any device or collar is to maintain neutral position of the neck such that there is optimal placement of the vertebrae with as little narrowing of the spinal canal as possible. In addition to maintaining neutral neck position during immobilization, preventing further vertebral motion is necessary. Most cervical collars are designed such that proper placement with an appropriate size will maintain the neck in a neutral position. Rigid cervical collars are better than soft collars in accomplishing the goal of limitation of movement, although using a method of sandbags taped to either side of the head limits motion more than any other method [45]. The Philadelphia and Miami-J collars also provide adequate protection from spinal motion. The best combination has been shown to be a rigid or semi-rigid collar combined with sandbags and tape around the head in the prehospital setting [45]. Cervical collars have generally demonstrated restriction of spinal movement with gentle patient movement, but are not adequate to prevent excessive vertebral displacement with non-physiologic external forces. Therefore, even when a patient is immobilized in a collar, special care must be taken in any movement of the patient, including transportation. Cervical collars have also resulted in increases in intracranial pressure, undue pressure on the skin with resulting pressure sores (long term use), and limitation of mouth opening with associated difficult intubation [46, 47].

Airway Management in CSI

Airway management in patients with CSI requires special attention for several reasons. First, these patients often require urgent intubation secondary to rapid progression into respiratory distress from both airway swelling and as a result of other injuries. Second, airway management can often be quite difficult in these patients given the potential for airway swelling and facial trauma, the relative urgency of intubation, limited mouth opening from immobilization techniques, and poor neck mobility. Finally, intubation in these patients carries the inherent risk of worsening of the spine injury and potential neurological injury with devastating consequences to the patient. These considerations create a very high risk situation whenever approaching intubation in a patient with CSI. In fact, some literature maintains that any patient with spinal cord injury above C5 should be intubated electively to prevent the need for emergent airway intervention should the need arise in the first 24 h after injury [48].

Airway intervention causes movement of cervical vertebrae even in the non-injured spine. The movement can be enough to create nonphysiological displacement of the vertebrae on one another, but in the normal patient, such movement does not create spinal cord injury. In the patient with CSI, there is little room for movement around the spinal cord without causing compression. Moreover, the ligaments surrounding the vertebra that normally keep them in place allow instability. Thus, there is an increased possibility of fractured vertebrae and fragments moving excessively and causing direct damage to the spinal cord or causing compression that may not be relieved when airway intervention is complete. The following discussion will address various airway interventions that are commonly used and their effects on movement of the cervical spine in injured and noninjured states.

Mask ventilation is one of the most basic airway interventions available; however, it is the airway technique that is associated with the most movement of the cervical spine. In a normal patient model, mask ventilation moves the cervical vertebrae up to 3 mm in a displacing motion, which is the upper limit for physiologic motion [49]. Another analysis found that in a patient with CSI, chin lift itself can distract the disc space up to 5 mm at the injured site [50]. While this is unlikely to cause a clinically significant neurologic injury, it is potentially enough to cause displacement of one vertebra on another and subsequent spinal canal narrowing. The amount of displacement was similar with collar immobilization of the cervical spine, demonstrating that this form of immobilization is far from perfect [50]. Overall, noninvasive airway management (face mask ventilation) causes a greater degree of movement in the cervical spine than more invasive techniques. This raises the potential argument that if any airway intervention is required, immediate and elective definitive airway management may be preferable to noninvasive management. This concept requires further study and analysis. An example of difficult mask ventilation is shown in Fig. 10.1 in a patient stabilized with Halo fixation.

Another form of airway intervention that may be used in these patients is securing the airway with a laryngeal mask airway (LMA) or other supraglottic airway device. The LMA has been the most studied of all these devices and will be discussed here. Initial observations demonstrated that the LMA was useful in the CSI setting because it caused little upper cervical movement, and thus, presented little risk for spinal cord injury [51, 52]. There were no neurologic adverse events or aspiration events in one series using the intubating LMA in spine injured patients and there was also >95 % first attempt success rate, which is a key finding in the acute trauma population [53]. Subsequent studies, however, have shown a much lower first attempt success rate due to difficulty with collar immobilization. Other studies have demonstrated issues with posterior displacement of the mid and lower cervical spine with placement and inflation of the LMA cuff [54, 55]. This causes a relative flexion of the vertebrae and may be relevant in patients with a

Fig. 10.1 Two person mask ventilation in a CSI patient with Halo fixation

hyperflexion injury, as there is increased instability in these segments. The clinical relevance is unclear as no studies to date have demonstrated an adverse neurologic outcome with LMA placement in cervical injury scenarios, but LMA placement may be reserved for situations in which traditional or fiberoptic intubation has failed or is excessively difficult.

The most common airway technique is direct laryngoscopy and orotracheal intubation. This technique has been extensively studied and the cervical movements associated with it are well understood in both cadaver and live models with fluoroscopic view [56, 57]. Typically, laryngoscope insertion causes little cervical spine movement. Elevation of the blade and insertion of the endotracheal tube will cause some superior rotation at the atlanto-occipital joint. Additionally, there is inferior rotation in the C3-5 segments, but the movement is much less than at the atlanto-occipital and atlanto-axial joints. The literature has demonstrated that the type of blade used (MacIntosh, Miller, or McCoy) has no effect on the amount of cervical motion which occurs during direct laryngoscopy [58, 59]. In the normal patient, these movements are physiologic and do not cause neurologic injury. The unstable spine, however, may display excessive rotational movement and hyperextension with direct laryngoscopy; in fact, the spinal canal can be narrowed by 6 mm, which is enough to compress the spinal cord [60]. When laryngoscopy is conducted with the neck in neutral position and immobilized with a collar, sandbags, manual in-line stabilization (MILS), or Gardner-Wells traction, there is acceptable reduction in cervical motion [56, 57, 60]. Therefore, direct laryngoscopy should be undertaken in patients with CSI only after adequate cervical immobilization has been achieved. MILS and Gardner-Wells traction have been proven far superior to collar or sandbag immobilization of intubation. The availability of traction is an issue as it should be applied under radiographic guidance by a specialist as a bridge to definitive therapy. MILS is a commonly used technique in airway intervention and is more relevant to discussion of urgent airway management.

MILS successfully reduces the movement seen in the cervical spine to physiologic levels, but it does not entirely eliminate movement [61, 62]. The key is that MILS must be applied correctly or the benefit is lost. It allows less movement at all levels than cervical collar immobilization. The proper technique requires a second person participating in the intubation to stabilize the patient's head and neck. Hands should be placed on the posterior parietal bones with fingers under the mastoid processes and thumbs on the forehead (Fig. 10.2). Alternatively, it can be performed with the stabilizing person standing next to the patient's body facing the laryngoscopist with forearms on the chest and hands holding the mastoid processes and parietal bones. One important aspect of applying MILS is the avoidance of axial traction [61]. This can cause undue distraction of injured spinal segments and result in subluxation and neurologic injury. The use of MILS can potentially worsen the view obtained by laryngoscopy, and removal of the anterior part of the cervical collar may be necessary to aid in obtaining an adequate view for intubation [63]. With proper use of MILS and direct laryngoscopy, a safe intubation may be performed in a CSI patient. Multiple case series show no correlation of secondary neurologic injury with intubation despite the presence of some movement in the spine [56, 64–66]. Nonetheless, on rare occasion, it may be necessary to avoid the use of MILS, such as unsuccessful direct laryngoscopy during a rapid sequence induction.

New technologies have led to the advent of video laryngoscopy, a technique which is becoming more commonly used in airway management. In fact, it is now included in the recently revised American Society of Anesthesiologists (ASA) Guidelines on Management of the Difficult Airway [67]. This technique involves the use of a laryngoscope that is fitted with a camera on the end, allowing the operator to see airway structures at the end of the blade without direct visualization. This allows intubation to be performed with far less laryngoscopic force and potentially less cervical spine motion. In fact, it is possible for intubation to be carried out with minimal, if any, lifting motion of the blade, which would theoretically allow for almost no atlanto-occipital rotation or mid-cervical motion. In fact, video laryngoscopy has been shown to reduce cervical motion by up to 57 % with an improvement in view of the glottis [68]. There is a slight increase in time to secure the airway in some studies, but the clinical relevance of this is unclear [68, 69]. Additionally, more experienced providers with this technology may not have as substantial an increase in time to intubation as non experienced personnel.

Fig. 10.2 Application of MILS during direct laryngoscopy in a CSI patient. Note that the patient's neck is maintained in neutral position without applying traction on the cervical spine

The literature has been unable to demonstrate the role of video laryngoscopy in the CSI population, and needs further study. As it becomes more common, practitioners will have more experience and the data regarding its use will be further developed and validated.

Another mainstay of airway management in the CSI population is flexible fiberoptic intubation. The benefit of this technique is that it can be performed with little, if any, cervical motion, except for the actual physical passage of the endotracheal tube. An example of flexible fiberoptic intubation is provided in Fig. 10.3. The neck should be kept neutral and even a rigid collar may remain in place for this technique. Anecdotally, most practitioners prefer this technique for intubation of CSI patients, presumably due to comfort that the spine is not being excessively manipulated [70, 71]. Anesthesiologists prefer this modality more than other practitioners. The caveat with flexible fiberoptic technique is that it is very operator skill dependent, and many practitioners feel uncomfortable with its use on a consistent basis. Due to limited skill of practitioners, there is a potential for greatly increased time spent in airway manipulation that may place a patient at risk, especially a patient with associated traumatic injuries and full stomach. Also, even in the best of hands, it is necessary to adequately anesthetize a patient's airway if the procedure is performed awake and not to advance the endotracheal tube past the larynx. In fact, flexible fiberoptic intubation has been shown to allow

Fig. 10.3 Video laryngoscope view of flexible fiberoptic scope entering the glottis during intubation. The endotracheal tube is preloaded on the fiberoptic scope and passed into the trachea over the scope

for up to 12 % of patients to experience decreased oxygen saturations during establishment of the airway, and the overall success rate is only 83 % [72, 73]. Finally, the literature does not demonstrate improved outcomes with flexible fiberoptic intubation as compared to direct laryngoscopy. This would be a very difficult to establish, as the incidence of secondary neurologic injury is exceedingly low and would require a massive number of patients to demonstrate any difference if, in fact, one exists.

Many alternative techniques exist for airway management in CSI patients. Nasal intubation is a modality that is occasionally used, yet it hasn't been shown to reduce posterior displacement of vertebrae any less than direct laryngoscopy, even when used as a blind technique. Nonetheless, the incidence of secondary neurologic injury is extremely rare. Rigid fiberoptic intubation has also been demonstrated to be as safe and effective as other modalities. It is recommended that rigid fiberoptic intubation also be conducted with the use of MILS to prevent excessive extension of the cervical spine. There is a potential benefit of rigid fiberoptic intubation over direct laryngoscopy of slightly less cervical motion; this is likely related to the fact that less manipulation of the airway is required in order to achieve adequate view of the glottis during intubation [74, 75]. Finally, and in any emergency, surgical cricothyrotomy and tracheotomy are options for airway management in CSI patients, and moreover, for trauma patients in general. This technique becomes far more difficult with immobilization techniques, as the collar overlies the surgical field. With cricothyrotomy, there is a posterior displacement of the cervical spine of 1–2 mm, but the clinical significance of this is unclear given the fact that assessment of neurologic function will be almost impossible in a patient requiring this procedure [76]. It continues to be an option for emergency management of a failed airway, but it may be necessary as a technique for securing a patient's airway with CSI.

Most current recommendations for airway intervention in patients with CSI indicate both direct laryngoscopy with immobilization or flexible fiberoptic intubation as mainstays for securing the airway. The literature does not demonstrate a difference in outcome between the two techniques. Both have been extensively studied and shown to be safe with an extremely rare incidence of secondary neurologic injury. Direct laryngoscopy has the advantage of being a customary technique that is almost universally available and can usually be performed rapidly, while flexible bronchoscopy has theoretical advantages of reduced spine movement and superior visibility of the glottis and trachea. One additional consideration is the necessary rapidity required to secure the airway. Especially in trauma patients, rapid deterioration and full stomach with aspiration risk are high considerations. In this light, direct laryngoscopy should be performed in a rapid sequence fashion. In the past, cricoid pressure has been a mainstay of rapid sequence induction in an effort to prevent regurgitation of gastric contents and potential aspiration, but most practice guidelines are now reluctant to require this maneuver as evidence of its effectiveness is scarce. Nonetheless, it is frequently practiced in rapid sequence induction and generally considered safe in patients with CSI. It does not have an effect on the movement at the craniocervical junction, but it can potentially cause displacement of the mid-cervical spine [60]. Its clinical significance is likely to be no more than the movement created by direct laryngoscopy. Rapid sequence induction is not a viable option for flexible fiberoptic intubation in most cases as it can potentially take much longer to secure the airway in this fashion.

A final consideration on the choice of anesthetic technique is choosing an awake intubation technique over an “asleep” technique for intubation. Awake intubation is most commonly performed with a flexible fiberoptic bronchoscope, and it affords many advantages over asleep intubation. It allows the airway to be secured with minimal or no cervical spine movement and for an immediate neurologic assessment afterward to ensure that no injury has occurred. It also solves much of the dilemma of positioning a patient with cervical injury in that the patient is able to communicate if symptoms worsen in one particular position over another. This is potentially a valuable tool in patients with very unstable injuries. Finally, awake intubation allows the patient to maintain protective airway reflexes in an effort to prevent aspiration, and in fact, has been shown not to contribute to an increase in aspiration, even when topical anesthetic and sedation are used [77]. Despite these advantages, there is no evidence to show its superiority in preventing secondary neurologic injury compared to asleep techniques [78]. It also has the disadvantages of patient discomfort, increased time required for airway preparation and intubation, and potential morbidity of hypoxemia and failure to secure the airway. Without a clear superiority in outcome, it is difficult to support this technique as a primary option for intubation of all patients with CSI. Awake intubation may be better reserved for patients in whom neurologic injury is highly suspected and who need monitoring, or in patients where difficult airway is predicted. These will both comprise a higher proportion of the population of patients in the setting of trauma and acute neck injury, thus, awake intubation has a significant role in airway management of CSI patients.

Conclusion

Airway management in the patient with CSI is one of the most perilous situations that a practitioner can face. Failure to secure the airway can have disastrous consequences for a patient, as can the onset of spinal cord injury after a traumatic injury. Practitioners must demonstrate great skill in navigating a very unclear field, but fortunately there are many techniques available to manage the airway of the acutely ill patient with cervical trauma. Given the lack of consensus in the literature, most airway intervention techniques in these patients will be acceptable with low risk of secondary injury, provided the intubation is carried out with special consideration to the patient's injury and to maintaining neck stability to the greatest extent possible throughout the procedure. A proper evaluation and management plan is essential in the care of these patients and will ensure the greatest possibility of rapid and safe conduct of airway management.

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Chapter 11
Indigenous Devices in Difficult Airway Management

Virendra K. Arya

Abstract Management of difficult airway has been always a challenge for the practising anaesthesiologist. Currently many gadgets are available to deal with difficult airway situations. However; these may not be available in remote locations and in all types of hospitals especially in developing nations. This chapter describes some simple valuable modifications of routinely available instruments in medical practice for dealing with difficult airway situations. All these gadgets are reported in the literature and familiarity with these can be helpful in certain difficult airway management situations with limited resources.

Keywords Difficult air-way · Retrograde intubation · Balloon laryngoscope · Indigenous devices

One of the prime considerations when providing anaesthesia at any level is the appreciation and management of the patient's airway. The improvement and development in the difficult airway management skills and instruments have led to a documented decline in the incidence of airway related perioperative morbidity. However, advanced intubation gadgets like fiberscope, intubating LMA, Bullard laryngoscope, Gum-elastic bougies etc. may not be available at all the places or these may not work in all the situations of difficult airway management [1]. There are many anecdotal reports of intubating 'tricks' and 'alternative indigenous devices' in the literature. These observations can be assembled to form a comprehensive plan for difficult airway situations with general type of equipment available in most of situations [2]. Moreover, these 'tricks' and 'indigenous devices' can also be applied in combination with special difficult airway management equipment, if available, to make procedure simpler or when the later fail alone. In certain situations these 'indigenous devices' have led to the development of standard advanced intubation

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gadgets. This chapter reviews clinical and practical utility of such devices and tricks in difficult airway management.

Finger Intubation: An Alternate to Laryngoscopy

This is one of the methods described in paediatric patients for resuscitation [3, 4]. However, it has been used with success in adults also. Essential prerequisites are adequate mouth opening allowing insertion of finger along with endotracheal tube (ETT), relaxed patient and ability of finger to reach up to laryngeal opening to feel for it and guide the ETT through it into the trachea. In old edentulous patients index and middle finger can be inserted along with ETT for intubation. The anaesthesiologist has to get experience in the feel of larynx before using this technique. Whenever conventional laryngoscopy fails and no other intubation gadget is immediately available, this technique should be kept in mind and can be helpful in urgent situations at remote places.

Balloon Laryngoscope: An Alternate and Aid to McCoy Laryngoscope

The laryngoscopic view grade is a component of the endotracheal intubation difficulty scale [5–7]. The visualisation of only the posterior glottis or less is associated with intubation procedure prolongation, need for external laryngeal manipulation and the potential use of additional or alternative airway management equipment or techniques. McCoy laryngoscope where tip of the blade can be manipulated upwards is designed to improve laryngoscopic view. The same benefit can be achieved by a modified Macintosh curved blade 4 carrying either two no. 10 Foley catheters or a 6 F Fogarty catheter (Fig. 11.1). This modification can be applied to McCoy laryngoscope blade 4 also to further enhance the laryngoscopic

Fig. 11.1 Making of balloon laryngoscope blade and its use in patient

view [8]. The two no. 10 Foley catheters or a 6 F Fogarty catheter should be firmly attached on the concave surface of the blade with transparent adhesive tape. This modification facilitates both the blade insertion into the vallecula by displacing the tongue-base upwardly and the epiglottis lifting as a result of adequate contact between the balloon's upper surface and the structures connected to the epiglottis (tongue-base and hyoid). This modification combined with external laryngeal manipulation gives additional benefit in improving laryngoscopic view.

Giving Hockey Stick Shape to ETT with Stylet

The curvature of the ETT can be modified by inserting ETT stylet. Using ETT stylet for giving "J" shape or "hockey stick" shape to ETT has special advantage than increasing the curvature of ETT. In difficult laryngoscopy, if posterior half of epiglottis is visualised, "J" shaped ETT can be placed behind the epiglottis in mid line and stylet gently removed while holding the ETT at dental level firmly. Withdrawing the "J" shaped stylet pushes the ETT tip forward towards the larynx.

Metal Stylet for Railroading ETT

A blunt soft, malleable, metallic stylet from a double lumen tube was given 'C' shape and used to lift the epiglottis from the posterior pharyngeal wall after laryngoscopy and was passed into the trachea [9]. While an assistant stabilized the laryngoscope in place, a 9 mm cuffed endotracheal tube (ETT) was passed over the metallic stylet and rail roaded into the trachea.

In case the metal stylet of a double lumen tube is not available, a substitute can be locally procured using soft aluminium wire, of sufficient length (approximately 33–35 cm), the two ends of which have been rounded off to prevent trauma from the rough tips. This is made more atraumatic by passing 2 red rubber catheters over the two ends of the stylet and stitched together in the centre after cutting off excessive length of rubber catheter. Stitching of rubber catheter ends together will prevent dislodgement of the rubber catheter during rail roading of the endotracheal tube. Although this appears similar to a gum elastic bougie, the cost of this metal stylet is negligible in comparison.

Rigid Bronchoscope Assisted Intubation in Upper Airway Oedema

In some circumstances rigid bronchoscopy may take long time and may be associated with upper airway oedema making subsequent endotracheal intubation difficult using conventional laryngoscope [10]. In such situation rigid bronchoscope

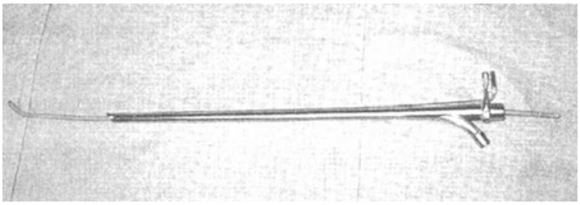

Fig. 11.2 Bougie passed through rigid bronchoscope

assisted intubation can be done by introducing gum elastic bougie or Forfes neoplex no. 4001(Rouch Bougie) dilator size 18 (Tracheal dilator) through rigid bronchoscope (Fig. 11.2). Since this bougie is almost completely embedded inside a 40 cm long 9 F rigid bronchoscope, a 40 cm long 16 F suction catheter is used to stabilize the bougie while removing the rigid bronchoscope. The bougie can be tightly fitted inside the funnel end of suction catheter and catheter can be made stiff to hold bougie in place by inserting ETT stylet inside it. The funnel end of suction catheter needs to be cut 2 cm at end to fit inside the bronchoscope. When uncut, its outside diameter (12 mm) exceeds the narrowest diameter of bronchoscope (7.8 mm). Subsequently ETT can be railroaded over the bougie into the trachea.

Reinforcement of LMA Cuff Position with ETT Cuff: An Alternate to LMA ProSeal

LMA design is based on the studies of normally positioned larynx in cadavers [11]. Experience with its use in difficult airway situations associated with anteriorly and superiorly placed larynx such as in contractures following anterior burns of neck, is limited. In such situations difficulty in maintaining patent airway by LMA classic, despite proper positioning, has been reported due to an inefficient seal, possibly in the area of the hypopharynx where the tip of LMA lies. This problem can be overcome by inserting a PVC endotracheal tube having high volume low pressure cuff by nasal route and positioning its cuff in the pharynx before inserting the LMA. LMA is inserted and cuff inflated. Subsequently ETT cuff is gradually inflated behind LMA cuff till there is no leak on gentle ventilation. A nasogastric tube can be passed through ETT into the stomach to remove air in stomach or other gastric contents. This arrangement is similar to LMA ProSeal with added advantage of using nasal ETT as nasal airway to assist in ventilation before LMA insertion.

