Difficult Mask Ventilation: What Needs Improvement?

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In their review, El-Orbany and Woehlck[1] shed light on the problem of difficult mask ventilation (DMV). They raise concerns about definitions and highlight the pathophysiology, incidence, and prediction of this rather neglected aspect of airway management. Their review analyzes the relationship between DMV and difficult intubation and outlines corrective measures and management options.

We concur with the authors that clear and meaningful definitions are needed for DMV as well as other aspects of airway management. There is no consensus on an exact definition of the sniffing, neutral, and simple extension positions. In general, the sniffing position implies extension at the atlantooccipital joint and flexion at the cervical spine, but it is not clear how high from horizontal the head should be elevated for the sniffing position. Should the head elevation be greater in tall-necked than in short-necked subjects? Because no strict definitions exist, research papers cannot be interpreted or compared fairly.[1–3]

In the algorithm proposed by El-Orbany and Woehlck[1] (and in the American Society of Anesthesiologists difficult airway algorithm), reference to 2-person mask ventilation is emphasized. Benumof[4] defined the optimal attempt at mask ventilation as a 2-person method with appropriately sized oro- or nasopharyngeal airways. Unfortunately, when unanticipated DMV is encountered, a second anesthesiologist is not always available.[5] Rather than relying on another colleague to compress the reservoir bag, the anesthesiologist can use both hands to obtain appropriate mask seal, while the ventilator can be used to deliver the desired tidal volume.[5] The lone anesthesiologist then uses both hands to advance the mandible, and the head straps are used to further improve the mask seal. Neither the 1-person, 2-handed mask ventilation, nor the use of the ventilator to deliver tidal volume is new. In 1959, Safar et al.[6] validated the usefulness of a 2-handed jaw thrust method for reversing pharyngeal obstruction. Ventilators have been utilized in studying the efficacy of mask ventilation in children[7] and in the management of DMV in adults.[8] Alternatives to the use of the ventilator include compressing the reservoir bag between the knees, under the axilla, or even under the foot,[5] while using both hands to maintain an adequate airway. These maneuvers, however, require that the reservoir bag be connected to a long corrugated hose, instead of being mounted on the anesthesia machine.[5]

The upper airway can be obstructed by soft tissue at the pharyngeal or laryngeal level, and by laryngospasm induced by opioids and anesthetics, or occurring after tracheal extubation. In patients with obstructive sleep apnea (OSA), anatomical imbalance between the upper airway soft tissue volume and craniofacial size is partially corrected for by the contraction of the pharyngeal airway dilating muscles during wakefulness.[9] When patients are unconscious, the neuromuscular control of the upper airway muscles becomes diminished or lost.[9] The tongue and structures attached to the hyoid bone gravitate toward the posterior pharyngeal wall, causing various degrees of airway obstruction. Maximum mandibular advancement with mouth opening (with the use of oro- or nasopharyngeal airways) and assumption of the sniffing position can be effective in opening the airway[8–10] by stretching the genioglossus muscle and pulling

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the tongue away from the posterior pharyngeal wall. Head-up or reverse Trendelenburg position also reduces the gravitational impact of the excessive soft tissue on pharyngeal patency.[8] When these maneuvers fail, occlusion of the glottis by supra-epiglottic cysts, base of the tongue tumors, or hypertrophy of lingual tonsils should be suspected.[11]

Understanding the mechanics of laryngospasm is crucial to proper treatment. Fink[12] described 2 types of laryngeal closure: the glottic shutter, controlled by the intrinsic laryngeal muscles, and the ball-valve closure, controlled by the extrinsic and intrinsic laryngeal muscles. The glottic shutter is caused by approximation of the vocal cords because of the loss of the tone of the abductor muscles. Glottic constriction is analogous to constriction of a Venturi tube. Because the velocity is greatest where the passage is narrowest, airway pressure is lowest at the subglottic area and becomes less than atmospheric during inspiration (Bernoulli effect). During spontaneous inspiratory efforts, passage of gases through the glottis generates a force that tends to draw the vocal cords together. Normally, this force is opposed by the tone of the abductor muscles.[12] During anesthesia, the tone is lost and the Bernoulli effect becomes pronounced, resulting in inspiratory stridor. Positive airway pressure neutralizes the Bernoulli effect and abolishes the stridor.[13]

In the ball-valve closure, the vocal cords are adducted, swiftly followed by adduction of the false cords.[12] In addition, the extrinsic laryngeal muscles come into play, shortening the thyrohyoid distance and completely closing the larynx. Applying positive airway pressure may worsen ball-valve closure. Inflation of the pharynx distends the piriform fossae, pressing the aryepiglottic folds more firmly against each other and reinforcing the closure.[12] In contrast, the jaw thrust maneuver is effective in correcting ball-valve closure. The forward mandibular movement is transmitted through the geniohyoid muscles to the hyoid bone and the hyoepiglottic ligament. The epiglottis is pulled away from the false cords and the laryngeal passage is reopened.[12] In some cases, it may be necessary to administer a small dose of succinylcholine to break this type of obstruction.[14]

The corrective measures outlined in the review apply only to common causes of upper airway obstruction. The reader is referred to other sources for the management of lower airway obstruction. Obviously, the safest approach is to plan for awake fiberoptic intubation in patients with expected difficult or impossible facemask ventilation.[15,16] Other interim measures in the management of expected or unexpected DMV clearly depend on etiology. Maximal mandibular advancement can be effective for pharyngeal soft tissue obstruction (OSA/obesity)[8–10] or laryngeal obstruction by ball-valve closure.[12] Muscle relaxation can be a lifesaving measure in severe ball-valve closure or opioid-induced vocal cord spasm. Supraglottic devices can be effective in overcoming pharyngeal soft tissue obstruction[16] but are not effective in the treatment of laryngospasm or lower airway obstruction.