The Upside-Down ILMA: A Technique for Cases of Fixed Flexed Neck Deformity

The intubating laryngeal mask airway (ILMA) has a rigid, preformed shape, a fixed height, and a long handle, which seem to make it unsuitable for use in cases of fixed flexed neck deformity such as post burn contractures of neck [12]. In such a situation, ILMA insertion with 180° rotation technique has been suggested. The ILMA is held such that the machine end and superior surface of the handle faces cephalad as the mask portion is slipped between the upper and lower incisors. Once the mask portion is inside the mouth up to its angulation, ILMA is rotated through 180°. Subsequently trachea can be intubated blindly by endotracheal tube that comes along with ILMA. It is better to leave ILMA in situ after intubation as removal of ILMA in such situation involves a 180° rotation again and the stabilizing rod holding the ETT can almost impinge on the chest. Moreover, such rotation can accidentally pull out the ETT.

Use of ENT Dilators as Bougies

The oesophageal and tracheal dilator used in ENT are good substitute for gum elastic bougies. Forfes neoplex no. 4001(Rouch Bougie) Dilator size 18 is most suitable for this purpose.

Alternatives to ETT Exchanger

Teflon sheath ureteral dilator 16 FG 62 cm long (used in urology) is an alternate to ETT exchanger. It has lumen through which ureteric guide wire can be passed during retrograde intubation or $EtCO_2$ monitoring can be done to confirm its position inside trachea. However, it tip is pointed and should not be threaded without the support of guide wire.

Ryle's nasogastric tube size 16–18 is another substitute for tube exchanger. However, it loses its rigidity at body temperature with passage of time and does not have hole on the tip for passing guide wire.

In paediatric patients the sheath covering of "J" guide wire of central venous line cannulation is good substitute for ETT exchanger. Smallest ETT that can be passed over it easily is 4 mm.

Use of Urological PCNL Instruments in Difficult Airway Management

Teflon sheath ureteral dilator (16 FG 62 cm long) passed over guide wire during retrograde intubation allows smooth insertion of ETT as compared to ETT passed directly over the retrograde guide wire (Fig. 11.3).

Ureteral guide wire (0.89 mm 150 cm, Terumo Europe NV, 3001 Leuven, Belgium) is very good for retrograde intubation (Fig. 11.3). This long wire can be used for assisting fibreoptic intubation also in certain situations when optic view is

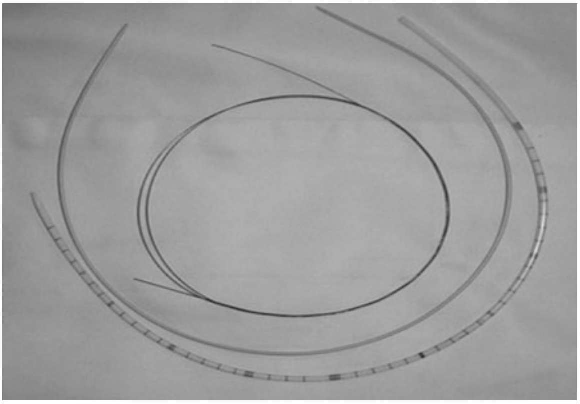

Fig. 11.3 Ureteric guide wire, ureteric guide wire sheath and Teflon ureteric dilator

poor due to blood in airway. Its "J" tip flexible end is non traumatic and its rest of length is strengthened by central wire. During retrograde insertion through cricothyrotomy puncture, if neck is kept flexed, this guide wire comes out through nose and if neck is kept in full extension, it comes out through mouth.

Ureteral guide wire sheath which is 150 cm long can be used for reinforcing nasogastric tube before insertion to prevent coiling in pharynx.

Aid to Blind Nasal Intubation: Nasogastric Tube

The open end of a stiff, wide bore nasogastric tube 16 G can be connected to an end-tidal CO_2 monitor and a Jackson Rees breathing system via a 4 mm ETT connector [13]. A size 7.5 Portex ETT can be passed into nasopharynx until breath sounds are maximally heard at its proximal end. The nasogastric tube with above described assembly can be then negotiated via the tracheal tube into the trachea using end-tidal CO_2 as a guide. The ETT cuff can be inflated to direct the nasogastric tube towards larynx [14]. Oxygen can be continuously supplemented via an Ayre's T-piece system. The ETT is then threaded over the nasogastric tube into the trachea after deflating its cuff. The advantages of using a nasogastric tube in this way include ready availability, a smooth tip, small calibre that is easy to negotiate the larynx of spontaneously breathing patient and stiffness. Soft tip suction catheter 14–18 FG can also be utilised for same purpose.

Pharyngeal Loop: An Aid to Difficult Retrograde Intubation

Pharyngeal loop is made by threading the ureteral guide wire (0.89 mm 150 cm, Terumo Europe NV, 3001 Leuven, Belgium) or any other guide wire that has good elasticity, through a 3 mm uncuffed PVC endotracheal tube in a doubled up fashion to form a loop (Fig. 11.4) [15]. By pushing or pulling the free ends of the guide wire, the loop diameter can be altered. This assembly can be passed into the oral cavity through minimum inter-incisor gap in cases of locked jaw such as TMJ ankylosis. Once inside, the loop is expanded to maximum to touch the pharyngeal wall circumferentially. Afterwards, the nasogastric tube by nasal route or retrograde guide wire through cricothyrotomy puncture is advanced to sufficient length. The pharyngeal loop is now tightened gently and withdrawn slowly, bringing out orally the nasogastric tube or retrograde guide wire caught inside the loop. This is a useful tool in difficult retrograde intubations where difficulty is encountered to bring out the retrograde guide wire or nasogastric tube orally.

Suction Technique to Retrieve Guide Wire in Retrograde Intubation

When retrograde guide wire is not getting retrieved through mouth or nose during retrograde intubation, use of a strong suction is described to retrieve it [16]. However, success rate is low and chances of hypoxemia are there by this method.

Lightwand/Flexible Fiberscope Guided Retrograde Intubation

In this technique, while pulling the retrograde catheter taut, the ETT with the lightwand in place [without the rigid stylet], is advanced into the glottis [17, 18]. A bright glow is seen in front of the neck as the ETT-lightwand assembly enters the glottis. This is specially suited in patients with cervical spine instability. Others have suggested that the retrograde catheter or the wire should be inserted through the “Murphy’s” eye of the ETT. Retrograde intubation using a guide wire together with a flexible fiberscope has also been shown to be very effective as the tip of the ETT can be guided into the glottis under direct vision.

Double Guidewire Aided Retrograde Intubation

One of the common difficulty encountered during retrograde intubation is that the distance between the puncture site on cricothyroid membrane and the glottic opening is small and more over the ETT does not pass glottic opening easily over the retrograde guidewire easily [19]. Many times it slips into the oesophagus at this final crucial step messing up whole the procedure. One way to over come this problem is to pass another semi-rigid guide wire or small sized ETT suction catheter through the ETT while holding the retrograde guide wire taught and keeping the ETT pressed against glottis. The second guide wire or small sized ETT suction catheter will pass into the trachea that can be confirmed by $EtCO_2$ waveform in case of ETT suction catheter. The retrograde guide wire is completely retrieved from the ETT end and ETT is subsequently pushed into the trachea over the second guide wire or small sized ETT suction catheter.

Pharyngeal Loop: A Device for Retrograde Submental Intubation

Submental intubation is useful for airway management during maxillofacial surgery when both nasal as well as orotracheal intubation are deemed unsuitable, and to avoid a tracheostomy, especially when long-term ventilatory support is not required in the postoperative period [20]. Adequate mouth opening is a prerequisite for all the techniques described for submental intubation, as the initial step is orotracheal intubation.

With the help of pharyngeal loop assembly (Fig. 11.4), an awake retrograde submental intubation can be done in a patient with maxillofacial trauma and restricted mouth opening, in whom oral and nasal intubations are not possible and tracheostomy will be the only alternative. In this technique a pharyngeal loop is introduced through the minimal inter-incisor gap orally at the point of maximal width. Once inside, the loop is expanded to the maximum to touch the posterior pharyngeal wall. Afterwards, the cricothyroid membrane is punctured and a guide wire with soft J-tip is advanced retrograde through it until some resistance is felt. The pharyngeal loop is then gently tightened and slowly withdrawn, retrieving the guide wire orally.

After local anaesthetic infiltration, a 1.5 cm skin crease incision is subsequently made in the left submental region, just medial to the lower border of the mandible approximately one third of the way from the symphysis to the angle of mandible. Blunt dissection with a curved artery forceps is carefully performed to enter the oral cavity, and proper haemostasis is achieved. The same pharyngeal loop is now introduced through this incision and directed towards the incisors and taken out through the mouth. Using this loop the retrograde guide wire is brought out of the submental incision. Afterwards, keeping the head and neck in full extension, a tube exchanger is threaded and advanced over the guide wire through the submental incision into the trachea. The guide wire is removed and the intratracheal position of the tube exchanger can be confirmed using end-tidal CO_2 waveform. Subsequently, a 32F flexometallic ETT with its connector can be threaded over the well-lubricated tube exchanger using gentle rotational movement. This procedure is well suited in adult cooperative patients suffering from maxillofacial injuries or deformities where oral and nasal intubation are not possible, restricted mouth opening expected to become normal after surgery and there is no indication for prolonged postoperative airway control.

This procedure is contraindicated in (1) uncooperative patient, (2) bleeding diathesis (3) disrupted laryngo-tracheal anatomy (4) restricted retro-molar space to allow suctioning during procedure (5) inability to pass pharyngeal loop assembly (7) gun-shot injuries of face (8) fresh maxillofacial trauma with soft tissue oedema and (8) need for prolonged postoperative airway control.

Retro-Molar Intubation: An Alternate to Submental Intubation

Submental intubation is described to prevent short term tracheostomy in maxillofacial surgical procedures where restoration of dental occlusion by means of intraoperative maxillomandibular fixation precludes conventional oro-tracheal intubation and nasal intubation is also not possible as surgeon work in maxillary area [21]. Retro-molar intubation has been described as an alternative to submental intubation. This technique is less invasive as compared to submental intubation. However, essential pre-requisite for this is that patient should have enough retro-molar space for ETT to be brought out through this into the space between alveolar margin and cheek.

Fibroscopic Aided Intubation Through LMA

The LMA has been recommended for use in maintaining airway patency following failed tracheal intubation. While it may be possible, at least temporarily, to maintain an airway by this means, the nature of conditions likely to precipitate such difficulty may also necessitate a secure airway with tracheal intubation for either surgical or anaesthetic reasons [22]. Use of the LMA to effect tracheal intubation using an intermediate device can be done by following methods:

(a) A wide bore jejunostomy tube can be loaded onto the fibreoptic laryngoscope prior to its insertion through LMA, and then placed in trachea for subsequent railroading of the ETT.
(b) Ureteric guide wire 150 cm long can be passed through working channel (suction port) of the fibreoptic into the trachea, subsequently Teflon ureteric dilator 16 FG is passed over it into the trachea and the ETT can be railroaded over it subsequently (Fig. 11.5).

In each of these solutions, the fibreoptic laryngoscope and LMA are withdrawn to leave the device in the trachea to permit a tracheal tube to be railroaded over it

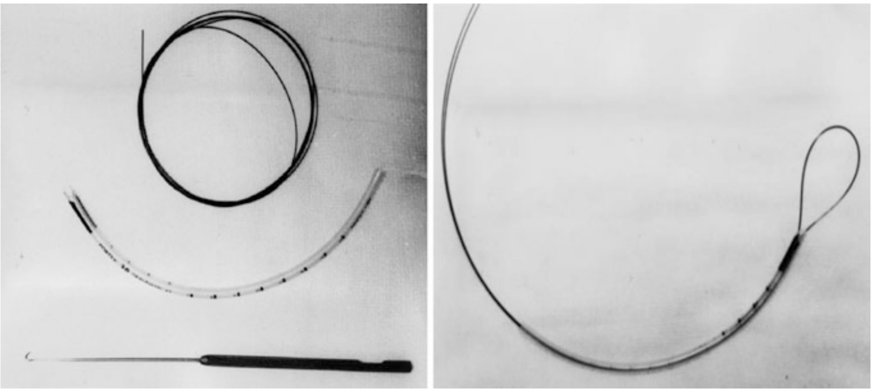

Fig. 11.4 Gadgets for making pharyngeal loop and pharyngeal loop shape

and effect tracheal intubation. These are alternative to ventilation exchange bougie 57 cm long with external and internal diameters of 6.5 and 4.5 mm respectively, recommended for this purpose.

Indigenous Needle Cricothyrotomy Set

Cricothyrotomy is an excellent life saving procedure for airway obstruction above the level of the cricoid cartilage in emergency situations or in "cannot intubate, cannot ventilate" situation following failed intubation [23]. Figure 11.6 shows the components of a kit that can be assembled indigenously. It contains a wire (flexible, straight tip), a 5-ml syringe with tapered end, no. 14 needle, no. 10 scalpel, dilator from an internal jugular kit, a 3-mm ETT (in case of Portex use 3.5 mm ETT) for paediatrics with a 3.5-mm adapter, and finally a 4.5-mm cuffed ETT (in case of Portex use 5 mm ETT) with a 5.0-mm adapter. Adapters are one size larger than the ETT, such that the internal lumen is not reduced. The dilator, 3-mm, and 4.5-mm ETT are all nested together (Fig. 11.5) and then inserted as a unit over the wire utilizing the Seldinger technique. If the patient is a child, the 3.0-mm ETT is used alone. The 3.0-mm ETT is also covered by a thin tube of Teflon tubing or some jelly like K-Y jelly may be used so that it slips easily within the 4.5-mm ETT when they are nested. These items can be assembled into a small kit. This kit meets all the desirable properties of a satisfactory cricothyrotomy device and these components are, however, common to any anaesthesia work room.

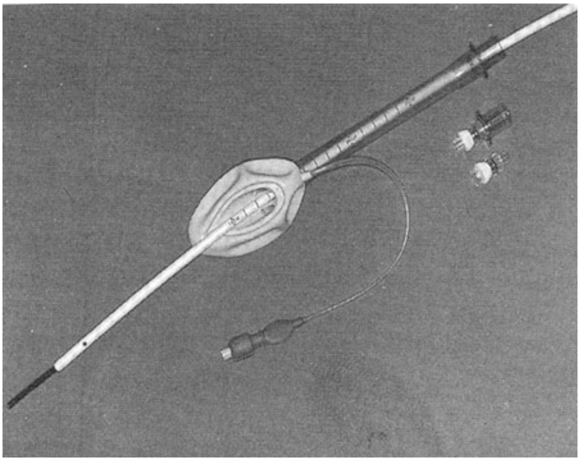

Fig. 11.5 Instruments for fibreoptic aided intubation through LMA

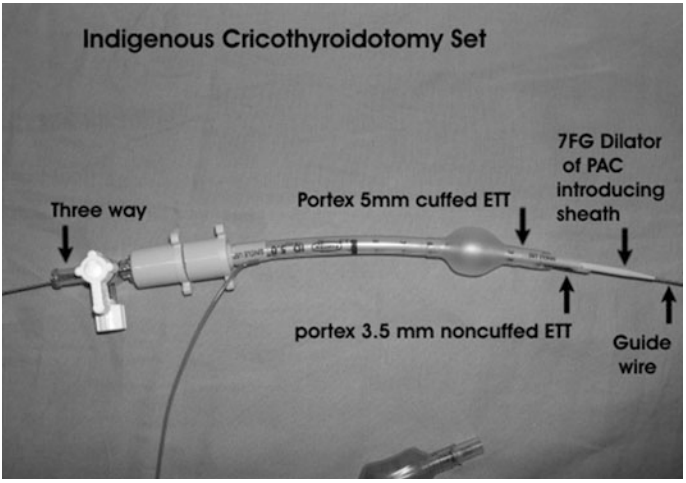

Fig. 11.6 Indigenous cricothyrotomy set

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Chapter 12
Cricothyrotomy

Virendra K. Arya

Abstract During management of difficult airway "Can not ventilate, can not intubate" is life threatening situation for the patients. This situation demand urgent need for creation of surgical airway if supra-glottic emergency air-way devices are not available or their use is not able to establish patent airway. Cricothyrotomy is a procedure that is life saving in such situations. All the physicians involved with resuscitation, initial trauma care and air-way management should be able to perform this emergency air-way rescue procedure safely in urgent situations of "Can not ventilate, can not intubate". This chapter describes step wise approach for cricothyrotomy procedure.

Keywords Cricothyrotomy · Needle cricothyrotomy · Seldinger technique · Cricothyroid membrane

Cricothyrotomy, also referred to as a laryngostomy, laryngotomy, cricothyroidotomy, or coniotomy [1, 2] is the procedure in which an opening is made in the cricothyroid membrane in order to establish an airway. Chevalier Jackson [3], in 1909, described the technique of tracheostomy, which is used today by ENT surgeons. He condemned surgical cricothyroidotomy and high tracheostomy, as it was associated with increased incidence of subglottic stenosis. Toye and Weinstein [4] were first to describe wire-guided cricothyroidotomy in 1969. This technique evolved from the premise that it was possible to achieve a functional airway in the trachea or cricothyroid membrane in a more expedient manner than with Jackson's standard surgical dissection method. However, it was still unpopular as prolonged use was associated with significant problems of voice changes and subglottic stenosis. Brantigan and Grow [5] in 1976, with a series of 655, disputed this outright condemnation of cricothyroidotomy and, as thoracic surgeons, they advocated its use in patients who had undergone median sternotomies. At present,

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cricothyroidotomy is advocated by the American College of Surgeons (ACS) Committee on trauma, in the Advanced Trauma Life Support course, as an appropriate alternative for emergency airway control if endotracheal intubation is not possible [6]. ASA algorithm for "cannot intubate, cannot ventilate" situation advocates use of LMA /ILMA and Combitube as supra laryngeal and transtracheal jet ventilation (TTJV) and cricothyrotomy as trans laryngeal alternatives.

Cricothyroidotomy is indicated in any situation where standard oral or nasotracheal intubation cannot be performed or is contraindicated. For anaesthesiologists this is a procedure of "failure" rather than a procedure of "choice". Cricothyrotomy is an excellent life saving procedure for airway obstruction above the level of the cricoid cartilage in emergency situations or in "cannot intubate, cannot ventilate" situation following failed intubation. For airway obstruction at the level of cricoid cartilage or below, a tracheotomy will be necessary. Cricothyrotomy is relatively contraindicated in patients with laryngeal fracture where this procedure may be difficult. In infants it is difficult to palpate and identify the landmarks of the neck, especially the cricothyroid membrane because of the small size. Some recommend tracheotomy rather than cricothyrotomy in these situations when endotracheal intubation is not possible [7]. However, needle cricothyrotomy may be better choice in infants and small children to avoid complications of tracheotomy and standard surgical cricothyrotomy [8].

The advantages of cricothyrotomy as an emergency airway management procedure include the following: Cricothyrotomy is faster (airway must be secured within 3 min of total airway obstruction), easier to perform, less invasive and less likely to cause haemorrhage than tracheostomy, require a minimum of instruments, does not require an operating suite, can be performed safely and quickly by non-surgeons, produces less encroachment on the mediastinum and is therefore preferred in patients with a midline sternotomy, has less need for hyperextension of the neck than does tracheostomy requires, results in a smaller scar and better cosmetic appearance, and has fewer long term complications [9, 10].

Cricothyrotomy can be performed either as surgical cricothyrotomy or as needle cricothyrotomy utilizing the Seldinger technique.

Surgical Cricothyrotomy

The technique consists of identifying the cricothyroid membrane and incising it, enlarging the incision and placing a tube in the trachea (see Fig. 12.1a, b and c for steps). The cricothyroid membrane lying in the space between the thyroid and cricoid cartilages can be identified by palpating a notch, slight indentation or 'dip' in the skin inferior to the laryngeal prominence [11]. It does not calcify with age and is immediately subcutaneous in location with no overlying large veins, muscles or fascial layers, allowing easy access. However, the right and the left cricothyroid arteries traverse the superior part and anastomose near the mid-line. A horizontal incision through the skin and the cricothyroid membrane is often

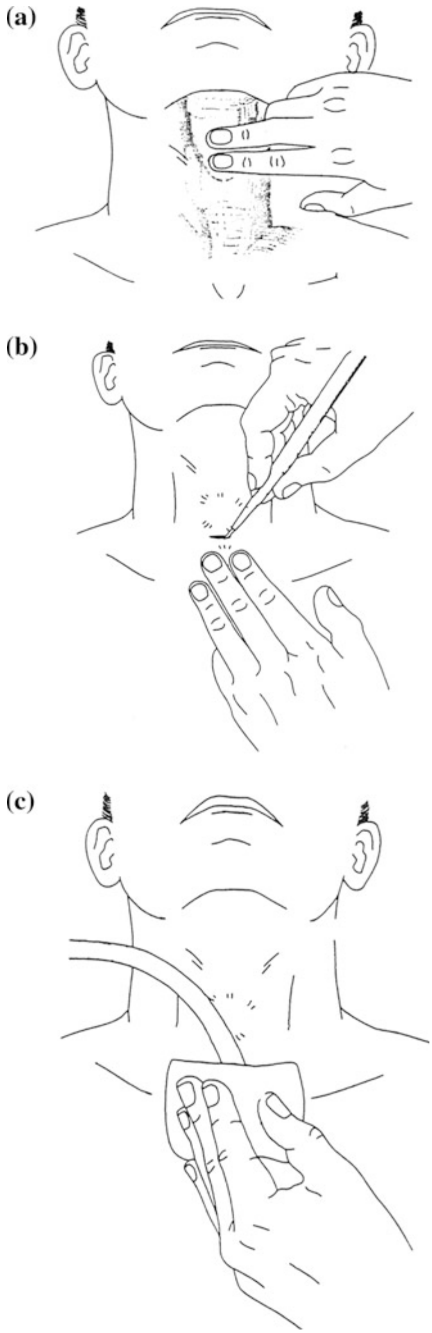


Fig. 12.1 Steps for surgical cricothyrotomy. **a** step 1: palpation of cricothyroid membrane **b** step 2: horizontal incision with No. 11/15 surgical blade **c** step 3: insertion of 6 mm endotracheal tube

advised [12]. Some advocate vertical incision presumably to avoid laterally placed vessels, however, this not only jeopardises the cricoid cartilage but also the cricothyroid arteries previously mentioned, with a potential for serious haemorrhage [13].