It is entrenched in the mind of many anesthesiologists that lung ventilation must be established after induction of anesthesia and before administration of a neuromuscular blocking drug (NMBD)[17]; the exception is the patient undergoing rapid sequence induction. However, in a survey assessing this practice, 30% of the respondents always checked mask ventilation before the administration of an NMBD, 39% never checked, and 31% did so in the case of a known or anticipated difficulty with the airway.[18] The basis for such a practice is that if mask ventilation becomes impossible after induction, unparalyzed patients can be awakened for application of an alternative technique, typically awake fiberoptic-aided intubation. However, this practice is not supported by evidence.[17] First, even if an NMBD is withheld, awakening patients with obstructed airways may not be feasible, and urgent restoration of the airway becomes necessary before hypoxemia supervenes. Second, studies do not show that awakening the patient under these circumstances is what happens in real-life situations.[19,20] In a report of 22,660 facemask ventilation attempts, DMV and impossible mask ventilation occurred in 313 (1.4%) and 37 (0.16%), respectively, but no patient was awakened.[19] Furthermore, all 37 patients with impossible mask ventilation had been given an NMBD to aid tracheal intubation.[19] Third, a suspicion that a patient with a questionable airway may need to be awakened for tracheal intubation may lead to underdosing of induction drugs, which could itself result in DMV.[17] Lastly, there is convincing evidence that an NMBD makes intubation easier,[17,21] although 1 study showed that neuromuscular blockade does not affect the efficiency of mask ventilation in patients with normal airways.[18] In patients whose lungs are difficult to ventilate via a facemask, ventilation becomes easier with neuromuscular blockade, which may be attributed to the onset of muscle relaxation. Reluctance to give an NMBD in these situations is more likely to result in DMV, compounding the difficulties that arise from a low-dose induction drug.[17]

Anesthesiologists have a variety of airway management devices from which to choose. The use of the laryngeal mask airway and other extraglottic devices should be encouraged when facemask ventilation is difficult. The laryngeal mask airway can be used as a substitute airway, as an aid to tracheal intubation, and as a bridge for smooth extubation of patients with a difficult airway.[22] Two devices, 1 old and 1 new, may function to improve DMV. The binasopharyngeal airway system incorporates 2 nasopharyngeal airways attached to an adapter, which can be connected to the Y-piece of the breathing circuit.[23] The lubricated airways are introduced through each nostril, and the

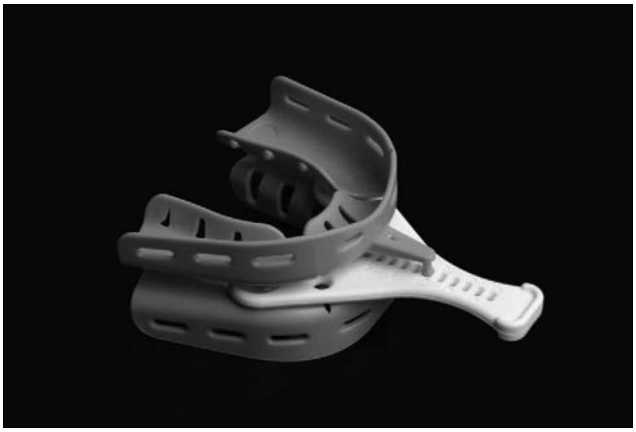

Figure 1. The intraoral appliance (EMA-T) used to advance the mandible. It consists of plastic trays for the upper and lower dental arches. When the appliance is in place, the mandible is manually advanced by securing a peg in the projection from the upper airway tray into 1 of the holes in the projection from the lower tray. (Reproduced from Kuna et al.[24])

distal end is situated just under the tip of the epiglottis. The advantage of the system is the use of 2 nasopharyngeal airways instead of 1, eliminating the need for the facemask by attaching the system directly to the breathing circuit. Such a system can be used early during induction and also after tracheal extubation to overcome naso- and oropharyngeal obstructions.[23] An intraoral appliance that is used to advance the mandible has recently become available (Fig. 1). Such appliances may become useful in maintaining pharyngeal patency in anesthetized patients with OSA.[24]

It is imperative that anesthesiologists master the science and art of mask ventilation. Even simple maneuvers, such as maximizing oxygenation before anesthetic induction, 1-person, 2-handed mask ventilation, prevention of gastric inflation during mask ventilation, and packing the inside of the mouth with gauze to achieve a tight-fitting mask in edentulous patients should be practiced to perfection. Familiarity with various devices including the binasopharyngeal airway system and appliances used to maximize mandibular advancement is highly desirable. Future research should be directed toward the development of algorithms for the management of specific situations and identifying conditions in which preservation of spontaneous ventilation or establishing lung ventilation before the administration of an NMBD is beneficial. Finally, clear meaningful definitions and nomenclature must be developed for all aspects of airway management.

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Difficult Mask Ventilation

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Mask ventilation is the most fundamental skill in airway management. In this review, we summarize the current knowledge about difficult mask ventilation (DMV) situations. Various definitions for DMV have been used in the literature. The lack of a precise standard definition creates a problem for studies on DMV and causes confusion in data communication and comparisons. DMV develops because of multiple factors that are technique related and/or airway related. Frequently, the pathogenesis involves a combination of these factors interacting to cause the final clinical picture. The reported incidence of DMV varies widely (from 0.08% to 15%) depending on the criteria used for its definition. Obesity, age older than 55 yr, history of snoring, lack of teeth, the presence of a beard, Mallampati Class III or IV, and abnormal mandibular protrusion test are all independent predictors of DMV. These signs should, therefore, be recognized and documented during the preoperative evaluation. DMV can be even more challenging in infants and children, because they develop hypoxemia much faster than adults. Finally, difficult tracheal intubation is more frequent in patients who experience DMV, and thus, clinicians should be familiar with the corrective measures and management options when faced with a challenging, difficult, or impossible mask ventilation situation.

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Mask ventilation (MV) is the most basic, yet the most essential, skill in airway management. It is the primary technique of ventilation before tracheal intubation or insertion of any airway device. Its most unique role, however, is as a rescue technique for ventilation should tracheal intubation fail or prove difficult. The ability to establish adequate MV has, therefore, become a major branch point in any difficult airway algorithm.[1,2] Anesthesiologists should acquire the skill of MV, the knowledge of the causes of difficult MV (DMV) or impossible MV (IMV), and develop alternative management options when the MV technique is difficult or impossible. It is surprising that, despite its lifesaving role, MV has received little attention in the extensive body of literature and book chapters addressing airway management.