A low horizontal stab of the membrane would avoid this risk. Either a tracheostomy tube or a standard endotracheal tracheal tube can he used in cricothyrotomy. Proper tube size is important in assuring successful cannulation without excessive trauma. Since the average size of the cricothyroid membrane in the adult is about 22–30 mm wide and 9–10 mm high, the tube ideally should have an outer diameter no greater than 8.5 mm. In general the tube is 1 mm smaller than that which would be used for orotracheal intubation [12]. The technique recommended is blunt and requires some guess-work to insert the endotracheal tube or cannula, leading some authorities to suggest that the tissues should be dissected onto the cricothyroid membrane and the cannula inserted under direct vision. However, this is not appropriate for the emergency cricothyrotomy. Safety of this procedure is enhanced if a Seldinger technique [14] is used for insertion. Use of a guarded needle to puncture the cricothyroid membrane and dilators passed over a guide wire to make a channel would reduce the chance of damage to blood vessels and incorrect placement.

Needle Cricothyrotomy Utilizing the Seldinger Technique

Anaesthesiologists use the Seldinger technique for vascular access. They use it daily with great skill and confidence despite the fact that a small surgical stab wound may be necessary sometimes for the insertion of cannula. This technique, applied to the airway access can carry with it the knowledge, the skill (constantly refreshed), and most important, the confidence non-surgeons feel they lack for cricothyrotomy.

Modifications of needle cricothyrotomy utilizing Seldinger technique will need to be explored but the cornerstone of this technique will be the accurate placement of an intra tracheal needle, anatomically in the midline of cricothyroid membrane that can be subsequently used to stabilize a scalpel to make an incision into the trachea in the same needle track. Accurate placement of the needle will be judged on the free flow of aspirated air and a wire inserted into the needle that “falls” into the tracheal lumen without resistance. These are the same criteria that affirm proper intravascular placement, i.e., free flow of aspirated blood and a guide wire that “falls” freely through the puncture needle into the vein without resistance. Following are the steps of needle cricothyrotomy utilizing the Seldinger technique:

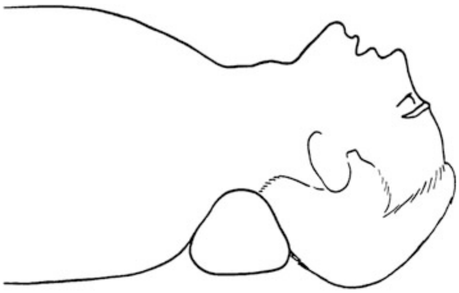


Fig. 12.2 Positioning head for cricothyrotomy

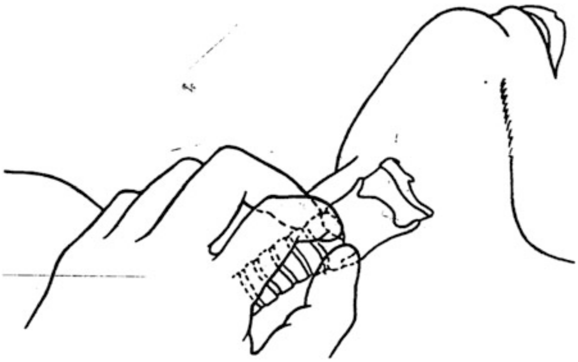


Fig. 12.3 Palpation of cricothyroid membrane

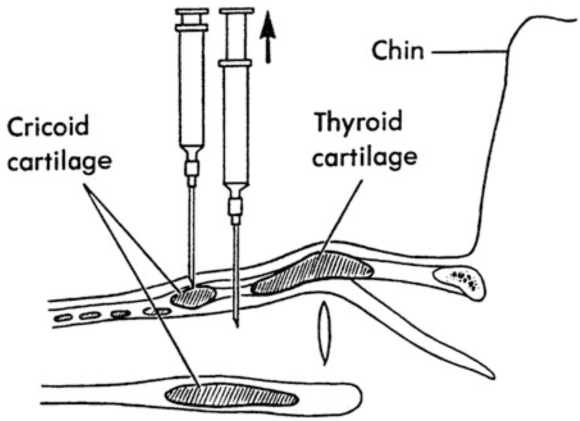
Locating the Cricothyroid Membrane

Access to the cricothyroid membrane will be facilitated by placing a towel under the neck to extend the head (Fig. 12.2). This should only be done if the cervical spine is stable. It is essential to identify the cricothyroid membrane in seconds. In men with a prominent thyroid cartilage it is easy to palpate caudal from the cartilage and have the fingers fall into the cricothyroid groove. Palpation is more difficult in women who do not have a prominent thyroid cartilage. A more reliable method is to palpate the trachea starting at the clavicular notch. Grasp the trachea with thumb and middle finger and quickly move the fingers cephaloid. Tracheal rings are quite uniform until the cricoid cartilage is reached, at which time the fingers will "splay out". Grasping the cricoid cartilage firmly with the thumb and middle finger (Fig. 12.3) will define the lateral borders of the trachea. This important maneuver will quickly identify the midline of trachea. The index finger can then be used to palpate the midline of the cricothyroid groove.

Needle Penetration

Moving the index finger to the side and still grasping the cricoid cartilage with the thumb and middle finger, use a needle mounted on a syringe to pierce the midpoint

Fig. 12.4 Piercing the cricothyroid membrane with needle



of the cricothyroid membrane (Fig. 12.4). It is important that the needle be firmly attached to the syringe and tested for air tightness by withdrawing the syringe plunger while the needle tip is obstructed, because an air leak at the needle hub connection that appears during syringe aspiration can be misinterpreted as tracheal air. This test should be done during setting up the equipment. During penetration, the needle should be positioned perpendicular to the skin in all planes. This is important because if the needle penetrates further than planned, it will first hit the posterior aspect of the cricoid cartilage, which lies directly under the cricothyroid membrane and thus reduce the chance to penetrate the esophagus. It is also important to use a large needle (No. 12–14) that is not as sharp as No. 16 and smaller. It is easy to inadvertently pierce the cricoid cartilage with the No. 16 needle. This can be disastrous because, as will be seen later, needle placement is used to stabilize the scalpel incision. In this case, the cricoid cartilage will be cut. As seen in Fig. 12.4, the blunt needle tip can be used to probe the firm cartilage and then moving cephaloid, differentiate cartilage from the softer cricothyroid membrane.

The needle is advanced into the trachea and negative pressure on the plunger should result in free aspiration of air if the needle is intratracheal (see Fig. 12.4). If air cannot be aspirated, the needle should be adjusted (in, out, rotated, or reinserted) until a free flow of air is obtained. This step is absolutely essential. Alternatively, a three way can be placed between needle and the syringe, side port of which can be connected to a capnometer. No aspiration of air is attempted and needle is advanced gently through cricothyroid membrane. Rise in $EtCO_2$ is detected with in 3 s after entry into the trachea of both breathing as well as apnoeic patients [15]. Once rise in $EtCO_2$ is detected on capnometery, air aspiration is done to confirm the placement. This avoids the chances of needle blockade by tissue plug, especially in thick neck, when needle is advanced with applying continuous negative pressure and landing in false negative aspiration test despite the needle being inside tracheal lumen.

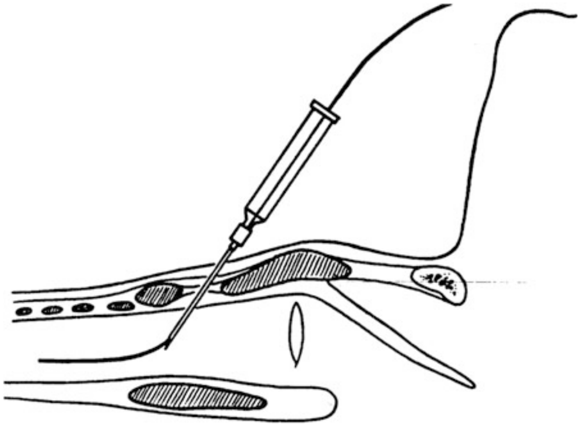


Fig. 12.5 Slanting the needle and inserting wire through syringe and needle

Inserting the Wire

The syringe plunger is now removed and a wire inserted through the syringe barrel and needle into the trachea (Fig. 12.5). It is essential to use a wire that is soft tipped but straight on both ends. A "J" wire with plastic straightener may waste time when moving quickly, unless modifications are made for its quick insertion. Leaving the barrel of the syringe attached to the needle provides two functions: (1) The syringe barrel acts as a broad funnel to direct the wire into the needle hub. For this a syringe with tapered end is preferred; and (2) Later, when the scalpel incision is made on the needle, it permits the operator to support the needle and syringe barrel as a unit with supporting fingers well up the syringe barrel and well above from the scalpel to minimize the chance for self-inflicted finger cuts.

As the wire is advanced, the syringe barrel and needle should be depressed and angled caudad. This will ensure that the wire does not pass cephaloid and will minimize the chance for the advancing wire tip to get caught on protruding tracheal rings. If the wire does not advance easily, the needle tip may be too close to the posterior tracheal wall. Repositioning the needle, angling more caudad, rotating 90°, or pulling the needle back slightly will usually resolve the problem. If these measures do not work, it may be necessary to remove the needle and start again.

Scalpel Incision

The next step is to make the scalpel incision. One will find it advantageous to move to the side of the patient such that the non-dominant hand supports the syringe barrel and needle and the dominant hand holds the scalpel resting on the caudal side of the slanting needle. It is both quicker and safer to do this because

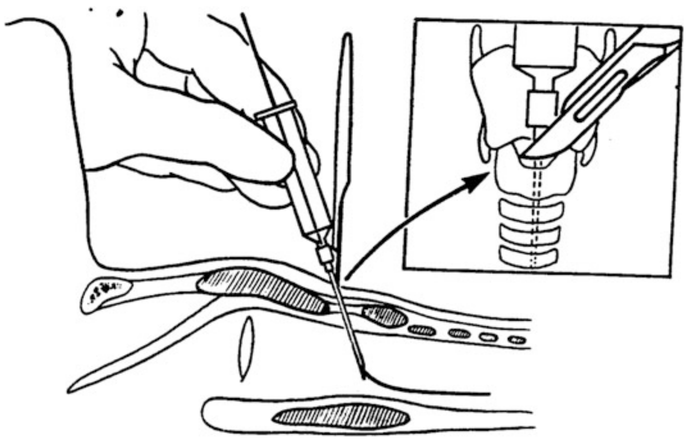


Fig. 12.6 Scalpel incision of cricothyroid membrane by resting blade on needle

crossing hands while performing this is extremely awkward. It is important not to remove the syringe barrel and needle until the scalpel incision is made, as it is not possible to make a firm cut on the wire alone. It is too flexible and will bend, kink, even be cut in the process. There are two objectives in making the scalpel incision: (1) The incision must be transverse across the trachea so that cricoid and thyroid cartilages can be stretched apart to permit the insertion of the airway tube. A vertical incision will not do this and can in fact sever the cricoid cartilage. (2) The incision must be in the same track as that made by the needle. This is important because the wire that will remain when the needle is removed must lie in this incision. If not, the dilator and tracheal tube, which, will be passed over this wire to gain access to the trachea will not pass easily, if at all, and the surgical incision will have to be repeated.

To meet this objective, the surgical blade must be supported on the caudal edge of the needle (Fig. 12.6). The blade is held perpendicular to the skin, resting on the needle, which is slanting slightly caudad. The blade is advanced through skin and cricothyroid membrane until the trachea is reached. It is extremely important that the blade maintain contact with the needle at all times because, as mentioned, the scalpel incision and needle hole must be one and the same. It may be necessary sometimes to make two or more incisions on the needle to ensure good tracheal entry. Air will usually return through the wound when the trachea is reached.

The surgical blade for the incision should be a No. 10. This has two advantages: (1) The blade is broad and is easily stabilized on the needle, and (2) It has minimal length such that the tip of the blade after full penetration is well away from posterior tracheal structures; the No. 15 blade is narrow and the No. 11 blade is a long dagger. Both are very difficult lo stabilize on a needle. The No. 11 advances a long distance at full penetration.

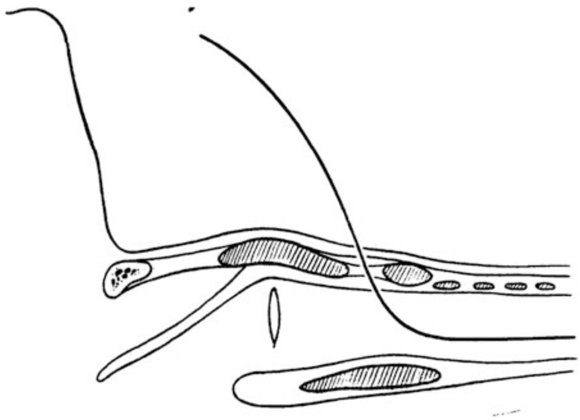


Fig. 12.7 Needle is removed and wire is left within the scalpel cut

Inserting the Tracheal Cannula

The next steps include: removal of the needle, leaving the wire alone in the incision (Fig. 12.7), followed by passing the nested dilator and tracheal tube over the wire (Fig. 12.8). Subsequently, the dilating portion is removed (Fig. 12.9). The tracheal tube is now in the trachea and the cuff can be inflated.

Desirable Properties of Any Cricothyrotomy Tubular Airway Device

Ideally, the tracheal tube should be one that permits spontaneous ventilation or mouth-to-tube or ambu ventilation in the field, where pressurized gases will not be available. It should also be as small as possible so that it will slide easily through the cricothyroid space and minimize the need for stretching. At the same time it should not impose too much work of breathing [16]. Minimum size of endotracheal tube that subjects can breathe through easily is found to be 4.5 mm ID with 12 cm length. In an experiment conducted by Bainton CR et al. [17], this size ETT tube was placed in the mouth with lips held tightly around it. The nose was closed with a pinch clamp. $EtCO_2$ was measured from the end of the ETT. Eighteen of 19 subjects found it comfortable to breathe through the 4.5 mm ETT. The one subject who was uncomfortable did not even like breathing in this way through a 9 mm ETT. Subjects maintained an average $EtCO_2$ of 38 ± 2 mmHg. Subsequently these subjects breathed through this 4.5 mm ETT while wa1king on a treadmill at 3 mph, which increased their VO_2 four times to 1000 ml/min. All subjects found it comfortable. The $EtCO_2$ rose on average only 1 mmHg. It was concluded from this study that a 4.5 mm ETT is quite satisfactory for maximum comfort and also has the ability to accommodate to the increased VO_2 that may well accompany the

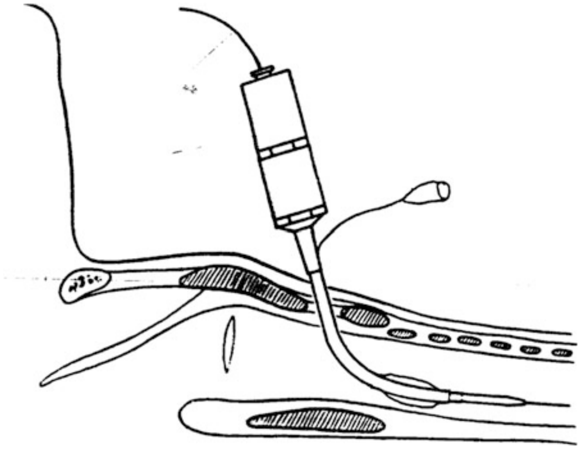


Fig. 12.8 Nested dilator and ETT tubes are passed over the wire into the trachea

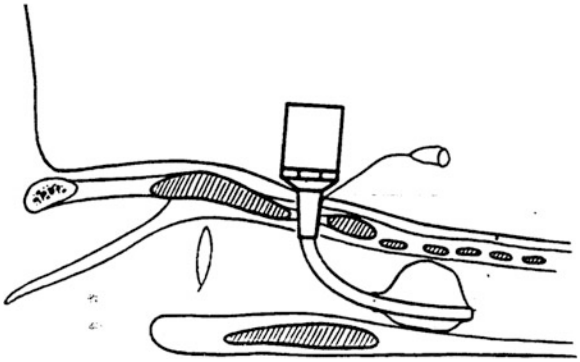


Fig. 12.9 Dilator, wire and small ETT removed, leaving the larger ETT, cuff inflated

hectic nature of the emergency situation. Other desirable properties of any tracheal device are that it should: (1) be flexible, because it must make a 90° fixed curve in passing through the cricothyrotomy stoma into the trachea, (2) have a length sufficient to accommodate to a potentially thick oedematous neck, (3) have a cuff so the airway can be contained and protected from foreign material and (4) have a second tube that will fit paediatric patients as well.

Available Cricothyrotomy Kits

Indigenous Kit with Common Anaesthesia Room Components

Figure 12.10 shows the components of a kit that can be assembled indigenously. It contains a wire (flexible, straight tip), a 5 ml syringe with tapered end, No. 14

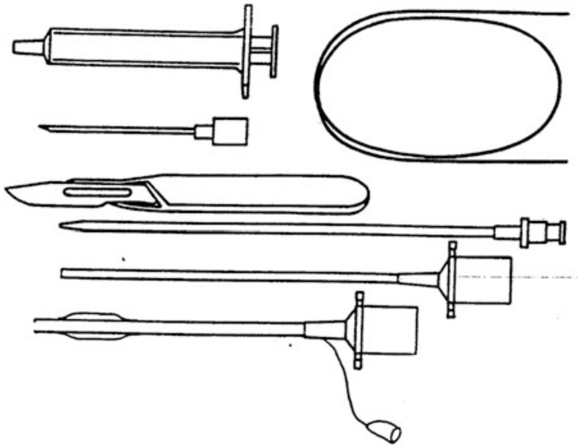


Fig. 12.10 Indigenous cricothyrotomy kit

needle, No. 10 scalpel, dilator from an internal jugular kit, a 3 mm ETT (in case of Portex use 3.5 mm ETT) for paediatrics with a 3.5 mm adapter, and finally a 4.5 mm cuffed ETT (in case of Portex use 5 mm ETT) with a 5.0 mm adapter. Adapters are one size larger than the ETT, such that the internal lumen is not reduced. The dilator, 3 mm, and 4.5 mm ETT are all nested together and then inserted as a unit over the wire utilizing the Seldinger technique. If the patient is a child, the 3.0 mm ETT is used alone. The 3.0 mm ETT is also covered by a thin tube of Teflon tubing or some jelly like K-Y jelly may be used so that it slips easily within the 4.5 mm ETT when they are nested. These items can be assembled into a small kit. This kit meets all the desirable properties of a satisfactory cricothyrotomy device. These components are, however, common to any anaesthesia workroom.

Commercial Kits

A few of popular commercially available cricothyrotomy kits are Pertrach kit, Nu-Trake kit, Cook's kit and Portex Minitrach kit. Pertrach kit has wire and dilator constructed as a single unit with the tracheal tube nested on outside of this. The penetrating needle is unique in that it can be split in half by pinching on the plastic wings after it is introduced into the tracheal lumen, and the wire resides within it. The needle halves are removed and the wire, dilator and tracheal tube are advanced into the trachea. Care must be taken when removing the sharp needle halves not to damage tracheal tube cuff. A No. 11 blade is supplied with it.

Nu-Trake kit resembles a trocar with metal dilating wings around an introducing needle. It does not use Seldinger technique, so placement is less certain. There is no cuff on the device so the airway cannot be isolated.

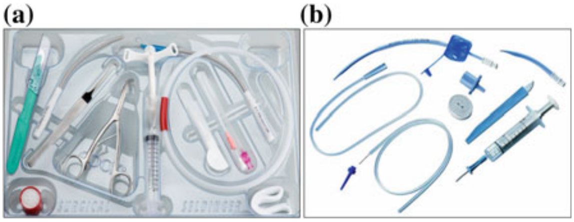


Fig. 12.11 **a** Cook's cricothyrotomy kit, **b** Portex Minitrach cricothyrotomy kit

Cook's and Portex Minitrach kits (Fig. 12.11) use the Seldinger technique. Cook's kit has a free wire that gives excellent "feel" when it enters the trachea. Its tracheal cannula is without cuff, which is a drawback. However, a Shiley No. 4 tracheostomy tube can replace it. Portex Minitrach has cuffed tracheal tube of 4, 6 and 8 mm ID.

Conclusion

All the personal involved in airway management must master a plan for "Cannot ventilate, cannot intubate" situation, and whatsoever device is mastered upon, should be made essential component of their difficult intubation cart. Only those solutions are likely to work in such emergent situations that are practised and mastered before. One should not rely on the textbook solution for such situations without confirming the efficacy and functioning of a device on artificially simulated conditions/manikins before hand themselves, as many problems will be found when they are put to use for the first time. In the present scenario of so many devices available for difficult airway management, the incidence of facing "Cannot ventilate, cannot intubate" situation is decreasing. However, one must be aware that in such emergency situations, the crucial step of urgently puncturing cricothyroid membrane accurately becomes extremely difficult in a patient making vigorous inspiratory efforts against obstructed upper airway, due to tracheal tug and especially, more so in infants. A wise approach for an anticipated difficult airway where possibility for landing in "*Cannot intubate, cannot ventilate*" situation is quite high, could be, to give trans laryngeal local anesthetic block and "*puncture and place intratracheal wire*" before attempts at intubation are made. If, attempts at intubation are successful, simply remove the guide wire, and, incase emergent situation arise, it will be easy to accomplish cricothyrotomy with in short time with less chances of complications.

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Chapter 13
Surgical Airway

Jinbin Zhang and Orlando Hung

Abstract There are four ways to achieve oxygenation: bag-mask-ventilation, ventilation using an extraglottic device, a tracheal tube and a surgical airway. The creation of a surgical airway is often viewed as the "last resort" in a dire "cannot intubate, cannot oxygenate" airway emergency. It is also incorporated into the difficult airway algorithms of various specialist societies. Despite its importance, there are many issues regarding timing of and the expertise of practitioners in performing a surgical airway. The aim of this chapter is to enhance the reader's understanding of the anatomy of the cricothyroid membrane, the technique of performing a cricothyrotomy, and the importance of skill maintenance. The recent developments in ultrasound technology may help practitioners in identifying airway anatomy in patients with a predicted difficult airway. It should be emphasized that having to perform an open cricothyrotomy cannot be viewed as a personal failure to secure the airway by conventional methods. It is, after all, one of the four methods of ventilation and oxygenation.

Keywords Surgical airway · Cricothyrotomy · Open cricothyrotomy · Seldinger's cricothyrotomy · Difficult airway

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Introduction

Surgical airway is an invasive airway intervention incorporated into the difficult airway algorithms of various specialist societies [1–4]. It involves the creation of an infraglottic conduit to allow oxygenation and ventilation when the trachea could not be intubated through the glottis. Anesthesia practitioners favor cricothyrotomy for surgical airway access due to multiple reasons. Firstly, the airway is superficial at the level of the cricothyroid membrane, separated from the skin by subcutaneous tissue and the anterior cervical fascia. It is also easily identifiable with palpable landmarks such as the thyroid and cricoid cartilages. The trachea on the other hand, is situated deep in the neck and in close proximity with the thyroid gland and major vascular structures. Tracheotomy is associated with higher complication rates. As such, in an emergency setting, cricothyrotomy is preferred over tracheotomy due to its simplicity, speed and fewer complications.