This review is intended to shed some light into the problem of DMV. It discusses the current knowledge base and controversy regarding its definition, pathophysiology, incidence, and prediction. It also analyzes the relationship between DMV and difficult intubation (DI) and outlines some basic corrective measures and management options.

A full discussion of all aspects of face mask ventilation is, however, beyond the scope of this limited review. Only issues pertinent to DMV will be covered. Other important issues have been elegantly reviewed elsewhere.[3]

DEFINITION OF DMV

At present, there is no standard definition for DMV that is based on precise and objective criteria. The current lack of an objective definition creates problems when clinicians attempt to communicate clinical information. It also complicates data interpretation and comparisons when investigators want to study the subject. Conversely, the subjective and operator-dependent nature of the ability to perform MV may render establishing such a precise and objective definition an unreachable goal.

In its original report in 1993, the American Society of Anesthesiologists (ASA) Task Force on Management of the Difficult Airway suggested the following definition: "DMV is a situation that develops when it is not possible for the unassisted anesthesiologist to maintain the oxygen saturation >90% using 100% oxygen and positive pressure ventilation, or to prevent or reverse signs of inadequate ventilation."[4] Because this definition is vague, the Task Force urged clinicians and investigators to use explicit descriptions of difficult airway situations and expressed its desire to develop descriptions that can be categorized or expressed in numerical values. Because inadequate ventilation should not be defined purely in terms of oxygenation, the definition was modified in the Task

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Table 1. Definitions Used in the Literature to Describe Difficult Mask Ventilation (DMV)

Definition of difficult mask ventilation	References
A condition that develops when: 1) It is not possible for the unassisted anesthesiologist to maintain the Spo_2 <90% using 100% oxygen and positive pressure mask ventilation in a patient whose Spo_2 was <90% before anesthetic intervention; 2) It is not possible for the unassisted anesthesiologist to prevent or reverse signs of inadequate ventilation during positive pressure mask ventilation signs of inadequate mask ventilation include (but are not limited to): cyanosis, absence of exhaled CO_2, absence of spirometric measures of exhaled gas flow, absence of breath sounds, absence of chest movement, auscultatory signs of severe airway obstruction, gastric air entry or dilatation, and hemodynamic changes associated with hypoxemia or hypercarbia (e.g., hypertension, tachycardia, arrhythmia).	ASA Task Force[4]
Mask ventilation is considered difficult when there is 1) Inability for the unassisted anesthesiologist to maintain oxygen saturation >92% using 100% oxygen and positive pressure ventilation, 2) Important gas flow leak by the face mask, 3) necessity to increase the gas flow to greater than 15 L/min and to use the oxygen flush valve more than twice, 4) no perceptible chest movement, 5) necessity to perform two-handed MV, and 6) Change of operator required.	Langeron et al.[42]
A condition that develops when: 1) It is not possible for the anesthesiologist to provide adequate face mask ventilation because of one or more of the following problems: inadequate mask seal, excessive gas leak, or excessive resistance to the ingress or egress of gas. 2) Signs of inadequate face mask ventilation include (but are not limited to) absent or inadequate chest movement, absent or inadequate breath sounds, auscultatory signs of severe obstruction, cyanosis, gastric air entry or dilatation, decreasing or inadequate oxygen saturation (Spo_2), absent or inadequate exhaled carbon dioxide, absent or inadequate spirometric measures of exhaled gas flow, and hemodynamic changes associated with hypoxemia or hypercarbia.	ASA Task Force[1]
Difficult mask ventilation develops when there are signs of inadequate ventilation evidenced by no perceptible chest movement, oxygen desaturation, and perception of severe gas flow leak around the mask. The authors classified the degree of difficulty based on the maneuvers used to establish adequate ventilation.	Yildez et al.[43]
Difficult mask ventilation was defined as mask ventilation that is inadequate to maintain oxygenation, unstable MV, or MV requiring two providers. Impossible mask ventilation is denoted by absence of end-tidal carbon dioxide measurement and lack of perceptible chest wall movement during positive pressure ventilation attempts despite airway adjuvants and additional personnel.	Kheterpal et al.[44]

Force's updated report that was published in 2003. In that report, DMV was defined as "the clinical situation that develops when it is not possible for the anesthesiologist to provide adequate MV due to one or more of the following problems: inadequate mask seal, excessive gas leak, or excessive resistance to the ingress or egress of gas."[1] The signs used to indicate inadequate ventilation were mentioned in both reports and are listed in Table 1. Several other definitions for DMV had also been suggested and used by various groups of investigators (Table 1).

The Task Force's definition, in its present language, lists the general mechanisms underlying a DMV situation. The clinical situation of DMV, however, constitutes a continuum, one end of which is "easy" MV and the other is IMV.

A definition that uses objective criteria to precisely describe the different stages of the continuum is obviously needed. Such a definition may help to standardize the language when describing a specific clinical situation along the continuum and when communicating airway information.[5]

Pursuing this goal, Adnet[6] encouraged the development of a numerical scale to replace the general subjective definition. In 2004, Han et al.[7] proposed a grading scale for the ability to perform MV similar to that used for grading the laryngeal view during direct laryngoscopy. Han's scale included four grades in ascending difficulty in which Grade 1 patients are those who can be ventilated easily, and Grade 4 are those who are impossible to ventilate (Table 2).

Table 2. Han's Mask Ventilation Classification and Description Scale

Classification	Description/definition
Grade 0	Ventilation by mask not attempted
Grade 1	Ventilated by mask
Grade 2	Ventilated by mask with oral airway or other adjuvant
Grade 3	Difficult mask ventilation (inadequate, unstable, or requiring two practitioners)
Grade 4	Unable to mask ventilate

For the purpose of risk stratification, the scale helps to segregate two groups of patients. Although Grade 1 and 2 patients usually do not raise significant clinical concern, Grade 3 and 4 patients are likely to be at increased risk of inadequate ventilation after anesthesia induction.

It is important to distinguish between DMV (Grade 3) and IMV (Grade 4) because the former may be resolved by applying certain corrective measures, whereas the latter signifies failure of the corrective measures to establish ventilation. An alternative to face mask ventilation is required at this point or critical hypoxemia may rapidly ensue.

The scale aims at standardizing the language and preventing confusion in data comparisons. It may also trigger some modification in the management plan in a future anesthetic provided that the grade is documented in the anesthetic record.[5]

There are several limitations to Han's scale that should be considered. First, the scale has not yet been validated. It may be useful for clinical description, but may not be reproducible or sensitive enough when used for data comparisons and/or research purposes. Second, similar to grading the laryngeal view, interpretation of DMV grade is partly subjective and operator dependent. However, this should not discourage the scale's future use.[8]

For the sake of standardization, we currently recommend the use of the Task Force's general definition, despite its vagueness and lack of objective criteria. Until a more precise definition is established, we also recommend the use of explicit descriptions and Han's scale when communicating information about a particular DMV situation.

Table 3. Common Causes of Difficult Mask Ventilation

1) Technique-related
   1. Operator: Lack of experience
   2. Equipment: Improper mask size
      Difficult mask fit: e.g., beard, facial anomalies, retrognathia
      Leakage from the circuit
      Faulty valve
      Improper oral/nasal airway size
   3. Position: Suboptimal head and neck position
   4. Incorrectly applied cricoid pressure
   5. Drug related
      a. Opioid-induced vocal cord closure
      b. Succinylcholine-induced masseter rigidity
      c. Inadequate depth of anesthesia
      d. Lack of relaxation?
2) Airway-related
   1. Upper airway obstruction
      a. Tongue or epiglottis
      b. Redundant soft tissue in morbid obesity and sleep apnea patients
      c. Tonsillar hyperplasia
      d. Oral, maxillary, pharyngeal, or laryngeal tumor
      e. Airway edema e.g., repeated intubation attempts, trauma, angioedema
      f. Laryngeal spasm
      g. External compression e.g., large neck masses and neck hematoma
   2. Lower airway obstruction
      a. Severe bronchospasm
      b. Tracheal or bronchial tumor
      c. Anterior mediastinal mass
      d. Stiff lung
      e. Foreign body
      f. Pneumothorax
      g. Bronchopleural fistula
3) Severe chest wall deformity or kyphoscoliosis restricting chest expansion

PATHOPHYSIOLOGY

Inability to establish adequate MV may result from different underlying mechanisms that can be broadly divided into technique and/or airway related (Table 3). Errors in technique, equipment malfunction, suboptimal head position, side effects of certain drugs, and above all, pathological partial or complete airway obstruction may all, separately or combined, lead to DMV.

Unless the underlying mechanism is corrected, there will be a recurring risk of failure of MV. For example, obstructive sleep apnea patients constitute a recurring risk unless the pharyngeal pathology is corrected.[9] On the other hand, although laryngeal spasm due to light anesthesia may result in DMV,[10] adequate anesthesia in a subsequent anesthetic will likely result in easy MV.

The following etiological factors are highlighted in the literature.

Operator-Related Factors

The skill of using the face mask for ventilation is acquired through formal training and retained by regular practice afterward. Unfortunately, in one study, more than 50% of emergency medical technicians were not able to ventilate a mannequin.[11] In another, 84% of emergency room nurses were not able to adequately perform MV.[12] Simple techniques to achieve a tight seal in patients with abnormal anatomy are learned by experience. Others, such as keeping the dentures in edentulous patients or placing an oral airway in patients with small chins are highlighted in textbooks and didactic teaching.[13]

Equipment-Related Factors

Basic equipment needed for MV comprises the face mask and the respiratory bag. Other adjunct airway devices like the oropharyngeal and nasopharyngeal airways (OPAs and NPAs) are sometimes needed for airway patency.

Face Mask

Redfern et al.[14] found that the design of the mask can affect the effectiveness of ventilation. Transparent disposable masks with cushion rims are the ones most commonly used in anesthesia. Regardless of the mask type or design, it is crucial to obtain a tight seal with the face. Leaks may develop due to the inability to obtain a tight seal. This may result from an improperly inflated cushion, improper mask size (too small or too large), presence of a beard, or abnormal facial anatomy. A tight seal is more easily obtained when using masks with high-volume, low-pressure cushions.[15]

Respiratory Bags

Either the self-inflating or the disposable reservoir bag in the anesthesia machine can be used for ventilation. The advantage of self-inflating bags is that they do not need a gas source to operate. However, the feel of compliance and airway resistance is poor when compared with reservoir bags.[3]

Oral and Nasal Airways

Different types and sizes of airways are available, and it is important to choose the correct size. A short airway may not relieve distal soft tissue obstruction and may in fact cause obstruction by pressing on the tongue. An extra long airway may elicit reflex responses like coughing, retching, vomiting, laryngeal spasm, or bronchial spasm especially when inserted at light planes of anesthesia.[15] The lumen of NPAs can be obstructed by dried mucus, clotted blood, or a piece of dislodged tissue.

Head Position

Suboptimal head and neck positioning may lead to DMV.[15] The sniffing position increases the pharyngeal space, which may render MV more efficient.[16,17] Head extension, chin lift, and jaw thrust (the triple maneuver) are important simple techniques to increase pharyngeal patency.

Cricoid Pressure

Improperly applied cricoid pressure may result in airway obstruction and inadequate ventilation.[18] Although MV is not performed during rapid-sequence intubation, oxygen desaturation before tracheal intubation or after failed intubation may, however, necessitate its institution.