This chapter will focus on the different techniques of cricothyrotomy, the associated complications and important issues surrounding the procedure.

History of Cricothyrotomy

> *In Virginia in December 1799…. the first President of the United States of America … lay struggling to breathe… The man kept shifting his position as he gasped for air. It was obvious the patient's airway was severely compromised … One of the physicians present … was aware of tracheostomy but was disinclined to perform it, especially on such an important personage, because he believed the procedure to be futile… George Washington died from fully preventable suffocation due to an upper airwayobstruction caused by bacterial epiglottitis* [5].

Some of the earliest descriptions of a surgical airway access were found on Egyptian and Bronze Age artifacts as early as 3600 BC, but modern evolution of this medical procedure began only in the 1800s. The pandemic of *morbus strangulatorius*, or diphtheria, swept through Europe in the eighteenth and nineteenth centuries. Pierre Brentonneau, a French surgeon, first attempted to relieve the airway obstruction caused by this infectious laryngotracheobronchitis by tracheotomy in 1818. He finally succeeded in 1825 and in his paper published in 1826, he gave the disease the name *diphterite* (from the Greek word '*diphtheria*', meaning 'leather'), describing the appearance of pseudomembrane in the throat. Over the next two decades, Armand Trousseau routinely performed tracheotomy when required in patients suffering from diphtheria, and published his experience in 1851, where 127 out of 222 cases survived [6].

In 1909, Chevalier Jackson, an American laryngologist, described the first systematic approach to tracheotomy. He devised non-irritating and appropriately shaped tubes which helped to reduce mortality of the procedure to approximately

3 % [7]. In 1921, he published findings of a prohibitively high incidence of subglottic stenosis (92.9 %) in patients who had undergone high tracheotomy, or cricothyrotomy. He concluded that high tracheotomy should be abandoned and the only acceptable point of access was below the first tracheal ring ("low" tracheotomy) [8]. It was this landmark paper that subsequently condemned cricothyrotomy into oblivion.

Five decades later, the report by Brantigan and Grow in 1976 sparked a renewed interest in cricothyrotomy, challenging Jackson's dogma against the procedure. The investigators reported their experience with 655 cardiovascular patients with cricothyrotomy tubes in place from hours to months and found no cases of chronic subglottic stenosis. Subsequent studies continued to refute Jackson's findings [9, 10]. Sise et al. performed a prospective analysis of cricothyrotomy in 76 critically ill patients, the largest prospective observational study reported on this procedure. Morbidity and mortality of cricothyrotomy in adults were found to be similar to that reported for tracheotomy with only two documented cases of subglottic stenosis. They occurred in adolescent trauma patients, who underwent cricothyrotomy only after they had experienced complications associated with antecedent endotracheal intubation. Based on the findings, the authors recommended avoidance of cricothyrotomy in children and adolescences in view of the risk of subglottic stenosis [10]. In 2010, Talving et al. conducted a review of the 20 published series (17 retrospective reports and 3 prospective observational series) on cricothyrotomy between 1978 and 2008. Collectively, a total of 1134 patients were reviewed, including 368 trauma patients who underwent emergency cricothyrotomy, with a follow up ranged from 2 to 60 months. The rates of chronic subglottic stenosis among survivors were 2.2 % overall and 1.1 % in trauma patients. The authors concluded that cricothyrotomy after trauma is safe for initial emergency airway access, but they also acknowledged that routine conversion of cricothyrotomy to tracheotomy remains controversial and a well-designed prospective investigation is warranted [11].

The discrepancy between Jackson's findings with the contemporary literature might be attributed to the following reasons. Firstly, many of Jackson's patients were children, in whom the cricoid cartilage is known to be the narrowest part of the airway. Secondly, most of the cricothyrotomies were performed for inflammatory and infectious diseases, such as diphtheria, tuberculosis and epiglottitis. Thirdly, the Jackson's technique for "high tracheotomy" involved the division of the cricoid and/or thyroid cartilages. Anatomical factors, disease process and traumatic surgical technique might have put these patients at a higher risk for subglottic stenosis.

The simplicity and relative safety of cricothyrotomy nowadays makes it an advantageous technique in an airway emergency.

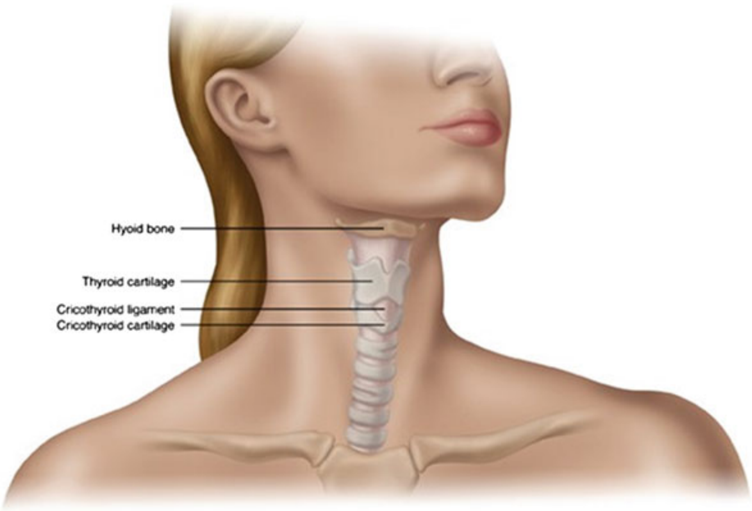

Fig. 13.1 Anterior view of the cricothyroid membrane (ligament) (Reproduced, with permission, from Hung and Murphy [41])

Anatomy of the Glottis and Trachea

The cricothyroid membrane is a superficial structure, and familiarity of its anatomy and its surrounding structures is crucial to a fast, safe and successful cricothyrotomy.

The cricothyroid membrane (CTM) is a dense, fibroelastic, trapezoidal membrane or ligament. It arises from the cricoid cartilage and attaches to the thyroid and arytenoid cartilages. The CTM is bounded superiorly by the thyroid cartilage, inferiorly by the cricoid cartilage and laterally by the cricothyroid muscles (Fig. 13.1). The size of the CTM varies with adults, but is generally 9–10 mm high and 22–33 mm wide (at its widest border) [12]. The vocal cords are located approximately 1 cm above the CTM, so the risk of direct trauma during cricothyrotomy is relatively low. The CTM can be palpated as a depression below the laryngeal prominence of the thyroid cartilage ("Adam's Apple").

The hyoid bone suspends the airway and is located above the thyroid cartilage. It is important to identify the hyoid bone so as to avoid misplacing the cannula or tube through the thyrohyoid membrane. In situations where the surface landmark is poorly palpable, the location of the hyoid bone is estimated to be at the midpoint of the horizontal distance between the mentum and the angle of mandible [13].

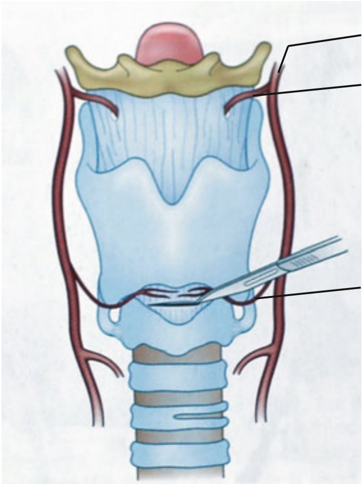

Fig. 13.2 Vasculature of the cricothyroid membrane (Adapted, with permission from Walls and Murphy [42])

Important Vascular Structures

The superior thyroid artery, a branch of the external carotid artery, gives rise to the cricothyroid artery. The left and right cricothyroid arteries traverse the upper third of the CTM, where they anastomose in the midline (Fig. 13.2) [14]. To minimize the risk of arterial injury, it is recommended to puncture or make the incision at the lower third of the CTM and the incision should also not extend more than 1 cm laterally [12].

Major vascular structures, such as the carotid arteries and internal jugular veins, lie posterolateral to the cricoid cartilage, deep to the pretracheal fascia. Injury to these structures is unlikely if the cricothyrotomy is performed in the midline. However, the anterior jugular veins travel vertically down along the SCM muscle in the lateral aspect of the neck. A vertical skin incision and keeping it in the midline may reduce the risk of injuring these lateral structures [15, 16].

The pyramidal lobe of the thyroid gland is present in up to 65 % of the population [17]. In some individuals, it may extend as high as the hyoid bone. As the thyroid gland is rich in venous plexus, injury to the pyramidal lobe can lead to severe bleeding.

Anatomical Variations

Individual anatomic variations may pose technical difficulties in performing cricothyrotomy. Palpation of the CTM is more challenging in females due to a less prominent thyroid cartilage, and human dissection studies also show that the CTM is smaller in females [14]. Obesity may make landmark identification more difficult due to the presence of overhanging submental fat and increased neck circumference.

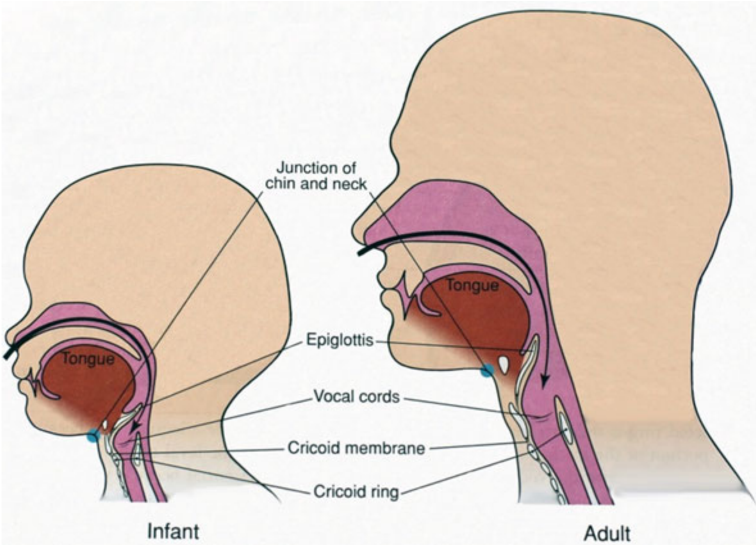

Fig. 13.3 Comparison of the pediatric and adult upper airway anatomy (Reproduced, with permission from Walls and Murphy [42])

The airway anatomy of the pediatric population differs from the adult airway (Fig. 13.3). In young children and infants, the cricoid cartilage is located more cephalad in the neck than adults. The hyoid bone and cricoid cartilage are more prominent than the thyroid cartilage. In addition, the adiposity of their short necks makes landmark palpation more difficult and confusing. The CTM of young children and infants are also much narrower, with a mean height of only 2.6 mm in neonates [18]. The fragile mucosa is more susceptible to laceration and edema, which increase the risk of subglottic stenosis [12]. As such, open cricothyrotomy is not recommended in children under 10 years old, and needle cricothyrotomy or surgical tracheotomy are the preferred choices in this patient population.

Indications for Cricothyrotomy

The primary indication for an emergency cricothyrotomy (Table 13.1) is the inability to secure the airway by intubation or other non-invasive means via the transglottic route, i.e. a failed airway. Cricothyrotomy is considered the "last resort" in an emergency "can't intubate, can't oxygenate" (CICO) situation in various difficult airway guidelines, such as those published by the American Society of Anesthesiologists (ASA) and the Difficult Airway Society (DAS) in the UK [1–4]. However, the timing for this potentially life-saving manoeuvre often gets delayed due to the inability to recognize a failed airway and repeated,

Table 13.1 Indications for cricothyrotomy

Inability to secure the airway by intubation or other non-invasive methods
Structural abnormalities (congenital or acquired)
Severe oropharyngeal or tracheobronchial tree hemorrhage
Massive aspiration
Major maxillofacial trauma
Upper airway obstruction
Edema (e.g. anaphylaxis, infection, trauma)
Tumor
Abscess
Hematoma
Foreign body

ineffective attempts at intubation or insertion of supraglottic devices [19]. In addition, the recent Fourth National Audit Project from the United Kingdom (NAP4) also identified poor planning, and lack of equipment as major contributory factors to poor outcomes [20]. Hence, it is crucial to have backup strategies when faced with a failed airway and promptly switch to alternative methods to minimize delay in establishing a surgical airway.

Although cricothyrotomy has been often taught as an emergency rescue technique in airway management, there are situations in which it should be considered as the primary airway of choice. An example would be a patient with severe maxillofacial injury, where it would be nearly impossible to intubate the trachea using the transglottic route. Another scenario would be a patient with severe upper airway edema (e.g. epiglottitis) or obstruction (e.g. tumor), where conventional techniques such as bronchoscopic and laryngoscopic intubation are unsuitable due to the distorted airway anatomy.

Contraindications to a Surgical Airway

When faced with an emergency CICO situation, and in the presence of severe hypoxemia, there are no true absolute contraindications to a surgical airway. However, there are various factors to consider when an emergency surgical airway is required (Table 13.2) [12].

Tracheal transection, cricoid cartilage and laryngeal fracture have been proposed as absolute contraindications to cricothyrotomy. Tracheotomy is the preferred method in these situations.

Obesity, burns to the neck, a large neck hematoma or infection, subcutaneous emphysema are relative contraindications as these pathologies may distort the airway anatomy and make surface landmark palpation much more difficult. Patients with systemic coagulopathy are more prone to bleeding and surgical airway should be performed with caution with careful hemostasis.

Table 13.2 Contraindications to surgical airway

Contraindications
Tracheal transection
Cricoid cartilage fracture
Laryngeal fracture
Relative contraindications
Young children
Obesity
Coagulopathy
Burns to the neck
Neck infection
Neck hematoma/massive subcutaneous emphysema
Acute or chronic laryngeal disease

A surgical airway is generally not recommended for children less than 10 years of age [18]. The cricothyroid membrane is much narrower in young children, and the surface landmark is less prominent. The mucosa is also more friable and more susceptible to edema and laceration, leading to subglottic stenosis [21]. Hence, needle cricothyrotomy or a formal tracheotomy are the methods of choice in young children and infants.

Preparing for Cricothyrotomy

Adequate preparation is essential to ensure a successful cricothyrotomy. The following steps should apply to all techniques of cricothyrotomy:

(1) Equipment
Airway practitioners should be familiar with the commercially available cricothyrotomy kits in their institutions. Kits for emergency surgical airway should be readily accessible and preferably located in a difficult airway cart.
(2) Preparation
The procedure should be performed under aseptic conditions. If time permits, every effort should be made to ensure asepsis and proper infiltration of the surgical site with local anesthetic.
(3) Patient positioning
While the patient with a potentially cervical spine injury should be placed in the supine position and the head and neck in a neutral position, it is necessary to extend the neck for proper exposure of the surgical landmarks. In patients with an anticipated difficult airway, practitioners may consider marking the site of the CTM before induction of anesthesia.
(4) Identifying the cricothyroid membrane

Fig. 13.4 Stabilizing the cricothyroid membrane between the thumb and the middle finger

Using the non-dominant hand, the laryngeal unit is stabilised by grasping the body of the thyroid cartilage between the thumb and middle finger (Fig. 13.4). This allows the index finger to move freely to palpate for the CTM. After identifying the laryngeal notch, the index finger moves inferiorly along the thyroid cartilage till it encounters a depression below the cartilage, which marks the location of the CTM. The hyoid bone, which lies above the thyroid cartilage, should also be identified, as wrongful insertion of a cricothyrotomy cannula through the thyrohyoid membrane will damage the vocal cords.

Should the surface landmarks be difficult to appreciate, the practitioner could estimate the level of the CTM by placing four fingers on the midline of the neck, with the last finger touching the suprasternal notch. The position of the index finger will coincide with the approximate location of the CTM.

Techniques

There are many methods of performing a cricothyrotomy. For simplicity, only the following methods of a surgical airway access will be outlined in this chapter:

(1) Open cricothyrotomy
(2) Seldinger cricothyrotomy

Fig. 13.5 Technique for open cricothyrotomy. Dilating the cricothyroid space with the index finger

Open Cricothyrotomy

Equipment required to perform an open cricothyrotomy include a #11 scalpel, tracheal hook, Trousseau dilator and a small cuffed tracheal tube or a tracheostomy tube. The steps in performing this procedure are as follows:

(1) A 5 cm vertical incision through the skin overlying the CTM is made in the midline and through the subcutaneous layer (Fig. 13.4).
(2) Palpate for the cricothyroid membrane through the incision
(3) Make a horizontal incision of the membrane along its lower border to avoid vascular injury.
(4) Retract superiorly using a tracheal hook to stabilise the laryngeal unit. Traction in an upward and anterior direction brings the airway closer to the skin. The tracheal hook is then passed to an assistant, and the incision site through the cricothyroid membrane should be dilated using the index finger (Fig. 13.5).
(5) Insert the Trousseau dilator to open up the cricothyroid space, and insert the small cuffed tracheal or tracheostomy tube in a caudad direction (Fig. 13.6)
(6) Inflate the cuff and confirm proper tube placement by presence of end-tidal CO_2 and auscultation
(7) Remove the tracheal dilator
(8) Secure the tube around the neck.

Fig. 13.6 Technique for open cricothyrotomy. Insertion of the tracheal tube with the aid of Trousseau dilator

Seldinger Cricothyrotomy

Numerous commercial Seldinger cricothyrotomy sets are available. These kits come pre-assembled and most of them use a modified Seldinger technique, which is more familiar to anesthesia practitioners, hence more appealing. In general, these kits contain a scalpel blade, a syringe, an 18 G catheter over needle or introducer needle, a guidewire, a dilator and a cuffed airway catheter.

(1) Make a vertical stab incision through the skin overlying the CTM
(2) A puncture of the CTM in a caudad direction using the needle attached to a syringe (Fig. 13.7)
(3) Positive air aspiration confirms entry into the intra-tracheal space
(4) Remove the needle and thread the guidewire through the catheter caudally into the trachea (Fig. 13.8). Remove the cannula, leaving the guidewire in place
(5) Make a small cut in the skin along the guidewire. With the dilator loaded through the cuffed airway catheter, advance the dilator/catheter unit over the guidewire into the trachea (Fig. 13.9)
(6) Remove the guidewire and dilator and inflate the cuff. Confirm proper tube placement with the presence of end-tidal CO_2 and auscultation
(7) Connect the patient to a ventilator and commence ventilation

Fig. 13.7 Technique for Seldinger cricothyrotomy. Aspiration of air confirms entry into the cricothyroid space

Fig. 13.8 Technique for Seldinger cricothyrotomy. Passage of the guidewire through the cannula

Fig. 13.9 Technique for Seldinger cricothyrotomy. Railroading the cricothyrotomy cannula and dilator en bloc over the guidewire

While it remains controversial, current recommendations view cricothyrotomy as a temporary life-saving measure. Conversion to a formal tracheotomy should be done once the patient is stabilized, usually within 72 h after cricothyrotomy.

Complications of Cricothyrotomy

The reported complication rates of cricothyrotomy vary depending on the technique used, the level of experience of the practitioner, the patient population, and the clinical situation. In general, the complication rates are higher for emergency cricothyrotomy (10–40 %) compared to their elective counterparts (6–8 %) [10, 13, 22].

Complications of cricothyrotomy can be divided into early and late complications, as illustrated in Table 13.3. McGill et al. reported an overall rate of 40 % in a study of 38 emergency cricothyrotomies. The most frequent problem identified was incorrect tube placement through the thyrohyoid membrane [13]. Bleeding is frequently associated with open cricothyrotomy and is usually due to superficial venous plexus injury, which can be easily controlled after securing the airway. Plexus injury can also be prevented by keeping the incision close to the midline and limiting its lateral extension. Severe bleeding is rarely encountered, although catastrophic and fatal hemorrhage due to laceration of the cricothyroid artery has been reported [13, 23, 24]. As the cricothyroid artery courses close to

Table 13.3 Complications of cricothyrotomy

Early
Initial misplacement of tube (e.g. paratracheal, superior/inferior to the cricothyroid membrane, through the posterior tracheal wall)
Bleeding
Technique-related
Kinking of guidewire
Laryngeal fracture
Posterior tracheal wall perforation
Aspiration
Esophageal/mediastinal perforation
Late
Subglottic stenosis
Voice changes
Scarring
Infection
Delayed bleeding
Swallowing dysfunction
Tracheo-esophageal fistula
Tracheomalacia

the thyroid cartilage, making the incision through the inferior half of the cricothyroid membrane for an open cricothyrotomy reduces the risk of hemorrhage. Caution should also be taken to avoid injury to the thyroid isthmus or its pyramidal lobe. Other early complications include prolonged procedure time, posterior tracheal wall perforation, aspiration of gastric content, and esophageal/mediastinal perforation.

Some complications are technique-related. Kinking of the guidewire is a common problem when performing the Seldinger technique and this increases the risk of tube misplacement. Laryngeal damage has been reported with open cricothyrotomy. McGill et al. reported a case of longitudinal fracture through the thyroid cartilage as a result of the insertion of an oversized tube, It is therefore recommended that the outer diameter of the tube should not exceed 8 mm [13, 25]. Reported long-term complications include subglottic stenosis, voice changes, scarring, infection, delayed bleeding, swallowing dysfunction, trachea-esophageal fistula and tracheomalacia [12]. Voice change is the most common complication, occurring in up to 50 % of cases [26]. Voice problems, such as dysphonia, hoarseness and weak voice, may be due to vocal cord paralysis from recurrent laryngeal nerve injury, vocal cord laceration, thyroid cartilage fracture or excessive traction on the thyroid cartilage [12]. Chronic subglottic stenosis occurs in approximately 2 % of cases [11] and is reported most frequently in long-term cricothyrotomy.

The mortality and morbidity of cricothyrotomy in adults are similar to that reported for tracheotomy [10]. Gillespie et al. also reported similar complication rates for emergency cricothyrotomy and tracheotomy, and no long-term complications were seen in the patients who received cricothyrotomy but were not subsequently converted to tracheotomy [27]. While conversion to a tracheotomy within 72 h of establishing cricothyrotomy has been advocated in view of the increased risk of subglottic stenosis, this remains a highly controversial subject which requires future investigations.

Other Considerations

Timing

Cricothyrotomy is indicated when maximal efforts at non-invasive methods have failed to relieve hypoxemia. Unfortunately, this decision is often delayed. The American Society of Anesthesiologists Closed Claims Project revealed that in two-thirds of the claims where airway emergency occurred, a surgical airway was obtained too late to avoid a poor outcome [19]. These findings were echoed in the Fourth National Audit Project (NAP4) in the UK, which showed that anesthetists failed to alter behavior even when faced with an airway crisis, favoring repeated attempts at tracheal intubation via direct laryngoscopy, despite knowledge that this strategy is rarely successful [20]. Although cricothyrotomy is placed as the final step in difficult airway algorithms, it must be instituted early to be an effective rescue option. Most reports of the timing of performing cricothyrotomy do not include "time taken to act" and "time taken to prepare" in their outcome measurements. Factoring the extra time required for preparation, cricothyrotomy should begin, and not just being considered, by the time hemodynamic instability supervenes. Surgeons should be present in the operating room, ready to perform an emergency tracheotomy in known challenging patients to minimize the delay of an airway rescue [28].

Training

A survey published in 2005 showed that most anesthetists preferred needle cricothyrotomy, and favored wire-guided (Seldinger) technique over open cricothyrotomy [29]. However, the NAP4 study revealed alarmingly low success with surgical airways performed by anesthetists, with a failure rate of 64 %. Success rates of narrow bore cricothyrotomy, wide bore cannula and open cricothyrotomy were 37, 57 and 100 % respectively. On the other hand, all surgical airways done by surgeons were successful. These observations concur with the findings of studies that reflected the poor ability of physicians to correctly identify the cricothyroid membrane in patients. Aslani et al. studied the accuracy of locating the cricothyroid membrane of fifty-six female patients by anesthetists and obstetrical trainees. Of the 112 identification attempts, only 30 % were correct, while only one accurate identification was made among 30 attempts in obese patients [30]. Elliott et al. showed that only 30 % of the attempts made by anesthetists accurately marked the area over the cricothyroid membrane, of which a mere 10 % were over its center point [31]. The authors conducted a similar study where 61 participants were asked to palpate for the cricothyroid membrane of 6 male and 6 female subjects. Out of the 186 attempts recorded, the overall success rate was only 42.5 %, with better success seen in male subjects (males 55.4 % vs. females 29.8 %, $p = 0.001$) [32]. Because cricothyrotomy is a life-saving core skill for the management of a CICO situation, these are disturbing findings.

The reasons for failure include problems with technique, training and equipment used. The rarity of having to perform a cricothyrotomy makes it a challenge to maintain the skill and to perform it proficiently when required. Training and confidence of practitioners in performing an open surgical airway need to be addressed. Many practitioners have little experience with the open technique and hence are uncomfortable with it, but those who have received training on manikins are more confident in using it in patients [29]. Systematic education using a combination of didactic teaching and hands-on practice will help improve practitioner skills and confidence [33, 34]. One study using a manikin model suggested that five percutaneous dilatational cricothyrotomies were required to reach a quick (<40 s), consistent, and successful performance [35]. Practitioners also need regular refresher training and practice on manikins, simulators, cadavers and/or animal models to maintain basic proficiency. The optimum retraining interval is unclear. However, one study demonstrated sustained skill retention for up to 6–8 months, and recommended training be repeated at 6 monthly intervals or less in order to maintain adequate skill level [36].

Other opportunities for practice and trainee education include the transtracheal injection of local anesthetics through a cricothyroid membrane puncture, as part of the topicalization process for an awake intubation [37]. Elective cricothyrotomies and percutaneous dilational tracheotomies in the operating room or ICU also offer similar opportunities for familiarization with airway anatomy and surgical skills.

Ultrasound of the Airway

With ultrasound machines now readily available in the operating rooms, emergency rooms and the ICU, there is an increased interest in the use of ultrasound to identify airway anatomy and to locate the cricothyroid membrane. Various techniques have been developed to allow quick identification of the anatomy relevant to cricothyrotomy [38–40]. Advantages of ultrasound include the ability to locate relevant structures for invasive airway intervention in patients with difficult landmark palpation and in confirmation of tracheal tube placement. Such technology is useful in patients with a known or predicted difficult airway, where ultrasound can be utilized for the identification of the cricothyroid membrane prior to the induction of anesthesia. However, the usefulness of ultrasound in a dire CICO situation where rapid identification of the cricothyroid membrane is required, remains to be investigated.

Summary

Cricothyrotomy is a life-saving procedure in a “cannot intubate, cannot oxygenate” situation. While proficiency is of paramount importance, the ability to recognize a CICO emergency and early decision making are critical to a successful emergency cricothyrotomy. It is recommended that practitioners be familiar with the equipment available in their institutions. Practitioners should also be proficient in more than one technique, so as to choose the most appropriate method in the context encountered.

Being a rare event, most practitioners have never performed a cricothyrotomy and are uncomfortable and unfamiliar with it, resulting in high failure rates. Frequent and effective training is required to improve and maintain this important skill set.

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Chapter 14
Surgical Approaches to Airway Management

Surender K. Malhotra

Abstract Securing the airway control through surgical techniques in an emergency has been illustrated in India and Egypt about 2500 years ago. In early twentieth century, Chevaliar Jackson described the technical details of tracheostomy. In the current era, almost all the algorithms dealing with difficult airway recommend that cricothyrotomy is the ideal and life-saving procedure and acts as the last resort in "cannot intubate, cannot ventilate" situation that may occur in variety of clinical settings both in and outside the hospital. The appropriate equipment should be available all the times, especially if the difficult airway is anticipated. Since the surgical airway is mostly accomplished in an emergency for difficult airway control, a detailed knowledge of anatomical landmarks, as well as thoroughly learnt and meticulously practiced techniques is a must before performing the procedure for successful outcome.

Keywords Surgical airway · Airway management · Cricothyrotomy

Introduction

Tracheostomy has been described in Egyptian and Indian history about 3600 years ago [1]. A publication by Chevaliar Jackson in 1909 on tracheostomy is still a milestone [2]. President George Washington succumbed to a serious upper airway obstruction in 1799. It is believed that he could have been saved had tracheostomy been performed [3]. Sanctorius, an Italian Surgeon, was perhaps the first one to describe tracheostomy in sixteenth century. The term Percutaneous tracheostomy was coined by Sheldon in 1955 as an alternative to surgical technique. Seldinger

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technique, used to perform percutaneous tracheostomy was described in 1969 by Toye and Weinstein [4]. In 1985, Ciaglia et al. introduced Percutaneous Dilatational Tracheostomy (PDT), a landmark technique [5]. 'Rapitrac', a dilating forceps device was reported by Schachner et al. in 1989 to advance a metal beveled cone into the trachea [6]. Ciaglia Blue Rhino (CBR; Cook Critical Care, Bloomington, IL), a technique for PDT, was introduced in 1999 that consisted of one-step-dilatation, using a curved dilator.

Various indications for surgical approaches to airway management are either elective or for potential difficult airway or in "cannot intubate, cannot ventilate" situation. The American Society of Anesthesiologists (ASA) task force on management of the difficult airway [7] has described cricothyrotomy as the life-saving procedure, as well as the final option for 'cannot ventilate, cannot intubate' scenario, whether in emergency, intensive care unit, or during anaesthesia. However, though cricothyrotomy may be life-saving in compromised airway situations, this technique is only a temporizing measure until a definitive airway can be established.

Gibbs and Walls [8] have defined surgical airway as "creation of new opening into the airway". They have further subclassified the surgical airways into (a) Surgical i.e., open technique, (b) Percutaneous (e.g., Seldinger technique), (c) Dilational (distinct percutaneous approach) and (d) Transtracheal catheter.

Surgical technique, either for cricothyrotomy or tracheostomy requires the use of scalpel and helps insertion of tracheostomy tube. On the other hand, percutaneous dilational technique involves the use of a kit to create surgical airway without a formal surgical cricothyrotomy. Minimal invasive surgical technique is ventilation through transtracheal catheter that is achieved through cricothyroid membrane [9]. There has been a controversy between supremacy of PDT versus surgical tracheostomy. Anaesthesiologists usually perform PDT, while the surgical tracheostomy is preferred by surgeons, particularly in Intensive Care Unit.

Indications

The basic indication of surgical airway is failure to secure airway in emergency through tracheal intubation or other techniques, such as supraglottic devices. Surgical airway is the last resort to secure airway in case of failure, as advised by ASA algorithm for difficult airway [10]. Though there are numerous devices available to access the airway, yet majority of anaesthesiologists depend on repeated laryngoscopy during difficult airway that usually results in fatalities [11, 12]. In case other techniques fail, it is a must to identify that 'can't intubate, can't ventilate' situation has arisen and the decision to secure airway through surgical approach must be taken before the cerebral damage due to hypoxia occurs.

Following are the indications of cricothyrotomy:

1. The situations when there is failure to secure airway with routine techniques, such as tracheal intubation and use of supraglottic devices. These include oedema or bleeding around the laryngeal structures, either due to trauma or

repeated intubation attempts; distorted anatomy due to faciomaxillary fractures; regurgitation of gastric contents and congenital airway anomalies.
2. Other indications are upper airway obstruction due to oedema following burns or trauma; foreign body in the pharynx or trachea; upper airway growth or tumour or some infection leading to abscess or inflammation.

In some situations, such as severe faciomaxillary trauma, cricothyrotomy may be the first choice to secure airway since routine techniques to secure are impossible due to distorted anatomy. But generally it should be used as a rescue technique and rarely employed as the basic method to secure airway. In cervical spine injuries, cricothyrotomy is considered safe provided neck is properly immobilized during the procedure [13]. In the current era, noninvasive airway techniques are so effective and successful that cricothyrotomy is rarely necessary. But in case multiple attempts are continued with nonsurgical methods likely to cause cerebral hypoxia, cricothyrotomy is certainly a better option. But at the same time, if obstruction to airway is below glottis, valuable time would be lost in undertaking cricothyrotomy, since it may not relieve the obstruction.

There are situations such as obesity or upper airway oedema following burns or inflammation, where anatomical landmarks are not well identified leading to unsuccessful procedure. In such cases, open surgical techniques need to be considered.

Contraindications

There are two situations where cricothyrotomy is contraindicated. One is transaction of trachea and the other one is fracture of larynx [14]. The preferred technique in these situations is tracheostomy that may not be readily available due to lack of skilled surgical help. So, the contraindication of cricothyrotomy may be relative and it should be performed when no other method is available to maintain airway. In child age group, contraindication of cricothyrotomy is almost absolute. The larynx in paediatric patients is mobile, flexible and small in size. Below the age of 12 years, it is recommended to depend on transtracheal catheter rather than cricothyrotomy to secure surgical airway. A few more relative contraindications are coagulopathy; any lesion in trachea and larynx such as abscess, hematoma or tumour in the area of procedure, since anatomical landmarks may be obscure.

Incidence

Emergency cricothyrotomy is considered to be a technique that is not so common and the incidence is not exactly reported [15]. In one study, the incidence of cricothyrotomy in the pre-hospital situation was much higher (10.9 %) than that in the emergency department (1.1 %), though the pre-hospital interventions constituted only 10 % of the total [16].

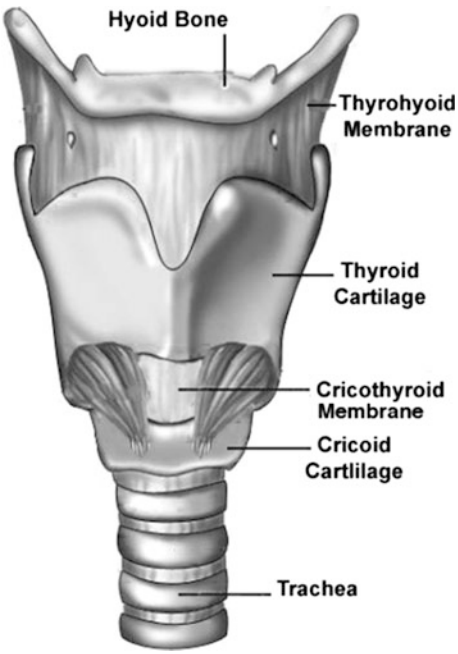

Fig. 14.1 Anatomy of larynx

Anatomy

For the safe and speedy performance of surgical airway, it is essential to understand the anatomy of upper airway. It is vital to be familiar with landmarks in the area, since bleeding during surgical procedure to secure airway may make the anatomy difficult to understand. Hyoid bone is about 1 cm below the laryngeal prominence, popularly known as Adam's apple. Laryngeal prominence is formed by the union of laminae of thyroid cartilage in the midline and their separation in upper part creates thyroid notch. Upper and lower borders of lamina form superior and inferior cornua. The laryngeal prominence is the most distinctive and easily identified landmark for carrying out the surgical procedure to secure airway. The inferior part of larynx is defined by a ring shaped cricoid cartilage (Fig. 14.1). The cricothyroid membrane joins cricoid to the lower part of thyroid cartilage.

The Cricothyroid Membrane (CTM) is trapezoid in shape (1 cm × 2.5 cm) that fills the space between cricoid and thyroid cartilage. It is placed about two fingers below the laryngeal prominence and one finger below the vocal cords [17].

For emergency surgical airway, CTM is the perfect option as it is superficial, lies just below the skin, easily palpated and does not contain blood vessels or nerves. The cricothyroid arteries lie superior to CTM and there is no venous plexus, hence there is negligible bleeding during cricothyrotomy. Between second to fourth tracheal rings lies the isthmus of thyroid that is about 1 cm in size.

In children, the laryngeal prominence appears between 14–18 years of age and the larynx lies at level of third cervical vertebra [18]. The CTM is small in size in children and anatomical landmarks are difficult to identify, hence it is not recommended to perform cricothyrotomy below 12 years of age. Instead, transtracheal catheter ventilation may be the technique of choice in this age group.

Similarly, in patients with neck trauma and obesity, anatomical landmarks are obscure leading to difficulty in carrying out cricothyrotomy.

Cricothyrotomy

Cricothyrotomy, also called thyrocricotomy, cricothyrodotomy or inferior laryngotomy, is well established procedure to secure emergency surgical airway, but there has been some debate since it may cause a complication i.e., subglottic stenosis [19]. There are reports of results of elective cricothyroitomy [20–22] performed under elective conditions such as in ICU. Emergency cricothyrotomy is carried out in the operating room or in emergency. It is a life-saving procedure in emergency and may have more complications, but is well accepted since it prevents morbidity and mortality associated with inability to secure airway. However, the controversies involving the cricothyrotomy are in elective cases and not in emergency situations. The advantages of cricothyrotomy over tracheostomy are that CTM is superficial, avascular and may not require incision. If performed competently with suitable indication, it may reduce the number of anaesthetic deaths following failure to secure airway. However, though cricothyrotomy may be life-saving in compromised airway situations, this technique is only a temporizing measure until a definitive airway can be established.

Techniques

Lidocaine 1 % solution into the skin and subcutaneous tissue offers satisfactory anaesthesia to perform cricothyrotomy, if the time allows and the patient is responsive. Position of the patient is supine and the neck is kept in neutral position.

Surgical Cricothyrotomy

This technique allows the placement of cuffed tube in the trachea as the ventilation is not a surety if uncuffed tube is inserted. In “cannot intubate, cannot ventilate” scenario, it quickly re-establishes oxygenation and ventilation. Surgical cricothyrotomy may lead to grave complications in case skilled staff is not available [23]. The scalpel preferred for the procedure is No. 20 since its width is enough to place a tube and its length is short, so the posterior wall of trachea is not injured

Fig. 14.2 Surgical cricothyrotomy set, "Surgicric I" (*Courtesy* of VBM India Co)

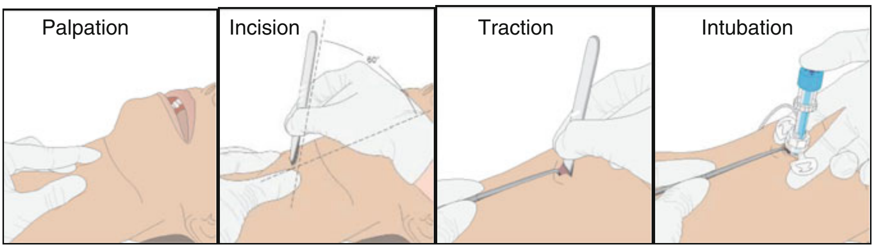

Fig. 14.3 Rapid four-step-technique (*Courtesy* of VBM India Co)

(Fig. 14.2). In case of an obese patient, incision given in first step is vertical so to identify the cartilage. The hemostasis is achieved once oxygenation is established. In expert hands, the 4-step cricothyrotomy (Fig. 14.3) can be performed in half a minute [24].

Equipment

- Cuffed tracheostomy or tracheal tube (Size 6 or 7 mm internal diameter)
- Scalpel (No. 20)
- Trousseau dilator
- Tracheal hook
- 4 × 4 gauze/sponges

Fig. 14.4 Melker universal cricothyrotomy set (*Courtesy* of Cook Critical Care)

Technique

Steps:

1. Position kept supine, extend the head and neck. Identify and immobilize the cricothyroid membrane (Initial vertical incision, if membrane not identified e.g., in obese patient).
2. 1–2 cm horizontal stab incision through the skin and cricothyroid membrane.
3. Downward and outward traction on the cricoid cartilage with the help of tracheal hook; scalpel is removed.
4. Tracheostomy tube inserted and the cuff inflated.
5. Ventilation carried out with low pressure.
6. Pulmonary ventilation is confirmed.

Percutaneous Cricothyrotomy (Seldinger Technique)

Most of the times, anesthesiologists are hesitant to perform emergency surgical methods, as they do not find them familiar. Therefore, Seldinger cricothyrotomy has been a popular and most practiced technique [25]. A number of modified Seldinger cricothyrotomy sets are available in the market such as Melker Universal Cricothyrotomy Set (Fig. 14.4). This set may be used for cricothyrotomy, both by surgical or Seldinger technique.

As shown by many studies, Seldinger technique takes longer time to secure surgical airway. However, since the technique resembles the one to place central venous catheter, anaesthesiologists find it comfortable and familiar. Moreover, it is easy to learn and may be performed in just 40 to 100 s, once well practiced [26].

Equipment

- Scalpel blade (No.11)
- Catheter-over-needle (18-gauge)

- Guidewire
- Dilator
- Cuffed Airway catheter (3–6 mm internal diameter)
- Syringe 10 ml

Technique

Steps:

- Prepare the anterior neck.
- Preoxygenate the patient for 3–5 min and throughout the procedure, too.
- Identify the cricothyroid membrane.
- Insert the introducing needle caudally through skin and membrane.
- Attach the syringe to needle and advance while aspirating through syringe till appearance of air bubbles, confirming the lumen of trachea.
- Remove the syringe and insert guidewire into trachea through needle.
- Remove the needle and leave the guidewire in trachea.
- Make a small skin incision along the guidewire.
- Insert airway catheter along with dilator over the guidewire into tracheal lumen.
- Remove guidewire and dilator simultaneously.
- Confirm the location of tube and secure it.

Needle (Cannula) Cricothyrotomy

This technique requires a cannula that is passed through cricothyroid membrane and a device for high pressure ventilation. It offers sufficient ventilation though the rate of success is not high [27].

The cannula used in this technique must be non-kinking unlike routine intravenous cannula (Fig. 14.5).

Equipment

- Over-the-needle catheter (Kink-resistant cannula) 12–14 gauge
- Syringe 10 ml
- Scalpel (No. 11)
- High pressure ventilation device

Fig. 14.5 Quicktrach II cannula for needle cricothyrotomy (*Courtesy* of VBM India Co)

Technique

- Cannula is inserted through CTM.
- Cannula is directed at 45° angle caudally with syringe attached.
- Tracheal lumen confirmed by aspiration of air using syringe.
- Syringe and needle are removed and cannula advanced into trachea till the level of hub.
- Ventilation system is attached to the cannula.
- Patency of upper airway is ensured by extending the neck.
- Ventilation started and expansion of lungs is confirmed.

Transtracheal Catheter Ventilation

Other than tracheostomy, transtracheal catheter ventilation is the only recommended surgical airway in children below 12 years. Some people opine that the term should be ‘transcricoid ventilation’ in case ventilation is carried out after cricothyrotomy. One of the cannulae used for transtracheal ventilation after percutaneous tracheostomy (Seldinger technique) is available by the name of Arndt

Fig. 14.6 Arndt cricothyrotomy cannula (*Courtesy* of Cook Critical Care)

cricothyrotomy cannula (Fig. 14.6). An effective ventilation in this technique is possible only if the pressure in the ventilation system is at least 50–60 psi. The oxygen flow of 12–15 l/min is recommended. An ideal jet ventilator consists of high pressure connector, a toggle switch and a Luer-Lock connector. With the help of toggle switch, oxygen can be safely jetted through transtracheal catheter. The Manujet III (VBM) has an adjustable dial to put a limit on maximum jetting pressure (Fig. 14.7). Ventilation should be commenced at a rate of 20 bursts a minute with a caution to avoid barotrauma. The Inspiratory to expiratory phase ratio should be 1:3 s [28].

The patency of upper airway is of paramount importance, otherwise the effective ventilation is not feasible. To keep the upper airway intact, the help of chin-lift, jaw thrust, extending the neck and even the use of LMA is recommended. Transtracheal ventilation may be continued for about 20 min in adults and 40 min in children [29]. If used for a longer period, It is likely to cause hypercarbia and thus in head injury patients, it should be used with caution.

Complications with the transtracheal catheter ventilation include hemorrhage, aspiration, surgical emphysema, barotrauma (e.g., pneumothorax, pneumomediastinum), inadequate ventilation, [30] and blockage /kinking/displacement of the transtracheal catheter [31].

Complications of Emergency Cricothyrotomy

The overall complication rates are higher in cricothyrotomy performed in emergency than in elective situations. McGill et al. [32] reported an overall complication rate of 40 percent. The most common complication is misplacement of the tube through thyrohyoid membrane rather than cricothyroid membrane. The bleeding during procedure, failure to place the tube correctly and taking time longer than 3 min to perform the procedure are other frequent complications.

Fig. 14.7 Manujet III for transtracheal ventilation (*Courtesy* of VBM India Co)

Erlandson et al. [33] reported a complication rate of 23 %, mainly due to bleeding and incorrect tube placement. Other complications [34] include subglottic stenosis, pulmonary aspiration, esophageal laceration, tracheoesophageal fistula and tracheal cartilage fracture (Table 14.1). Transtracheal ventilation may lead to complications such as barotrauma, surgical and medistinal emphysema and tension pneumothorax [35]. The emphasis has been laid on kinking and displacement of transtracheal catheter, distal airway secretions and outlet obstruction [36].