Drug-Related Causes

Opioid Induced

High doses of opioids may decrease ventilatory compliance and result in DMV. The main reason for the difficulty was originally thought to be chest wall rigidity.[19] In 1983, however, Scamman[20] noted that patients with tracheostomies experienced only a slight decrease in pulmonary compliance after high-dose fentanyl induction. Abrams et al.[21] reported similar findings in patients who had a tracheal tube placed before high-dose opioid administration. Bennet et al.[22] used a fiberoptic bronchoscope to examine the vocal cords before and after anesthesia induction with 3 μg/kg sufentanil. Vocal cord closure occurred in 28 of 30 patients after sufentanil administration and improved only after muscle relaxant administration. They concluded that vocal cord closure is the main mechanism of opioid-induced DMV. The mechanism of vocal cord spasm and muscle rigidity is probably central stimulation of mu_1 receptors increasing efferent motor traffic particularly to the laryngeal muscles.[23]

Masseter Spasm After Succinylcholine

The masseter muscle responds to the initial depolarization by a contracture.[24] This response can result in clinically significant jaw rigidity (jaw of steel), impeding ventilation attempts.[25] Masseter spasm can be a benign phenomenon, but it may also be an early sign of malignant hyperthermia.

Inadequate Depth of Anesthesia

Light anesthesia may be associated with increased chest wall muscle tone, breath holding, and coughing. This may lead to decreased chest wall expansion and reduced compliance resulting in DMV.[26]

Inadequate Muscle Relaxation

Immediately after anesthesia induction, there may be some resistance to MV attempts. This phenomenon can be interpreted as DMV. However, coinciding with the onset of muscle relaxation, this resistance gradually eases, and adequate MV is eventually established. Therefore, it was concluded that muscle tone was the factor behind the initial resistance to MV. This phenomenon may place into question the value of testing MV before muscle relaxant administration.[27,28] Conversely, Goodwin et al.[29] were able to demonstrate that muscle tone does not affect efficiency of ventilation. The authors measured inspired (V_{TI}) and expired (V_{TE}) tidal volume before and after muscle relaxant administration in 30 patients with normal airways. They found no difference in the ratio V_{TE}/V_{TI}, which they used as a measure of efficiency of ventilation. The authors concluded that muscle relaxation did not affect the efficiency of MV in patients with normal airways. It is not known, however, whether the V_{TE}/V_{TI} ratio provides the best reflection of "efficiency of ventilation" or not. Currently, the issue remains controversial; further research is needed before a final recommendation can be issued.

Upper Airway Obstruction

The most common causes include large tongue in relation to the pharyngeal space, tonsillar hyperplasia, redundant tissues leading to pharyngeal wall collapse in morbidly obese and sleep apnea patients, and pharyngeal and neck tumors.[30] Upper airway trauma, including iatrogenic trauma induced by repeated attempts at tracheal intubation, can lead to edema and swelling of the tongue and pharyngeal and laryngeal structures.[31] Carotid pseudoaneurysms may bulge into the pharynx causing partial obstruction.[32] Facial and maxillary tumors may lead to an impossible mask fit or encroach on the upper airway.[33] Thyroid tumors, laryngeal polyps, and laryngeal carcinoma can all lead to DMV and in some cases IMV.[34]

Lower Airway Obstruction

Mediastinal or tracheal masses, foreign body aspiration, severe bronchospasm, stiff lungs, pneumothorax, bronchopleural fistula, and bronchial tumors have all been reported as causes of DMV or IMV.[35,36] Severe kyphoscoliosis and chest wall deformity can also impede expansion and decrease compliance.[37]

It is important to go through the list of differential diagnoses when managing a DMV situation to rectify the correctable causes and consider alternative interventions if initial measures fail.

INCIDENCE

There is a wide variation in the reported incidence of DMV in the literature. Whereas one study reported an incidence as low as 0.08%, another reported a 15% incidence.[38,39] The highest incidence (15%) was reported from a retrospective study of subjects who had DI. It is unclear whether the trauma induced by repeated tracheal intubation attempts was the cause of this higher incidence or whether abnormal anatomical features may have predisposed patients to both DMV and DI. The majority of prospective studies, on the other hand, reported a lower incidence. Rose and Cohen, Asai et al., Langeron et al., and Yildiz et al.[40–43] prospectively studied DMV and found the incidence to be 0.9%, 1.4%, 5%, and 7.8%, respectively. The largest prospective study of 22,660 MV attempts used a DMV grading scale and reported an incidence of 1.4%.[44] Because this is the largest and most recent study and because the reported incidence is in agreement with several other studies,[7,40,41] 1.4% may be considered the most likely estimate in the general population.

The lack of standard criteria to define DMV may be the reason behind the discrepancies in the reported incidences.[45] The population chosen for the study may have also caused this variation. For example, sleep apnea patients have a much higher incidence of DMV than the general population.[46]

The incidence of IMV is much less than that of DMV. Langeron et al.[42] reported that only one patient in 1502 (0.07%) had IMV, and Kheterpal et al.[44] reported an incidence of 0.16%. Unfortunately, there are few studies that were able to comment on the incidence of IMV, because its occurrence had mostly been sporadic and limited to anecdotal reports.

PREDICTION AND RISK ASSESSMENT

Airway evaluation, currently based on history and physical findings, is used to detect potential difficulties with tracheal intubation.[47] The ability to predict DMV is equally or, arguably, even more important to patient safety. Unfortunately, Asai et al.[41] reported failure to anticipate DMV before anesthesia induction in 57% of the patients who were ultimately difficult to ventilate. The ability to achieve adequate MV should always, thus, be assessed preoperatively. Potential problems that may interfere with MV can be elicited from prior anesthesia records, a thorough history, and a focused airway examination. It is crucial that practitioners document the effectiveness of MV, grade of difficulty, adjunct devices used, and consequently the ability or inability to establish MV. This can help future clinicians in formulating a safe airway management plan. Airway examination should also include assessment of signs that increase the risk of DMV.