Tracheostomy

The traditional surgical or open tracheostomy is performed by incision of skin and subcutaneous tissue, separation of the strap muscles and division of isthmus. It is followed by incision of trachea and placing the tracheostomy tube. The position

Table 14.1 Complications of cricothyrotomy

Early	Late
Hypoxia	Subglottic stenosis
Aspiration	Tracheal stenosis
Surgical emphysema	Obstruction of tube
Mediastinal emphysema	Tracheoesophageal fistula
Blocking/kinking/displacement of needle	Tracheomalacia
Bleeding	Persistent stoma
Pneumothorax	
Oesophageal laceration	
Vocal cord injury	

recommended is supine with extension of neck. Tracheostomy performed as an emergency is not an easy procedure and the complications are severe [23, 37].

A small number of surgeons may perform tracheostomy within 3 min but majority take longer time. If tracheostomy done in emergency to secure the surgical airway gets delayed, it may be fatal. If difficult intubation is anticipated, such as in the case of laryngeal growth, elective tracheostomy is indicated. It is better to perform elective tracheostomy in already intubated patient. In case difficult intubation is anticipated and airway is likely to be compromised, tracheostomy must be carried out under local anaesthesia. Elective tracheostomy is also indicated in patients in intensive care who require airway and ventilatory support for long time. Currently, percutaneous dilational tracheostomy (PDT) is becoming popular and used frequently even as a bed side procedure. PDT is a safe and technically simple alternative to open surgical tracheostomy.

Percutaneous Dilational Tracheostomy

Percutaneous dilational tracheostomy (PDT), is also described as bedside tracheostomy. In this technique, tracheostomy tube is inserted without visualizing the trachea directly. This is least invasive procedure that may be performed at bedside or in ICU without difficulty. The procedure is indicated in patients requiring prolonged intubation or ventilation and to make pulmonary toilet easy. However, there is a debate that it may be used as a method to secure airway in emergency. This is discouraged in obese patients due to difficult landmarks; large thyroid and coagulopathy that are yet to be corrected.

The severely ill patients who require elective tracheostomy may be the right candidates for PDT [38]. This causes less infection and can be performed at bedside. Also, it is more economical as compared to traditional surgical tracheostomy [39]. Elective tracheostomy is also recommended in patients with upper airway obstruction, such as growth, stenosis and inflammation. In these patients, emergency PDT is controversial unless the airway is adequately protected [40]. In case, PDT is planned, sufficient neck extension must be ensured, so that cricoid cartilage and other landmarks are well identified. PDT is avoided in cases where landmarks are obscured due to the presence of a big thyroid gland. The high innominate artery and bleeding disorders may pose problems in performing this procedure. The platelet count and INR ratio must be above 50,000 and 1.5, respectively. Pneumothorax and surgical emphysema may occur following PDT, if the patient is on high positive end-expiratory pressure of 12 cm H_2O or above. Acute airway compromise and paediatric age group are also relatively contraindicated for performing PDT.

Technique

PDT is basically an elective method, though it has been reported that PDT may be performed in certain emergency conditions without much risk. For emergency surgical airway, cricothyrotomy is a better option. A difficult airway cart should be handy in the event of accidental extubation. The most commonly used kit for PDT is the one based on Ciaglia technique [41].

There are three insertion techniques for Ciaglia method:

a. Seldinger, single dilator technique: Utilizes Seldinger technique.
b. Ciaglia Blue Rhino G2 percutaneous tracheostomy Kit: It has a curved dilator that is advanced over a guiding catheter and creates a tracheostomy opening in one pass, without using multiple dilators.
c. Ciaglia Blue Dolphin Balloon Percutaneous Tracheostomy Kit: This system combines balloon dilation and tracheal tube insertion in a single step (Fig. 14.8).

The patient is positioned as for the standard surgical tracheostomy. All steps are performed with bronchoscopy under general anesthesia.

Steps (using Seldinger technique)

- Make skin incision and remove the pretracheal tissue through dissection.
- Withdraw tracheal tube so that the cuff is at the glottic level.
- Place the tip of the bronchoscope at level where the tip light is visible through surgical wound.
- Enter the tracheal lumen with introducer needle below the second tracheal ring.
- Dilate the tract between skin and trachea over a guide wire.
- Insert a tracheostomy tube over a dilator under bronchoscopic vision.
- Confirm the placement of the tube.
- Secure the tube to with sutures and the tape.

Two other techniques by the name of Shachner (Rapitrac) system and Translaryngeal tracheostomy (Fantoni's technique) are also commercially available to perform percutaneous dilational tracheostomy.

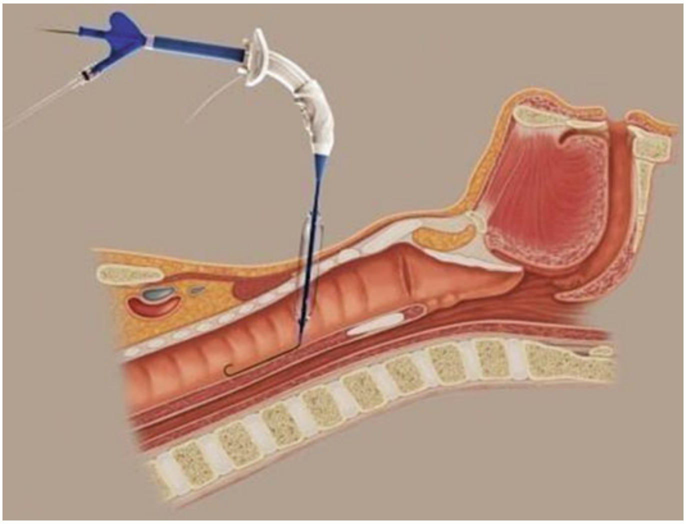

Fig. 14.8 Ciaglia balloon-assisted tracheostomy introducer (*Courtesy* of Cook Critical Care)

Conclusion

When multiple attempts for mask ventilation and tracheal intubation fail and the patient not able to maintain adequate oxygenation, emergency surgical airway is indicated. In this life-threatening situation, the decision to do cricothyrotomy as an emergency procedure is not easy, more so if the clinician is inexperienced. Though, the opportunity to perform a cricothyrotomy is rare for clinicians, yet efforts should be made to perform it quickly and properly when the emergency occurs. For the anaesthesiologists, percutaneous dilational cricothyrotomy is easy to practice since it is close to Seldinger technique that is commonly used for central venous access, while surgeons prefer surgical cricothyrotomy. The appropriate equipment should be handy all the times, especially if the difficult airway is anticipated. The proper size cuffed tube with standard connector is a must to facilitate ventilation and to prevent pulmonary aspiration. The experience and the technique selected to perform emergency cricothyrotomy decides the speed to complete the procedure. The risk of damaging neck vessels and posterior wall of trachea must be kept in mind. The immediate complication may be hemorrhage and failure to place the tube correctly. Transtracheal catheter ventilation has the advantage of simplicity and is considered the procedure of choice, particularly in children below 12 years where cricothyrotomy is relatively contraindicated. Though, cricothyrotomy ensures oxygenation but ventilation may not always be effectively possible. Therefore, one must be prepared for a definitive surgical airway, such as tracheostomy. An easy and technically safe alternative to surgical tracheostomy is percutaneous dilational tracheostomy (PDT). It may be performed as a bedside procedure in the critically ill patients with vital supports, without shifting them to operating room. Nevertheless, PDT should be thoroughly planned and properly performed keeping in view the likely complications. A thorough knowledge of anatomical landmarks and sufficient practice to perform the procedure for surgical airway is crucial for a successful outcome, not only in operating room but in other settings, too where anaesthesiologists are called to manage difficult airway. To keep up the training of clinicians, each procedure of surgical airway should be practiced live or using mannequins, at least twice a year.

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Chapter 15
Difficult Airway in Obstetrics

Sunanda Gupta and Apoorva Gupta

Abstract Management of the difficult obstetric airway is a challenge to all anaesthesia care providers. Since there is no single test to reliably predict difficult airway, many a times the anaesthesiologist is faced with unexpectedly difficult airway problems. This chapter focuses on the anatomical and physiological changes that have implications for management of the airway for the anaesthesiologist and how to evaluate and prepare the parturient in the preoperative phase to avoid catastrophes. Guidelines and simplified algorithms to manage the expected and unexpected difficult ventilation or intubation scenario, with or without fetal distress, along with a failed intubation protocol has been incorporated.

Keywords Failed intubation · Laryngeal mask airway · Anticipated difficult airway · Unanticipated difficult airway · Difficult obstetric airway

Introduction

Practice of obstetric anaesthesia has become safer with the introduction of regional anaesthesia, which has pushed anaesthesia as the cause of maternal mortality from the 3rd to the 8th position [1, 2]. There is an increased incidence of maternal mortality due to general anaesthesia, with a case fatality risk ratio of 16.7 as compared to regional anaesthesia [3]. This increased mortality is predominantly due to failure of tracheal intubation, oesophageal intubation, inadequate

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ventilation leading to cardiac arrest, anoxic cerebral injury, or aspiration of gastric contents. The reported incidence of failed intubation during obstetric general anesthesia has been reported to range from 1 in 2,836 to 1 in 2,130 [4]. Two deaths have been reported during extubation, due to failure to ventilate followed by cardiac arrest in a report from the confidential enquiries into maternal and child health for 2006–2008 [5].

Although the use of general anesthesia has been declining in obstetric patients, it may still be required in selected cases. Since difficult intubation in obstetric anesthesia practice is frequently unexpected, careful and timely preanesthetic evaluation of all pregnant women should identify the majority of patients with difficult airway and avoid unexpected difficult airway management [6, 7].

However, current data, on analysis shows that anaesthetic-related deaths are rare and the incidence in the obstetric and nonobstetric populations seems to be declining over time. In the obstetric population, airway problems seem to remain the predominant cause of anesthesia-related death. The introduction of pulse oximetry and end-tidal carbon dioxide monitoring along with practice guidelines related to difficult intubation, may have contributed to the declining rates to some extent [8]. Also, the increasing use of regional anesthesia for obstetrics has resulted in a decreasing exposure of parturients to the risks of airway management.

Anatomical and Physiological Changes

The anatomical and physiological changes which occur during late pregnancy and early labour make the pregnant airway much more difficult to intubate by direct laryngoscopy, as compared to the non pregnant females. Hormonally induced (progesterone) fluid retention during pregnancy results in oedema of the upper airway. This is further exacerbated by iatrogenic fluid infusions, valsalva maneuvers during labour, head down position and beta adrenergic tocolytic therapy. Elevation of blood pressure in pregnancy induced hypertension and pre-eclampsia is thought to worsen mucosal and interstitial oedema. Engorgement of the mucosa and capillaries of the nasal, oropharyngeal and laryngeal structures results in increased friability with bleeding, secondary to trauma during laryngoscopy and endotracheal intubation. Maternal weight gain with increased fat deposition in the upper airway further leads to increase in tongue size, and decrease in soft tissue mobility with narrowing of the oropharynx. The Mallampatti classification for mouth opening and the Samsoon and Young classification for laryngoscopic view [9] is found to change during labour due to oedema of the upper airway as labour progresses [10]. The engorged breasts further interfere with placement of the laryngoscope necessitating the use of a short handle.

During induction apnea, parturients tend to desaturate more rapidly as compared to the non pregnant patients. This has been attributed to the increase in oxygen consumption from 30 to 60 % during pregnancy, a decrease in FRC to

80 % at term as compared to prepregnancy values and a decrease in cardiac output in the supine position due to aortocaval compression. Therefore, the parturient requires optimal preoxygenation and denitrogenation before intubation, to tide over the period of apnoea during induction.

Management of the airway in the parturient is further compromised by changes in the gastrointestinal system which makes the parturient more prone to the risk of aspiration during induction of anaesthesia. There is relaxation of the lower oesophageal sphincter with increase in intragastric pressure, displacement of the stomach, decrease in gastric ph and delayed gastric emptying at term due to the enlarging uterus and hormonal effects. Mechanical prophylaxis includes application of cricoid pressure with rapid sequence intubation, to protect the airway from regurgitation and aspiration. However, incorrect application of the cricoid pressure may obscure the obstetric airway anatomy with further difficulty during laryngoscopy and intubation.

Positioning the parturient on the operating table necessitates the use of a wedge under the right hip to create a left lateral displacement of the uterus to avoid aortocaval compression. This may also alter the position of the airway, making laryngoscopy and intubation more difficult.

The emergent nature of caesarean delivery occurring outside usual hours with minimal backup, and concerns about minimal exposure to anaesthetic agents, causes haste and anxiety among anaesthesiologists. Inadequately trained assistants who are less familiar with the obstetric anatomy, may further compound the situation and subject anaesthesiologists to undue pressure. The increasing use of regional anaesthesia for caesarean deliveries and the use of supraglottic airway devices as rescue devices for ventilation in case of difficult intubation, has been further blamed for inadequate exposure of the trainee residents to master the art of intubation.

Preparing the Obstetric Patient to Avoid Catastrophes

Anticipating a difficult airway in obstetrics ensures safe obstetric practice, so one should assume that every parturient has a difficult airway. Hence, no obstetric patient should undergo general anaesthesia without a proper preanaesthetic evaluation of the airway and a ready back-up plan. Obstetric airway algorithms and availability of difficult airway equipments with regular safety drills, expert trained manpower, 'prophylactic epidurals' in difficult airway labeled parturients and using regional anaesthesia instead of general anaesthesia are some of the measures that can be taken to prevent airway problems. The most common indication for emergent intubation in Obstetrics is fetal distress. Other indications, include a failed regional technique or a high sympathetic block during regional anaesthesia, local anaesthetic toxicity, and respiratory, neurological or cardiac emergencies. Some of the important steps to provide safe obstetric anaesthesia practice includes:

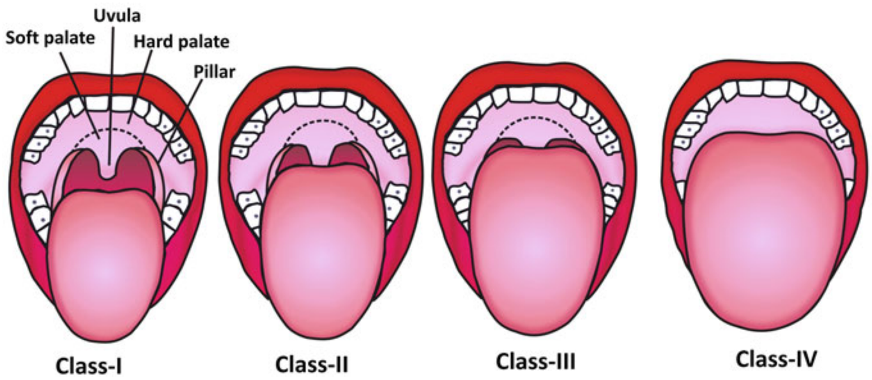

Fig. 15.1 Difficult laryngoscopy and intubation: Modified Mallampati classification (Class I–IV)

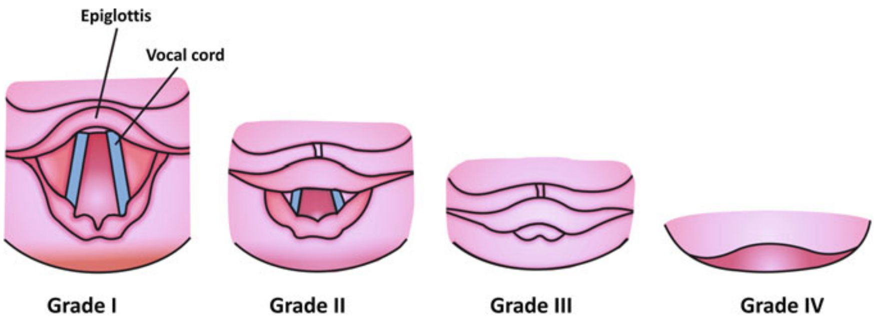

Fig. 15.2 Difficult laryngoscopy: Cormack Lehane grading (Grade I–IV)

1. *Airway Assessment*: An adequate and timely airway assessment should be undertaken of all those parturients admitted to the labour floors especially those who are scheduled to undergo analgesia or anaesthesia. A quick assessment involves looking out for facial oedema, obesity, and short neck, neck movements to assess the atlanto occipital extension, mouth opening for mandibular space with its length and compliance, dentition (size, degree and protrusion), and thyromental distance. This assessment, should also include grading by Modified Mallampati scores (Fig. 15.1) and Cormack and Lehane laryngoscopy view (Fig. 15.2) grading, as Mallampati had hypothesized that the degree to which oropharyngeal structures can be visualized upon examination should correlate with the structures that could be seen on laryngoscopy. Breast size and the degree to which they will affect placement of laryngoscope and an assessment of the ease of mask ventilation should be done, based on factors such as whether the patient is obese, edentulous or shows signs of respiratory obstruction. Anaesthesiologists should also be aware, that the grading of airway assessment, at the start of labour may worsen as labour progresses [10] and may persist up to 48 h postpartum [11].
2. *Fasting Guidelines*: The uncomplicated laboring parturients should be allowed to take modest amounts of clear fluids. Solid foods should be avoided, as delay

in gastric emptying for solid foods, especially if parentral or neuraxial opioids are given, has been reported [12]. For elective caesarean delivery, clear fluids up to 2 h before surgery can be given, while 6 h abstinence for light meals and 8 h for fatty meals should be observed prior to surgery [12].

3. *Aspiration prophylaxis*: It is difficult to eliminate the possibility of aspiration, so attempts should be made to reduce the acidity and volume of gastric contents. All parturients should be considered as "full stomach", irrespective of their fasting status. Non particulate antacids, H2 receptor antagonists or proton pump inhibitors and prokinetics should be given as premedication. Oral sodium citrate effectively raises the stomach ph, but has a duration of approximately 1 h. To reduce gastric volumes and increase the pH, H2 receptor antagonists like Ranitidine and Omeprazole, given a night before and on the morning of surgery is found to be effective. Antiemetics like Metoclopramide have been found to reduce the gastric volume. The obstetric team should be warned early, not to exert fundal pressure and avoid head-down positioning so as not to potentiate regurgitation of the gastric contents.
4. *Positioning the parturient*: Pregnant patients should be carefully positioned, keeping in mind the difficulties one may encounter during laryngoscopy and intubation. First and foremost, the operating table should be raised to the level of the anaesthesiologist's intercostal margin and the table tilted 15° to the left to avoid aortocaval compression. Obtaining the ideal 'sniffing' position involves flexing the lower cervical spine and extending the upper cervical spine by extending the head on the atlanto-occipital joint. In the obese parturient, provide a 'ramped' position, by using pillows and blankets, so that the external auditory meatus and xiphoid process are in a horizontal plane. This position also moves away the enlarged breasts from the airway and brings the oral axis in alignment with the laryngeal and pharyngeal axes.
5. *Preoxygenation*: Since parturients tend to desaturate more rapidly, it is important to preoxygenate them properly and for a sufficient time to tide over the apnea phase during intubation. At least 3–5 min of tidal volume breathing with 100 % oxygen or 4 deep vital capacity breaths of 100 % oxygen or 8 deep breaths over 60 s, is sufficient to denitrogenate the parturient before induction [13, 14].
6. *Cricoid pressure*: Application of cricoid pressure of 20 N (approximately 2 kg) going up to 40 N, in a backward, upward and right ward pressure (BURP), improves the view at laryngoscopy and prevents regurgitation into the oropharynx. In the pregnant woman, the thyroid cartilage may not be prominent, in this case, palpation of the tracheal cartilage rings from the sternal notch upwards, may help to identify the cricoid cartilage. This should be applied during induction, before the patient loses consciousness, and with the gradual increase in pressure, the oesophagus is compressed on the vertebral column. During LMA insertion, cricoid pressure release is recommended and may be reapplied once adequate ventilation is established. The efficacy of applying the cricoid pressure in parturients has been questioned recently, on the plea, that

incorrect application may increase the difficulty in viewing the larynx, and make the parturient more prone to regurgitation [15–17].

7. *Difficult obstetric airway cart*: The following equipments should always be available in a portable cart.

a. *Routine devices*: Apart from basic devices like masks, suction devices, standard monitoring equipment, self inflating bag and mask for positive pressure ventilation, lignocaine spray, lubricating jelly, anaesthesia and resuscitation drugs and adhesive plaster on the anaesthesia workstation, the following equipments should be available:

Endotracheal tubes size 5–7
Oropharyngeal airways size 3, 4
Macintosh/Magill laryngoscope with standard blades (3–4)
Short handle, Polio/McCoy blade
Stylet
Magill forceps
Gum elastic bougie
LMA, LMA Proseal™ (sizes 3, 4)

b. *Alternative rescue devices*:

Trachlight/Light wand
Intubating LMA (Fastrach) or LMA CTrach
Laryngeal tube S
Flexible fibreoptic laryngoscope /Bronchoscope
Video laryngoscope (Glidescope/Airtraq/C-Mac)
Transtracheal jet ventilation (TTJV) apparatus
Retrograde intubation equipment
Cricothryroidotomy seldinger kit

Anaesthesiologists should be familiar and experienced in using whichever rescue device they plan to use. These equipments should be regularly checked for proper functioning and kept in a separate difficult airway cart.

8. *Approach to the difficult obstetric airway* [2, 18–21]: The obstetric airway has become more difficult with the lack of experience among trainees and consultants due to increased use of neuraxial techniques rather than GA for caesarean deliveries. Though simulators have tried to bridge this gap, but certain features peculiar to anaesthetizing the obstetric patient, has resulted in limited success in training the trainees. The emergent nature of CD, variations in maternal and fetal anatomy and physiology, concerns for wellbeing of both the mother and fetus and preference for spontaneous breathing in obstetric patients have been identified as important causes.