Table 4. Predictors of Difficult Mask Ventilation

Risk factor	References
Increased body mass index	Langeron et al.[42] Yildiz et al.[43] Kheterpal et al.[44]
History of snoring/sleep apnea	Langeron et al.[42] Yildiz et al.[43] Kheterpal et al.[44]
Presence of beard	Langeron et al.[42] Kheterpal et al.[44]
Lack of teeth	Langeron et al.[42]
Age >55 yr	Langeron et al.[42] Yildiz et al.[43] Kheterpal et al.[44]
Mallampati III or IV	Yildiz et al.[43] Kheterpal et al.[44]
Limited mandibular protrusion test	Kheterpal et al.[44]
Male gender	Yildiz et al.[43]
Airway masses/tumors	Moorthy et al.[48]

Langeron et al.,[42] in a prospective study of 1502 patients, performed a multivariate analysis of preoperative findings that were correlated with DMV. They found five risk factors to be significantly associated with DMV and thus may be used as predictors. These were: age older than 55 yr, body mass index (BMI) more than 26 kg/m^2, lack of teeth, history of snoring, and presence of a beard. The presence of at least two of these factors indicated a high likelihood of DMV. Similarly, an analysis by Yildiz et al.[43] found age, weight, history of snoring, male gender, and Mallampati Class IV to be significantly associated with DMV. In a multivariate regression analysis, Kheterpal et al.[44] identified age older than 57 yr, BMI more than 30, history of snoring, the presence of a beard, Mallampati Class III or IV, and limited mandibular protrusion test as independent predictors for Grade 3 MV (DMV). In contrast, however, they were not able to identify lack of teeth as a predictor. They also identified history of snoring and thyromental distance of <6 cm as predictors of Grade 4 MV (IMV).

It is obvious that patients with upper or lower airway masses encroaching on the airway are at increased risk of DMV.[48] Table 4 summarizes the independent risk factors that can be used as predictors of DMV. These "red flags" should, therefore, be recognized and documented during preoperative airway evaluation. For purposes of risk stratification and as illustrated by Kheterpal et al., the risk for developing DMV increases as the number of risk factors increases in the same patient.

Similar to the prediction of DI, probably a large percentage of patients in whom DMV is anticipated may turn out to be easily ventilated (false positives).[49] Anticipation of the potential problem, better planning, and preparation, however, may potentially reduce the morbidity and mortality associated with failure to ventilate the true positives.

It is to be noted that some of the risk factors shown in Table 4 can be modified preoperatively.[42] Further research is needed, however, to confirm the impact of these preparations on the incidence of DMV. It is obvious that the highest risk lies in patients who are predicted to have both DMV and DI for whom an alternative airway management technique should be sought.

OUTCOME

Relationship Between DMV and DI

Unanticipated difficult laryngeal visualization occasionally may be encountered after a variable period of "easy" MV. Reciprocally, when MV proves difficult in some instances, a Grade 1 view may be obtained with direct laryngoscopy.[44] Therefore, having a difficulty in one of these techniques does not mean by necessity that the other will be also difficult. There is a relationship, however, between DMV and the incidence of DI. Langeron et al.[42] found patients with DMV to have a higher incidence of DI than those with easy MV. The authors found the incidence of DI to be 8% in patients who had no DMV, and 30% in those who had DMV, a fourfold increase. They also found a 12-fold increase in the incidence of impossible intubation (0.5% vs 6%) in patients who had DMV. Although the true incidence of DI is probably <8%,[50] the important message is that patients with DMV have a higher incidence of DI. Kheterpal et al.[44] found that many factors that predispose to DMV also predispose to DI. Obstructive sleep apnea, history of snoring, obese neck anatomy, limited mandibular protrusion, and BMI of 30 kg/m^2 or more predicted both DMV and DI. Because these factors are shared as predictors, then it follows that patients with DMV have a higher chance of also having DI. Despite this apparent association, however, a large percentage of patients who experienced DMV in that study eventually had successful tracheal intubation. Little data, on the other hand, were found in the literature about the relationship between IMV and DI. Of 37 patients (0.16% of the studied subjects) who experienced IMV in the last study, 26 were easily intubated, 10 had DI but were eventually intubated, and only one patient required emergency cricothyrotomy.[44] Although this is the largest reported group of patients with IMV, the number is still too small to draw any meaningful conclusions.

Management

As previously mentioned, it is crucial to identify high risk patients preoperatively, because the management depends on whether DMV is expected.

Patients with Expected DMV

Most of these patients will also have signs indicative of a potential DI. In this subgroup of patients, the safest approach is to plan for an awake fiberoptic intubation.[47] Some patients, however, may have risk factors for DMV but with no signs to indicate a possible DI (e.g., elderly man who is edentulous and has a beard, yet he has a Mallampati Class I, thyromental distance of >7 cm, and a normal neck range of motion). Others may have history of "easy" tracheal intubation. Although there are no clinical studies to prove the assertion, it has been recommended to address the correctable risk factors in these patients preoperatively. Shaving the beard or applying an adhesive film over it, weight loss, and keeping the dentures in place are just a few examples of the correctable factors.[42]

Preparation for all possible scenarios when anesthesia induction is planned both enhances success and minimizes risks of the anticipated difficult airway.[4] Preparatory steps should also include checking the availability and working condition of all contents of the difficult airway cart, formulating alternative plans, preparing rescue ventilation devices, and ensuring the availability of an experienced assistant in case help is needed.[1,4]

In most of the situations, it is advisable to avoid the development of the difficulty, e.g., by applying continuous positive pressure ventilation (CPAP) to stent the airway open, before it actually collapses after loss of consciousness. Partial obstruction may result in negative pressure efforts that lead to further collapse and complete airway obstruction creating a vicious cycle that is difficult to break.[51] It is crucial that patients who are expected to have DMV receive adequate oxygen administration, as this will give the anesthesiologist some extra time to manage the problem.[52]

Patient with Unexpected DMV

The management of DMV is a dynamic process in which close observation of the effectiveness of ventilation should be simultaneously accompanied by modifications in the maneuvers, the use of adjuncts, and the call for help as soon as it appears to be needed.