Difficult Airway Management

(i) Anticipated difficult airway
(ii) Unanticipated difficult airway with or without fetal distress:

a. Can ventilate, cannot intubate
b. Cannot ventilate, cannot intubate

(iii) Failed intubation drill
(i) *Anticipated difficult airway* (Fig. 15.3)
Regional anaesthesia is always considered the best option for caesarean delivery in cases of anticipated difficult intubation cases. Fiberoptic intubation of the spontaneously breathing patient has been the gold standard for elective anticipated difficult airway intubation. However, some anaesthesiologists prefer awake fibreoptic intubation over regional anaesthesia in such cases [22], on the plea, that complications from regional anaesthesia can turn an anticipated difficult airway(DA) to an emergent DA crisis. Ideally, a safe back-up plan should always be kept ready along with a 'prophylactic epidural' in place, if possible, before the patient goes into labour. Awake intubation, has the advantage of maintaining the muscle tone with spontaneous respiration, using selective nerve blocks or direct application of local anaesthetic agents. There are several case reports, describing successful fibreoptic bronchoscope guided intubation in both expected and unexpected difficult airway. Airway adjuncts such as lighted stylets, intubation bougies, intubating LMA, can all play a role in intubation. However, suitable equipment for airway management should be readily available with a minimum of time required to obtain and set up a fiberoptic intubating scope. Cautious use of local anaesthetic agents is also advocated, due to increased vascularity of the oropharyngeal mucous membrane, resulting in enhanced uptake and short duration of action, which may tempt repeated use of these drugs, increasing the chances of local anaesthetic toxicity. Through out these attempts at awake intubation, supplemental oxygen should be delivered, as hypoxia is a common complication. Nasal route should ideally not be used, due to hyperaemia of the nasal mucosa with increased risk of epistaxis. Thus success of intubation will depend on an adequate topical anaesthesia of the upper airway and an experienced operator. In the event of bleeding and oedema following attempts at intubation with the above adjuncts for intubation, a retrograde intubation attempt can prove life saving. This involves, introducing the catheter through the cricothyroid membrane and then using it as a guidewire through the suction port for introducing the fibre optic bronchoscope. Another useful device is the Video laryngoscope, which is increasingly becoming the rescue strategy of choice, and some authors have even advocated it as the primary laryngoscopic technique and have used it successfully in obstetric patients [23, 24]. In future, it is possible that this technique may emerge as a potential alternative to fiberoptic intubation in selected cases.

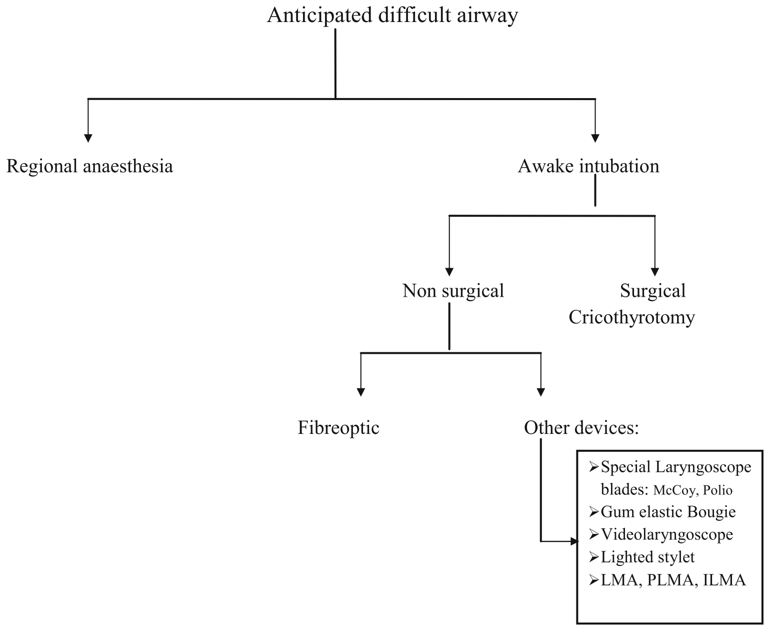

Fig. 15.3 Anticipated difficult airway

(ii) *Unanticipated Difficult Airway* (Fig. 15.4)
Management of unanticipated difficult airway in the parturient depends on the urgency of the situation, whether due to maternal or fetal causes. If there is no urgency, then the mother should be awakened, the surgery postponed and pathway of anticipated difficult airway should be followed. In an emergent situation, again the management will depend on whether she can be ventilated by mask or it is a 'cannot ventilate cannot intubate situation.'

(a) *Can ventilate, cannot intubate with no fetal distress*: Mask ventilation with appropriate size of mask, aided by an oropharyngeal airway should be combined with cricoid pressure, provided it does not interfere with ventilation. External laryngeal manipulations, readjustments of the sniffing position, calling for expert help, using different laryngoscope blades, gum elastic bougie, or video laryngoscope, should be tried. If intubation is still not possible, the mother should be awakened and either regional anaesthesia or awake fibreoptic intubation can be attempted at a later date. Mask ventilation should be continued throughout, so that fetal oxygenation is not compromised.

(b) *Can ventilate, cannot intubate with fetal distress*: In this situation, the surgery has to proceed, and our prime concern should be maintenance

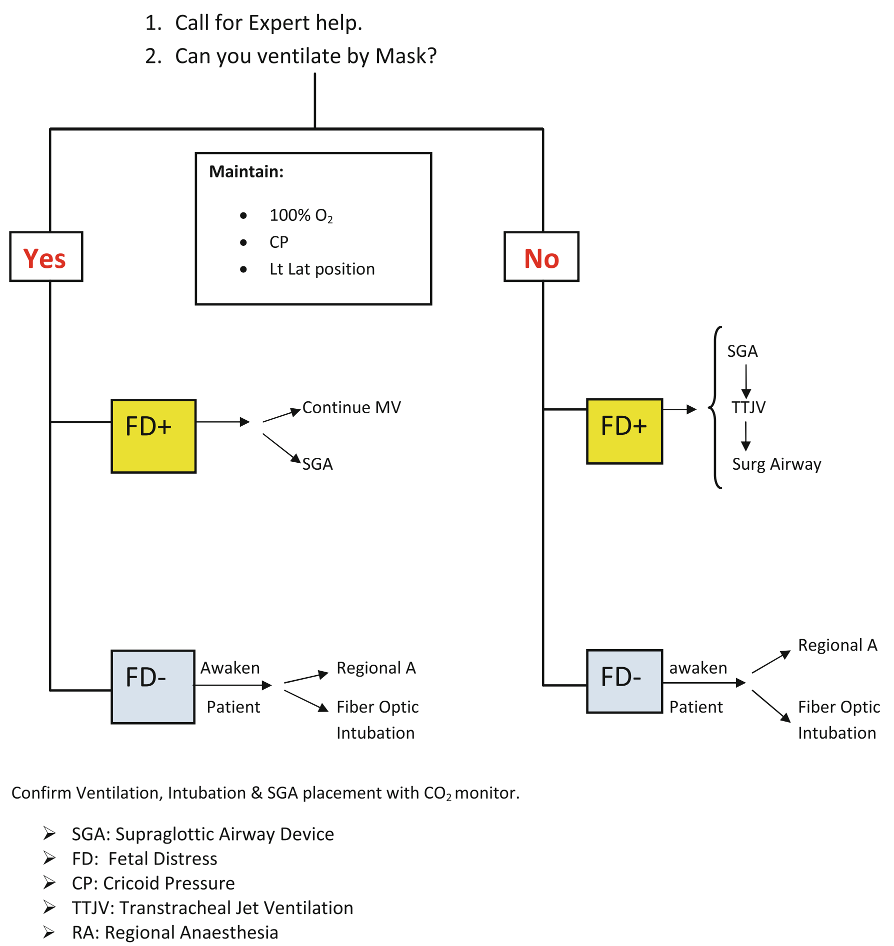

Fig. 15.4 Unanticipated difficult airway

of good ventilation to ensure an adequate oxygen supply to both mother and fetus. Patient should be continued with bag mask ventilation, cricoid pressure and intermittent muscle relaxation (with muscle relaxants, as and when required) along with volatile inhalational anaesthetics and spontaneous ventilation. Introduction of a laryngeal mask airway (LMA), intubating LMA or Proseal LMA has been reported to provide a more safe and effective anaesthesia in these situations. Fundal pressure and uterine exteriorization should be avoided to prevent regurgitation of the stomach contents. A left lateral tilt and trendelenburg position should be maintained.

(c) *Cannot ventilate, cannot intubate*: This is a life threatening situation and needs to be managed urgently. The LMA is generally considered to be the most useful device if ventilation is not possible by mask. During insertion of LMA(ILMA or Proseal) the cricoid pressure may need to be released for ease of insertion. Combitube or Laryngeal tube S are other alternative devices which have been used successfully in the pregnant population. If ventilation and oxygenation are adequate with these devices, then surgery can be commenced. If ventilation is still impossible, needle cricothyrotomy should be attempted which would improve oxygenation but not ventilation. A tube with an internal diameter of 4 mm is required to achieve adequate ventilation. Hence, this should be followed by placement of a definitive airway or a surgical cricothyrotomy. *It should be remembered and continuously stressed that patients do not die from failure to intubate but failure to oxygenate.* All emergency situations encountered, can be dealt positively if ventilation and oxygenation is maintained in the parturient. In difficult situations, the anaesthesiologist should use only those alternative equipments with which he/she is familiar and proficient. Ideally, placement of these airway devices should be confirmed by quantitative and qualitative measurement of end-tidal CO_2.

(iii) *Failed intubation drill* (Fig. 15.5)
In the event of inability to intubate the trachea following general anaesthesia, a failed intubation drill has to be initiated. This drill should be simple, visible at strategic places to help accurate recall and once initiated should elicit a quick response from the difficult airway providers and team. Each institute should develop its own improvised failed intubation drill, according to the available resources and ensure regular training programs for use of rescue airway devices.
In the event of a failed intubation, the following points should be remembered:

a. If adequate laryngoscopic view is not achieved, then call for additional help and readjust the position of the head, neck and upper torso so that the external auditory meatus and manubrium sterni are in one plane. Cricoid pressure should be eased and repositioned, ideally by an experienced operator, and another laryngoscope blade (McCoy or Polio blade) with short handle of laryngoscope should be tried. Use a gum elastic bougie and a smaller size endotracheal tube. Each attempt at laryngoscopy and intubation should be well planned, and each provider should take less than a minute to attempt intubation.
b. If intubation is not successful after two attempts, Haemoglobin saturation is <90 % and cyanosis develops, oxygenation and ventilation should take priority over intubation. A two handed technique for face mask ventilation with an oropharyngeal airway (if patient can tolerate) should be used. Give 100 % oxygen, ventilate and maintain cricoid pressure.

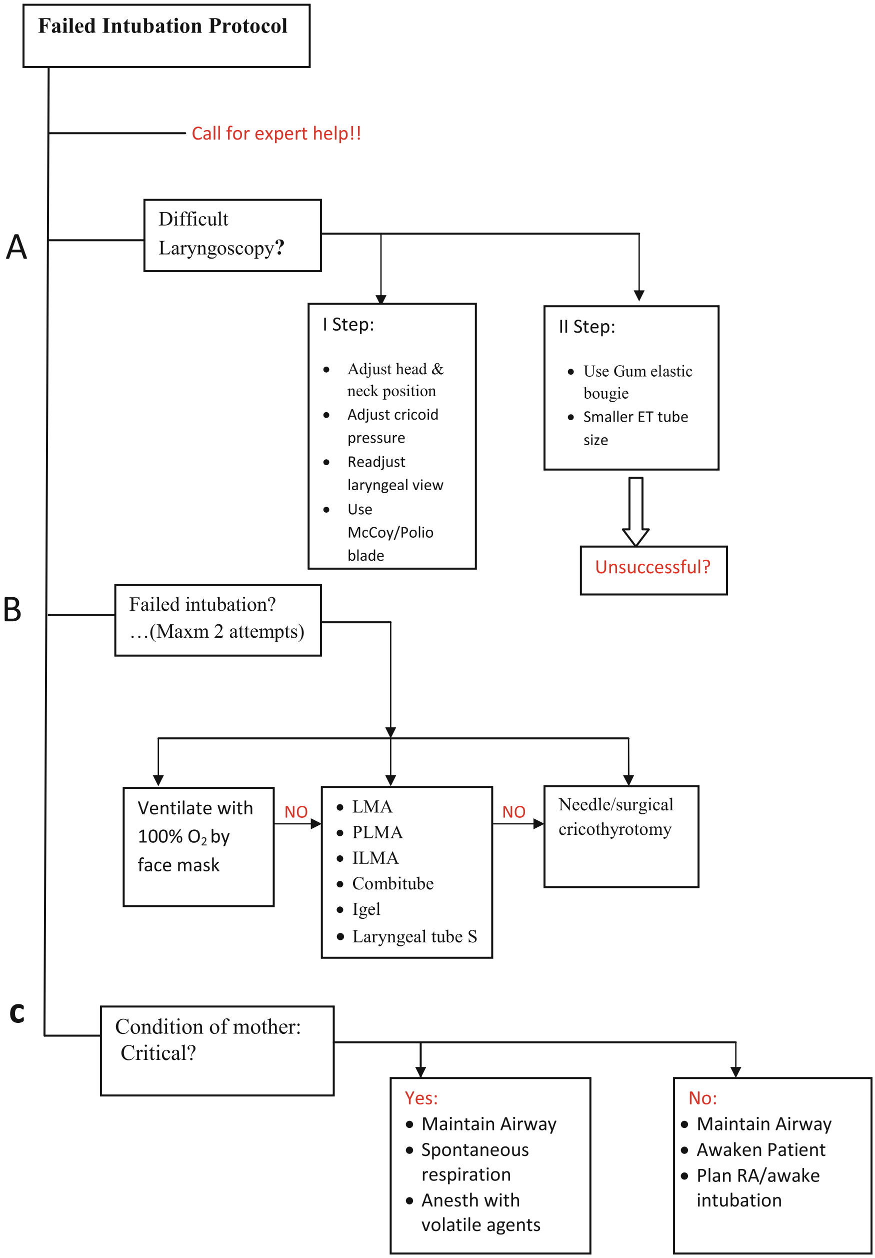

Fig. 15.5 Failed intubation protocol

c. If ventilation is not possible, release the cricoid pressure and insert a supraglottic airway (Proseal LMA or intubating LMA or Combitube or Laryngeal tube S). The most popular rescue device for failed intubation situations is the laryngeal mask airway (LMA). This device can be used as a ventilatory device or as a conduit for intubation.
d. If ventilation is still not possible, do a needle cricothyroidotomy followed by securing a surgical airway. All anaesthesiologists should familiarize themselves with the locally available cricothrotomy kit.
e. Proceeding with surgery will depend on the urgency of caesarean delivery. For emergent CS, attempts to intubate, provided ventilation is adequate, should be deferred till the neonate is delivered. After delivery, intubation should be attempted ideally with a video laryngoscope. Patients can be awakened and converted to regional anaesthesia if there is no urgency for CD.
f. Caution should be exerted while extubating the 'difficult intubation trachea' as airway compromise during emergence in the post anaesthesia phase has been highlighted as one of the main causes of mortality in the obstetric population due to airway mishaps [25].
g. In the event of a difficult airway episode, anesthesiologist should inform the patient (or responsible person) of the airway difficulty that was encountered. The intent of this communication is to provide the patient (or responsible person) with a role in guiding and facilitating the delivery of future care. The information conveyed may include (but is not limited to) the presence of a difficult airway, the apparent reasons for difficulty, how the intubation was accomplished, and the implications for future care [26].

Conclusion

A successful attempt at ventilation and intubation during crisis depends on, availability of the difficult airway cart, availability of good assistance, a quick recall of airway protocols and staying calm. It is very important that anaesthesiologists train all staff on the obstetric floors, about airway management, so that during a crisis, they can provide the necessary support. Each institution should establish regular orientation programs for all personnel involved in managing obstetric patients, so that they become familiar and gain expertise in using different airway devices and surgical techniques. Institutions should also earmark the appropriate responders for difficult airway and providers for maintaining the equipments in a ready state. Finally, each institution should follow its own difficult airway algorithm, according to the available equipment, manpower and resources.

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Chapter 16
Ultrasonography: Heralding a New Era in Airway Management

Michael Seltz Kristensen and Wendy H. L. Teoh

Abstract Ultrasound (US) can help anesthesiologists locate the cricothyroid membrane before managing a difficult airway, rule out an intraoperative pneumothorax, locate the optimal level for elective dilatational tracheostomy, distinguish between tracheal and esophageal intubation before initiation of ventilation, and help clinicians overcome many other challenges related to the upper and lower airways. Indeed, the availability of easily transportable ultrasound machines, combined with increasing familiarity with the use of this technology, now makes ultrasonography a fundamental tool in airway management.

Keywords Airway management · Ultrasonography · Dynamic tool

Introduction

Management of the upper and lower airways and diagnosis of pathological conditions and complications are essential clinical skills for any physician in anaesthesia, emergency medicine, respiratory medicine and intensive care settings. As inadequate airway management remains a major contributor to patient mortality and morbidity [1], any clinical tool that can improve airway management must be considered as an adjunct to the conventional clinical assessment. Ultrasonography (US) has many obvious advantages (it is safe, quick, repeatable, portable, widely

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available, and gives real-time dynamic images) in the anesthesia and emergency settings and several studies have evaluated its role in both management of the airways and diagnosis of pathology in the upper and lower airways. Ultrasonography must be used dynamically—in direct conjunction with both airway procedures and assessment of a patient with suspected pathology in the airways—for maximum benefit in airway diagnostics and management.

Optimal airway management typically is the anesthesiologists' most important task before and during surgery, and it is the area in which the specialty has the ultimate knowledge and final responsibility. Ultrasonography has become an inherent part of the anesthesiologists' armamentarium, a natural tool for vascular access and for locoregional anesthesia. Therefore as ultrasound machines are widely available in anesthetizing locations, we anesthesiologists should become familiar with their use—including for managing airways.

Ultrasound (US) can help anesthesiologists locate the cricothyroid membrane before managing a difficult airway, rule out an intraoperative pneumothorax, locate the optimal level for elective dilatational tracheostomy, distinguish between tracheal and esophageal intubation before initiation of ventilation, and help clinicians overcome many other challenges related to the upper and lower airways. Moreover, because ultrasonography can be performed at the point of care by the anesthesiologist, it is not merely another procedure to be ordered from another specialty.

This chapter summons the status and perspectives of ultrasonography and airway management in the hands of the anesthesiologist, [2, 3] supplemented with practical guides to implementing specific techniques.

Airway Ultrasonography

Equipment

Airway ultrasonography can be performed with a standard laptop sized US-machine. A standard high frequency probe, like the one most often used for regional anesthesia and vascular access, will be sufficient for most airway sonography. For evaluation of the prandial status, a convex ("abdominal") probe will be more suitable and for examination between two ribs, a micro-convex probe is very convenient (Fig. 16.1).

Airway Anatomy: What Can We Depict with Ultrasound?

Ultrasound does not penetrate air, so which structures relevant for airway management can it help clinicians to visualize? When the US beam reaches air, a strong echo, in the form of a bright white line will appear. This line delineates the border between tissue and air; everything beyond it is artifact (Fig. 16.2). The result is that

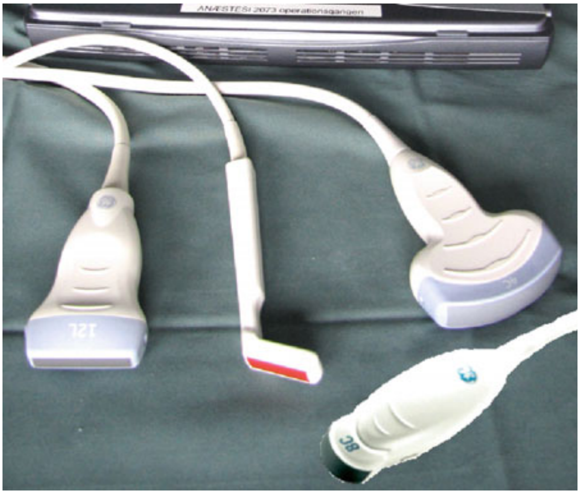

Fig. 16.1 Ultrasound transducers useful in airway management. *Left* Linear 7–12 MHz high-frequency transducer. Second from *left* Small linear 6–10 MHz high frequency “hockey stick” transducer. *Upper right* Curved, Convex 2–6 MHz low frequency transducer. Foreground, insert, micro convex 4–10 MHz transducer

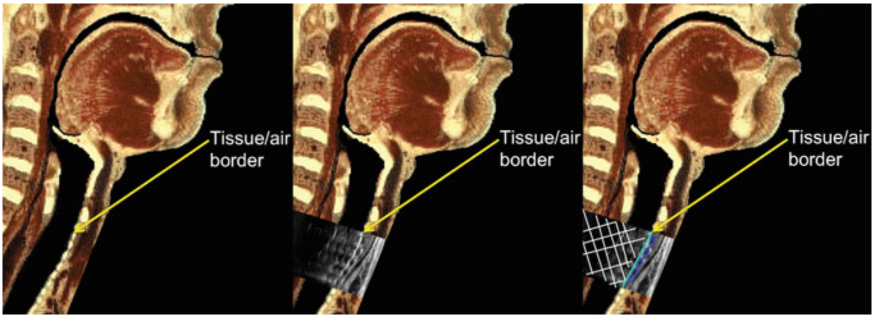

Fig. 16.2 The tissue/air border. *Left* A cadaveric slice of the upper airway. The arrow indicates the tissue/air border. *Middle* The ultrasonographic image. *Right* Explanation of the ultrasonographic image. *Blue rings* indicate the anterior part of the tracheal rings; the *green line* is the tissue/air border between the mucosal lining of the anterior trachea and air. The image area covered by the *white grid* is entirely made up of artifacts

tissue appears distinct from skin until the anterior part of the airway, as for example the posterior surface of the tongue, the mucosal lining of the anterior trachea, and the pleura. Intraluminal air will thus prevent visualization of structures such as the posterior pharynx, posterior commissure, and posterior wall of the trachea. Different tissues have different acoustic impedance and sound reflection occurs at interfaces between different types of tissues. Impedance differs most when soft tissue is next to bone or air. Some tissues, such as fat and bone, for example, produce a strong echo; these structures are called *hyperechoic* and appear white on US. Other tissues—fluid collections or blood in vessels—have little resistance to

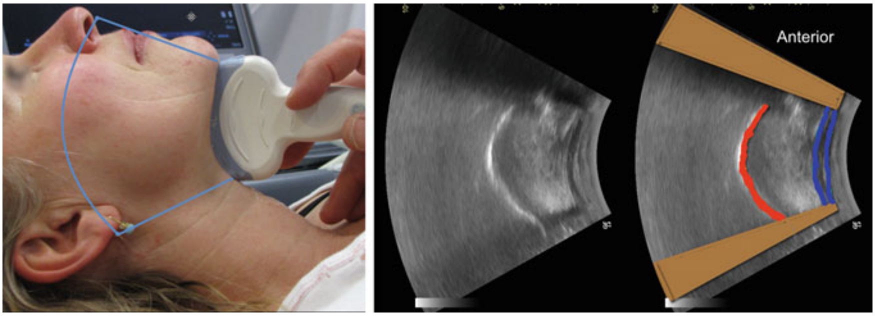

Fig. 16.3 From the tip of the tongue to the hyoid bone. *Left* The light *blue* marking indicates the scanning area. *Middle* Ultrasonographic image. *Right Brown* indicates the shadow from the mandible anteriorly and from the hyoid bone posteriorly; the *red line* indicates the surface of the tongue; *blue* is base of the floor of the mouth

the US beam and thus generate little echo; they are called *hypoechoic* and appear black on the screen.