Figure 1 outlines the management steps that can be followed to establish adequate ventilation in DMV situations. The figure is based on the ASA difficult airway algorithm and other evidence from the literature.[1,4,53–59] Simple maneuvers and corrective measures like those shown in the figure may resolve the situation. Operator change or two-person MV may be successful. Discontinuation of the anesthetic should be seriously considered to awaken the patient if MV is still impossible. Waiting for the patient to spontaneously awaken, however, is not always a feasible option and may end in a fatal outcome. In those cases when recovery from anesthesia induction is rapid, the procedure can be rescheduled, or if not feasible, an awake tracheal intubation technique is most prudent.

When MV is impossible, the anesthesiologist may either proceed with tracheal intubation or use an alternative ventilatory device. Crosby et al.[53] considered an attempt at tracheal intubation a prudent first intervention in cases of IMV. Kheterpal et al.[44] reported successful tracheal intubation in 36 of 37 patients who had IMV, and only one patient required

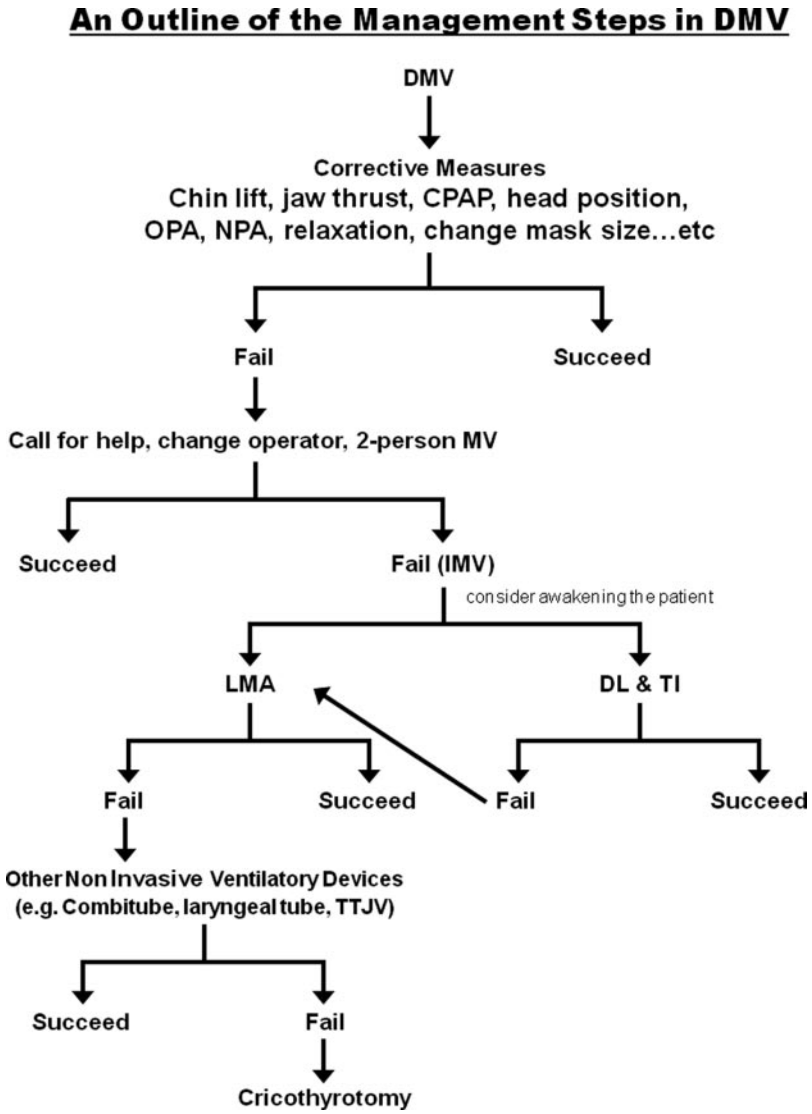

Figure 1. An outline of the management steps in DMV. DMV = difficult mask ventilation; CPAP = continuous positive airway pressure; OPA = oropharyngeal airway; NPA = nasopharyngeal airway; MV = mask ventilation; IMV = impossible mask ventilation; LMA = laryngeal mask airway; DL and TI = direct laryngoscopy and tracheal intubation; TTJV = transtracheal jet ventilation.

cricothyrotomy. Based on these results (because this was the largest group of IMV patients studied), direct laryngoscopy and tracheal intubation should be considered. The laryngeal mask airway (LMA) is considered by many to be the first choice rescue ventilation device.[54] Unfortunately, there are no studies that compared these two management options in terms of patient outcome. The decision to proceed with either technique will be dictated by the urgency to establish ventilation and the patient's oxygen saturation. Because of its success rate, ease of insertion, and increased familiarity with its use, the LMA was included in the ASA difficult airway algorithm as an option to be considered or attempted before others in IMV situations.[1] The combitube or other supraglottic airway devices may be tried if both face mask and LMA fail to establish adequate ventilation.[1,56,57]

Two relatively new supraglottic devices deserve mention because of the reported success in their use to rescue ventilation. These are the laryngeal tube (LT) and the LMA CTrach. The LT (King Systems, Noblesville, IN) is a silicone tube with a proximal (pharyngeal) cuff and a distal (esophageal) cuff and ventilatory apertures in between.[60] This device is easily inserted even by inexperienced personnel.[61] Its ventilatory efficiency has been demonstrated with both controlled and spontaneous ventilation.[62,63] There are many reports of the LT used as a rescue ventilation device in difficult airway situations.[57,64] Placement, however, may sometimes be difficult or impossible in patients with upper airway masses. The LT cannot prevent or treat airway obstruction at or beyond the glottis.[65] The LMA CTrach (LMA North America, San Diego, CA) is another device that was successfully used in patients with difficult airways.[66] It is a modification of the intubating LMA that incorporates a built-in fiberoptic system to transmit images to a small screen. The device can be used to rescue ventilation while simultaneously performing tracheal intubation under visualization.[67] More time is required, however, for its accurate placement.[68] More clinical trials are currently needed on the use of these two promising devices and their role in difficult airway management.

Several other devices have also been introduced. The choice of the proper device should be based on the etiology of the problem, limitations of the device, experienced clinical judgment, and familiarity with its use, which can be crucial to its successful application.