When the US beam reaches the surface of a bone, a strong echo appears and absorption of US energy results in the depiction on the screen of bony tissue of limited depth. Acoustic shadowing obscures nearly everything beyond the bone. Cartilaginous structures, such as the thyroid, the cricoid, and the trachea, appear homogeneously hypoechoic but tend to calcify with age. Muscles and connective tissue membranes are hypoechoic but appear more heterogeneously striated than cartilage. Glandular structures such as the submandibular and thyroid glands are homogeneous and mildly to strongly hyperechoic compared to nearby soft tissues [2]. We have previously described, in easy-to-follow steps, how to visualize the airway from the tip of the chin until the mid-trachea with ultrasonography [2]. Table one lists airway structures of special interest that can be visualized on US (Figs. 16.2, 16.3, 16.4, 16.5, and 16.6). Because of the superficial location of the larynx, US offers images of higher resolution then computed tomography (CT) or magnetic resonance imaging [4].

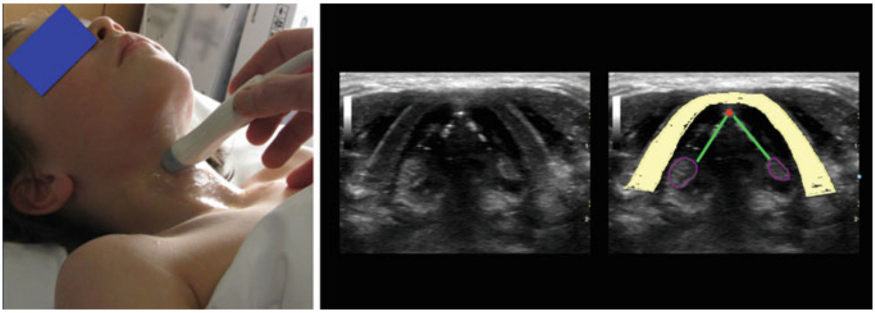

Fig. 16.4 Larynx with vocal cords. *Left* The linear transducer is placed transversely over the thyroid cartilage at the level of the vocal cords. *Middle* The ultrasound image. *Right* thyroid cartilage (*light yellow*); the free edge of the vocal cords (*green*); the anterior commisure (*red dot*); the arytenoid cartilages (*purple*)

Studies comparing different modes of depiction of the airway have found a good concordance between ultrasonography and CT, and between ultrasonography and direct cadaveric dissection [5] (see Table 16.1).

Table 16.1 Important Airway Structures Visible on Ultrasound [3–10]

Mouth
Tongue
Oropharynx
Hypopharynx
Hyoid bone
Epiglottis
Larynx
Vocal cords
Cricothyroid membrane
Cricoid cartilage
Trachea
Esophagus
Stomach
Lungs
Pleura

Clinical Applications

Table 16.2 lists the major clinical applications for airway ultrasonography. Below the table we have described 3 particularly useful applications in more detail: Localization of the cricothyroid membrane, distinction between tracheal and esophageal intubation and diagnosis of pneumothorax.

Guide to Clinical, Hands-On, Use of Ultrasound for Specific Selected Airway Scenarios

Identification of the Cricothyroid Membrane Before Management of the Difficult Airway

In all airway algorithms, the final solution if everything else fails is always oxygenation through the cricothyroid membrane (CM), either as a small-bore jet-insufflation catheter, a larger-bore needle technique, or as a surgical emergency cricothyroidotomy. Localization of the CM often is difficult or impossible, and even when anesthesiologists think that they have found it, they may be mistaken. As a result, emergency oxygenation through the CM has a disappointingly low rate of success.

Fig. 16.5 Trachea and esophagus. The transducer is placed transversely over trachea just cranially to the suprasternal notch. The *purple lines* indicate the anterior part of the tracheal cartilage behind which artifacts are seen (turquoise). Esophagus is visible posteriorly and laterally to the trachea as a multilayered structure (various *orange colors*). *Red* is the lumen of the common carotid artery

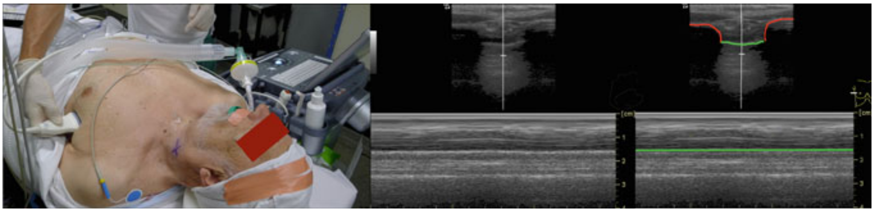

Fig. 16.6 Lung sliding. *Left* The ultrasound probe is placed transversely in an inter-space between two ribs during normal ventilation. *Middle* The scanning image, *upper* B-mode scan, *lower* M-(Motion-)-mode. *Right* The *green line* indicates the *pleural line*. The *red lines* indicate the anterior surface of 2 ribs behind which shadowing is seen. Note that the outline of the ribs and the pleural line forms the image of a flying bat = the "bat sign" demonstrating that 2 ribs are involved which is necessary in order to identify the pleural line among the many *white lines*. Note that in the M-mode image it is easy to distinguish the non-moving tissue above the *pleural line* from the artifact created from the respiratory movement of the visceral pleura relative to the parietal pleura. This is called the "sea shore sign" or the "sandy beach sign" because the non-moving part resembles waves and the artifact pattern below resembles a sandy beach

It therefore is warranted for all patients that the anesthesiologist must ensure that he or she can identify the CM before proceeding with the delivery of anesthesia. In patients with slim necks and no history of radiation or pathology, inspection alone or inspection combined with palpation may be sufficient. However, for patients whose CM is not easily visible or palpable, ultrasonography is an ideal method of locating the membrane (Fig. 16.7). Once located, the clinician should mark the CM with a pen so that it is easy to access in the rare event that the subsequent airway management results in the need for oxygenation via that route.

Table 16.2 Major clinical applications of airway ultrasonography

Clinical applications of airway ultrasonography	Comment
Screening/Prediction of difficult airway management [6]	Only demonstrated to be useful in smaller series in obese patients
Diagnosing pathology that can affect airway management [7]	For example tumors in the neck, tongue, vallecula, pharynx or larynx or a Zenker diverticulum that can represent an increased risk of aspiration [8]
Identification of the cricothyroid membrane [3]	Should be performed prior to management of a difficult airway, in case that identification by palpation is not straightforward. Allows preparation for emergency cricothyrodotomy, oxygen insufflation, distribution of local anesthetics or retrograde intubation
Measuring gastric content prior to airway management [9]	Best performed in the right lateral decubitus position
Airway related nerve blocks [10]	
Prediction of the appropriate diameter of endotracheal, [11] endobronchial, or tracheostomy tubes	
Differentiating between tracheal and esophageal intubation [12]	Allows detection of esophageal intubation before ventilation is initiated and works when there is no circulation (e.g., cardiac arrest), as opposed to CO_2-detection
Differentiating between tracheal and endobronchial intubation	Useful in noisy environments where a stethoscope is useless
Confirmation of gastric tube placement [13]	
Diagnosis of pneumothorax [14]	By far, the fastest way to rule out a suspicion of intraoperative pneumothorax
Differentiating between different causes of dyspnea/hypoxia and pulmonary oedema [15]	Diagnosing pulmonary edema and allowing differentiation between different types of lung and pleura pathology
Prediction of successful weaning from ventilator treatment [16]	Obtained by measuring whether the respiratory forces of the patients, and/or the width of the airway, are large enough to allow extubation of the trachea
Localization of trachea and tracheal ring interspaces for tracheostomy and percutaneous dilatational tracheostomy [17, 18]	

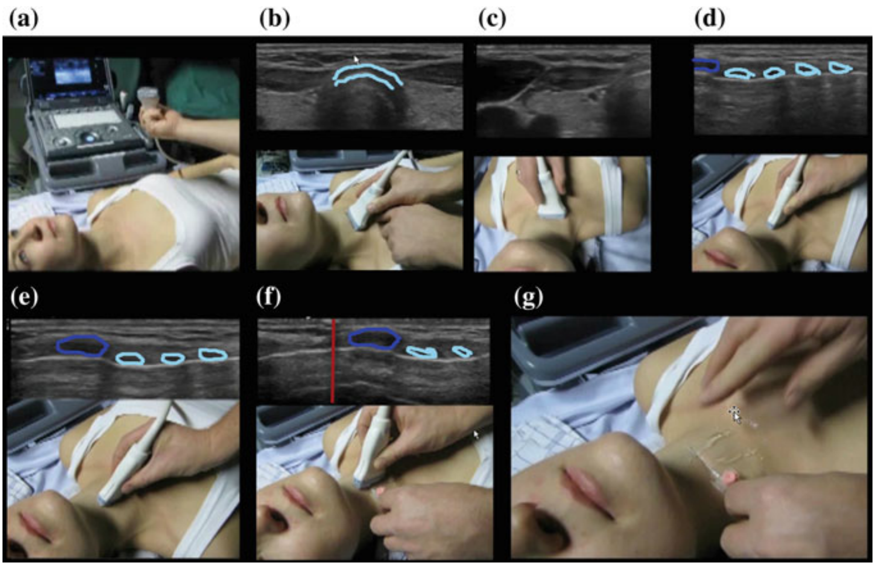

Fig. 16.7 Identification of the cricothyroid membrane. *Light blue* is the anterior part of tracheal rings. *Dark blue* is the anterior part of the cricoid cartilage. The *red line* is the shadow from the needle that has been slid underneath the transducer and placed just cranial to the cricoids cartilage, thus indicating the position of the lower part of the cricothyroid membrane, where an emergency airway access should be performed

The CM can be identified by following these seven steps (Fig. 16.7):

Step 1. Stand on the patient's right side and palpate the sternal bone. The sternal bone can be located even in extremely obese patients and in the vast majority of patients with pathology or post-radiation changes that make direct identification of tracheal and laryngeal structures impossible.

Step 2. From the sternal bone move fingers cranially and locate the suprasternal notch.

Step 3. Place the linear US transducer transversely on the neck just cranially to the sternal notch and watch for the trachea to appear on the screen (Fig. 16.7b).

Step 4. Slide the transducer laterally towards the patient's right side, until the midline of the trachea is at the right border of the ultrasound image/the transducer (Fig. 16.7c).

Step 5. Keep the right border of the transducer over the midline of the trachea and rotate the left edge of the transducer into the sagittal plane to obtain a longitudinal image of the trachea. Adjusting the transducer position with subtle movements from side to side can optimize the image so that "pearls on a string" appear; the pearls represent the cartilages of the anterior part of the tracheal rings (Fig. 16.7d).

Step 6. If the neck is long the transducer must be slid cranially, staying in the midline, until a more prominent and anterior "pearl" comes into sight.

This landmark is the cricoid cartilage. Immediately cranial to the cricoid cartilage is the distal part of the CM (Fig. 16.7e).

Step 7. The CM can be identified by sliding a needle underneath the transducer (avoid hitting the patient with the tip of the needle) until it creates a shadow just cranially to the shadow from the cricoid cartilage (Fig. 16.7f). The transducer now can be removed and the needle indicates the position of the CM. This spot can be marked with a pen so that it is easily located in case it must be used during subsequent management of the difficult airway (Fig. 16.7g).

Detection of Whether the Tube Is Entering the Trachea or the Esophagus

The tracheal tube entering the trachea or the esophagus can be confirmed by direct performance of real time scans of the anterior neck during intubation, by indirectly looking for ventilation at the pleural or diaphragmatic level or by combining these techniques. Accidental esophageal intubation can be recognized immediately when US scans are done real-time, and corrected before ventilation is initiated and before air is forced into the stomach resulting in an increased risk of emesis and aspiration. When looking for ventilation at the pleural level it has the advantage of distinguishing between tracheal and endobronchial intubation, at least to some extent. Both the direct and the indirect confirmation have advantages over capnography as they can be applied in the very-low-cardiac-output-situation. Ultrasonography is also better than auscultation in noisy environments, such as helicopter retrievals. In a cadaver model where a 7.5 MHz curved probe was placed longitudinally over the cricothyroid membrane it was possible for residents given only 5 min of training in the technique to correctly identify esophageal intubation (97 % sensitivity) when this was performed *during* the intubation, dynamically. When the examination was performed *after* the intubation the sensitivity was very poor [19].

Accidental esophageal intubations were detected in all five incidents among 40 elective patients when a 3–5 MHz curved transducer was placed at the level of the cricothyroid membrane aimed cranially at 45°. Tracheal passage of the tube was seen as a brief flutter deep to the thyroid cartilage whereas esophageal intubation created a clearly visible bright (hyperechoic) curved line with a distal dark area (shadowing) appearing on one side of, and deep to, the trachea [20].

By placing a linear probe transversely on the neck just superior to the suprasternal notch, it was possible to differentiate tracheal from esophageal intubations in 33 patients with normal airways, and in another 150 patients intubated either in the trachea or in the esophagus in random order [21]. In a controlled operating room setting, skilled ultrasonographers have been able to consistently detect passage of a tracheal tube into either the trachea or esophagus in normal airways [22].

Using a portable hand-held ultrasound machine, indirect confirmation of tracheal tube placement in 15 patients was possible by scanning the third and fourth intercostal spaces bilaterally during pre-oxygenation, apnea, bag-mask ventilation, intubation and positive pressure ventilation post-intubation [23]. Furthermore, colour Doppler can be used as a supplement to observe lung sliding, confirming lung ventilation [23].

The distinction between tracheal and endobronchial intubation can to some extend be made by scanning the lung bilaterally. If the there is lung sliding on one side and lung pulse (see section on pneumothorax) on the other side it indicates that the tip of the tube is in the main stem bronchus on the side where lung sliding is observed. The tube should be withdrawn until lung sliding is observed bilaterally, indicating that the tip of the tube is again placed in the trachea [24]. Indirect confirmation of intubation by detection of lung sliding was studied in fresh cadavers where the tip of the tube was placed either in the esophagus, trachea or right main-stem bronchus. A high sensitivity (95–100 %) was found for detection of esophageal versus airway (trachea or right men stem bronchus) intubation. There was lower sensitivity (69–78 %) in distinguishing right main stem bronchus intubation from tracheal intubation, possibly due to transmitted movement of the left lung from right lung expansion [25].

Indirect confirmation of tracheal versus oesophageal intubation can be obtained by depicting diaphragmmatic movement bilaterally in pediatric patients [26]. However, when the technique is used to distinguish between main- stem bronchus versus tracheal intubation, chest radiography is better than diaphragmatic ultrasound [27]. The *combination* of direct transverse neck scan at the cricothyroid membrane and detection of lung sliding on lung ultrasound correctly detected cases of esophageal intubation despite inclusion of cases with pneumohemothorax in emergency department patients [28], and in patients with difficult laryngoscopy in the clinical emergency setting [29]. Filling the tracheal cuff with fluid helps in visualizing cuff position, [30] but a metal stylet does not augment visualization of the endotracheal tube [31]. Passing of the tracheal tube is visible in all children and characterized by the widening of the vocal cords when the transducer is placed at the level of the glottis [32]. Ultrasonography is also useful in confirming the correct position of a double-lumen tube [33, 34].

Authors Recommendations

By performing a transverse scan above the sternal notch over the trachea, the location and appearance of the esophagus can be noted. Intubation should then be performed. If the tube is seen passing into the esophagus, remove it without ventilating the patient and make another intubation attempt, possibly using another technique. If the tube is not seen, or if it is seen in the trachea: ventilate the patient via the tube. Move the transducer to the midaxillary line, and look for lung sliding bilaterally. If there is bilateral lung sliding, it is confirmation that the tube is in the airway, but intubation of a mainstem bronchus cannot be ruled out. If there is one sided lung sliding and lung pulse on the other side, then mainstem intubation is likely, and the tube should be withdrawn gradually until bilateral lung sliding is present. If there is no lung sliding on either side, but lung pulse, there is a small risk of the tube having entered the esophagus. If there is neither lung pulse nor lung sliding, then a pneumothorax should be expected. In experienced practitioners verification of endotracheal tube placement is as fast as auscultation alone and faster than the standard method of combined auscultation and capnography [12, 35].

Diagnosis of Pneumothorax

Ultrasonography is an obvious first choice for diagnosis in cases of suspected intraoperative pneumothorax, or if a pneumothorax is suspected during or after central venous cannulation or nerve blockade. It is particularly helpful if US is already in use for the procedure itself and therefore is immediately available. Lung ultrasonography is better than chest x-ray for ruling out pneumothorax; [36] it has a sensitivity of 91 % and specificity of 98 % in diagnosing pneumothoraces in supine patients, whereas chest radiography has a sensitivity of 50.2 % and a specificity of 99.4 % [14].

The presence of lung sliding (Fig. 16.6) or lung pulse (Fig. 16.8) on ultrasonographic examination indicates that at the position under the transducer, the 2 pleural layers are in direct contact with each other—in other words, no pneumothorax exists in that location. Free air in the part of the pleural cavity beneath the transducer will prevent lung sliding or lung pulse from being seen. In the M-mode, the "stratosphere sign"—parallel lines throughout the entire depth of the image—will appear.

If the transducer is placed at the border of the pneumothorax where the visceral pleura intermittently is in contact with the parietal pleura, the "lung point" will be evident. The lung point appears as a sliding lung alternating with the stratosphere sign synchronous with ventilation. The lung point is pathognomonic for pneumothorax. The clinician can systematically "map" the rib interspaces of the thoracic

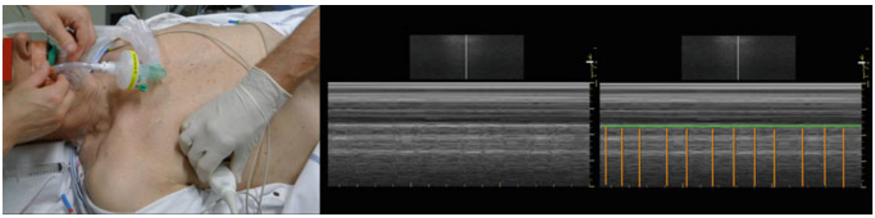

Fig. 16.8 Lung Pulse. *Left* The ultrasound probe is placed transversely in an inter-space between two ribs during normal ventilation. *Middle* The scanning image, *upper* B-mode scan, *lower* M-(Motion-)mode. *Right* In the non-ventilated, but inflated, lung the heart will make the two pleural layers (*green*) move a bit with every heartbeat, creating the artifact known as "lung pulse" (*orange*)

cavity and confirm or rule out a pneumothorax. The lung point is best seen on real-time ultrasonography (http://www.airwaymanagement.dk/ultrasonography-in-airway-management). A systematic approach is recommended when examining the supine patient. The anterior chest wall can be divided in quadrants; the probe is first placed at the most superior aspect of the thorax with respect to gravity—in other words, the caudal part of the anterior chest wall when the patient is supine. The probe is positioned on each of the 4 quadrants of the anterior area followed by the lateral chest wall between the anterior and posterior axillary lines and the rest of the accessible part of the thorax [37].

How to Gain Proficiency in Ultrasonography for Airway Management

The following studies give an insight into what requirements, and how little, it takes to learn basic airway US. After 8.5 h of focused training (2.5 h didactic course covering essential views of normal and pathologic conditions; and three hands-on sessions of 2 h duration) physicians without previous knowledge of US could competently perform basic general ultrasonic examinations [38]. The examinations were aimed at diagnosing the presence of pleural effusion, intra-abdominal effusion, acute cholecystitis, intrahepatic biliary duct dilation, obstructive uropathy, chronic renal disease, and deep venous thrombosis. For questions with a potential therapeutic impact, the physicians answered 95 % of the questions correctly [38]. The acquisition of sonographic skills to make a correct diagnosis is more task specific, meaning, the basic skill required to detect a pleural effusion may be acquired in minutes and may then improve with experience [39].

After reading this chapter and supplementing with one of the more complete reviews [2, 3] the reader is ready to start practicing. We suggest that you, every time you've used ultrasound for central venous access or for upper extremity/ truncal regional anesthesia, should also slide the US transducer over the thoracic wall looking for lung sliding and practice localizing each tracheal ring and the cricothyroid membrane. Thereafter you can practice the other applications.

At a point in time you'll appreciate supervision:

The authors can arrange and conduct lectures and hands-on workshops in ultrasonography in airway management by appointment (contact info: Michael.seltz.kristensen@regionh.dk and teohwendy@yahoo.com). Hands-on courses are available at the American Society of Anesthesiologists (ASA) annual scientific meeting (next course October 11-15 in New Orleans, USA), at the ESA (European Society of Anaesthesiologists) annual pre-congress airway course (next course Berlin, Germany 30 May-2 June 2015) and at the Scandinavian not-for-profit-course" Airway management for anaesthesiologists" (www.airwaymanagement.dk) held yearly in Copenhagen, late November/early December, next course Dec 4-5,2014.

Internet resources: Some airway ultrasonography videos are available, and more will come, at our not-for-profit website: http://www.airwaymanagement.dk/ultrasonography-in-airway-management.

Conclusion

By using ultrasonography before, during and after anesthesia induction and when suspicion of a pneumothorax arises, the anesthesiologist can locate a variety of anatomical structures and diagnose clinical conditions highly relevant to safe management of the airway of our patients. In this chapter we give an overview of these techniques, a specific guidance for locating the cricothyroid membrane, for distinguishing between tracheal and esophageal intubation and for diagnosing intraoperative pneumothorax. Furthermore we advise about how to get clinical experience with these techniques.

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