Transtracheal jet ventilation may be considered when supraglottic ventilation devices fail, but the operator must be familiar with its use.[58] If all other measures fail to establish ventilation, cricothyrotomy may be the only lifesaving alternative.[1,59]

Complications

The most serious complication of DMV is failure to establish ventilation, resulting in death or hypoxic brain damage.[69] The availability of many new alternative airway devices, the adoption of the ASA difficult airway algorithm, and better monitoring techniques have resulted in safer airway management practices and reduced the incidence of these grave complications.[70,71] Other less serious complications may occur if the operator is not attentive to the anatomical structures under the mask. This is especially evident when MV is difficult because most of the attention is focused on establishing adequate ventilation.

1. The eyes and eyelids are vulnerable to injury from a foreign body, pressure, dry gases, or the anesthesiologist's hands.[72] Pressure necrosis and trauma to the nose bridge and chin have been reported.[73] Lip and nerve injuries may also occur.[74,75]
2. Vomiting and aspiration: High inflation pressures in the ventilating bag will lead to stomach insufflation and regurgitation of stomach contents.[76] Limiting positive airway pressure to no more than necessary to achieve acceptable ventilation is advisable. When MV is inadequate, however, positive airway pressure should not exceed 20 cm H_2O because any extra gas will be insufflating the stomach. If vomiting is witnessed, it is advisable to turn the patient's head to the side and place the patient in a head-down position (Trendelenburg), thus facilitating vomitus removal by gravity and suction and preventing aspiration. Tracheal intubation may be needed to solve the ventilatory problem and protect the tracheobronchial tree.[15]
3. NPA insertion may cause nasal bleeding or create a false passage by dissecting nasal tissues. OPAs may cause airway obstruction if the inappropriate size is chosen.[77] Damage to the teeth and lips may occur due to biting or grinding. Soft palate, uvular, and nerve injury have been reported after the use of OPAs.[15] Ensuring adequate anesthesia and gentle placement of these airways reduce these risks.

DMV IN THE PEDIATRIC POPULATION

The problem of DMV can be even more frequent and challenging in the pediatric age group. Because of anatomical differences, children are more prone to upper airway obstruction under sedation and general anesthesia than adults.[78] In addition, they have higher oxygen consumption and less oxygen reserve than adults. Consequently, they develop hypoxemia much faster if their ventilation is compromised.[79] DMV may develop during the light anesthesia (excitement) stage when using an inhaled induction. Children are also prone to pharyngeal collapse, enlarged adenoids/tonsils, laryngeal spasm, recurrent upper respiratory tract infection, and foreign body aspiration.[80] Craniofacial abnormalities and congenital neck masses may also interfere with MV.[81] A recent study showed the incidence of DMV to be 2.1% in nonobese and 8.7% in obese children.[82] When faced with a DMV, the pediatric anesthesiologist should be aware of the impact of performing simple airway maneuvers on establishing airway patency and restoring adequate MV. Meier et al.[83] compared the effects of different airway maneuvers on glottic opening in 40 anesthetized children. They used a flexible fiberoptic bronchoscope to visualize the effects of chin lift, jaw thrust, and the use of 10 cm H_2O of CPAP. Both chin lift and jaw thrust increased glottic opening but the application of CPAP with either maneuver resulted in an almost double increase. They concluded that CPAP worked as a pneumatic splint that stented the airway open, leading to an increased airway size including the glottic opening. The management follows the same principles outlined in Figure 1. For children who are expected to have both DMV and DI, a technique that allows incremental sedation while preserving airway tone and respiration should be used. Tracheal intubation can then be accomplished by using an LMA as a conduit or a fiberoptic bronchoscope before anesthesia induction.[84] In unexpected DMV, corrective maneuvers and measures, such as insertion of NPAs or OPAs, should be tried as well as two-person MV.[85] Care should be taken to avoid gastric insufflation, which may impair further ventilatory attempts. The stomach should be vented, because gastric distension is common in children after MV and especially in DMV situations.[86] The efficiency of the LMA as a rescue ventilatory device in pediatrics has been well documented.[87] In rare occasions, transtracheal jet ventilation or needle cricothyrotomy may be needed to establish the patent airway.[88]

ADDRESSING THE PROBLEM: FUTURE RECOMMENDATIONS

Better understanding of the problem of DMV and its management can have a major impact on patient outcome. Many scientific societies and organizations have recently recognized the importance of addressing this long neglected problem. Additional steps that may be considered are:

1. Increasing awareness about the problem through publications, lectures, seminars, and airway workshops in the scientific meetings held by different societies.

2. The implementation of formal airway management rotation in all anesthesia training programs, where residents can acquire the skills necessary to manage difficult airway situations including DMV.[89]
3. The use of simulation to create different scenarios of DMV with the availability of different rescue devices and techniques.[90] The use of simulation has been shown to improve trainees' responses and skills in managing DMV.[91]
4. Periodically attending airway courses and workshops to keep up to date with new information, devices, and techniques.[92] A certificate of competence with limited time validity may be issued after attending the course (similar to basic or advanced life support certificates).
5. Clinical research: Airway management is still a novel field with many unanswered questions. Prospective controlled clinical trials may help us answer these questions and improve our management plans.

SUMMARY

An objective and precise definition of DMV is currently needed. The pathophysiology of DMV is operator, technique, or airway related. The likely incidence of DMV ranges between 1.4% and 5% depending on the criteria used for definition. Age, obesity, snoring, presence of a beard, lack of teeth, Mallampati Class III or IV, abnormal mandibular protrusion test, and male gender are independent risk factors that can be used as predictors. There is an increased likelihood of DI in DMV patients. Anesthesiologists should be aware of the complications and management options of DMV situations. DMV can be more challenging in pediatrics, and the time window to rescue the situation is much narrower than in adults. Eliciting the predictors, formulating alternative plans, preparing the proper equipment, and above all, increased awareness of the problem, will ultimately increase patient safety and improve outcome after DMV.

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