The Technology of Video Laryngoscopy

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Tracheal intubation via laryngeal exposure has evolved over the past 150 years and has greatly expanded in the last decade with the introduction and development of newer, more sophisticated optical airway devices. The introduction of indirect and video-assisted laryngoscopes has significantly impacted airway management as evidenced by the presence of these devices in the majority of published difficult airway algorithms. However, it is quite possible that many airway managers do not have a thorough comprehension of how these devices actually function, an understanding that is vital not only for their use but also for assessing the devices' limitations. This article discusses the development of video laryngoscopy, how the video laryngoscope works, and the impact of video laryngoscopy on difficult airway management. (Anesth Analg 2018;126:1527–34)

Tracheal intubation via laryngeal exposure has evolved over the past 150 years and has greatly expanded in the last decade with the introduction and development of newer, more sophisticated optical airway devices. The introduction of indirect and video-assisted laryngoscopes has significantly impacted airway management as evidenced by the presence of these devices in the majority of published difficult airway algorithms.[1–3] However, it is quite possible that many airway managers do not have a thorough understanding of how these devices actually work, an understanding that is vital not only for their use but also for assessing the devices' limitations.

The original laryngoscopes, developed in the 19th century before the availability of electricity to consumers, used mirrors and sunlight to indirectly view the glottis (Figure 1). In the early 20th century, rigid direct laryngoscopes were introduced that could elevate the epiglottis and expose the larynx, allowing insertion of an endotracheal tube. The use of indirect techniques to visualize and instrument the larynx reemerged in the 1960s with the invention of the fiberoptic bronchoscope, followed by the launch of video technology in the early 2000s. The pendulum has shifted once again, and indirect viewing of the glottic opening has become popular in the last decade. This new technology has brought us back to the original concept of indirectly identifying the glottis, which now includes use of video monitors in addition to prisms.

DEVELOPMENT OF VIDEO LARYNGOSCOPY

The initial inventors of laryngoscopes focused on designing a system to retract pharyngeal and supraglottic tissue, originally using mirrors and sunlight or candles as light sources.[4] The addition of distal illumination, ergonomic handles, and external power in the form of batteries were major advances after the advent of electricity. In the 1940s, the iconic straight (Miller) and curved (Macintosh) blades were introduced, followed by a proliferation of direct laryngoscopy and intubation.[5] In the 1960s, Murphy was the first to describe intubation via flexible endoscopy (using a choledoscope), allowing intubation to be performed nasally, orally, or via a stoma, as well as visualization of the laryngeal structures beyond the range of a typical rigid laryngoscopy blade.[6] In the early 1990s, Peter Bumm[7] coupled a rigid endoscope to a conventional laryngoscope blade to retract soft tissues, using an endoscopic instead of a direct approach to view the glottis. This technique paved the way for the development of modern video laryngoscopy. Precursors of current devices were the Bullard, the Wu, and the Upsher laryngoscope systems: rigid fiberoptic devices that granted visualization of the laryngeal inlet and intubation when the mouth opening was limited.

By the end of the 1990s, technology developments in electronics and microchips accelerated the release of products in many economic sectors, including health care. Karl Storz launched the first video devices using direct coupled interface technology. John Pacey modified a 45° arthroscopic optical device to create the Glidescope. In 1999, the first prototype of the Glidescope was introduced by Saturn Biomedical (later acquired in 2006 by Verathon); it was a revolutionary device that was created by gluing a semiconductor (complementary metal oxide semiconductor [CMOS] technology) camera to a conventional laryngoscope blade (Figure 2). In 2000, both Karl Storz and Verathon introduced their video laryngoscopy systems to the market: the Macintosh intubating video laryngoscopy system and the Glidescope, respectively.

Widespread development and distribution of video laryngoscopy boomed in 2006, and since then, the popularity and widespread adoption and availability of different blades and sizes has led to video laryngoscopy becoming common not only in the operating room but also in the emergency department and in out-of-hospital settings for both pediatric and adult patients. Currently, it is unknown how many different video laryngoscopes are available in the clinical arena, as the list of optical and digital devices continues to grow and there are many devices being used in countries such as India and China that are not available in North America. The veterinary anesthesia market possesses additional devices that are not approved for human use.

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HOW A VIDEO LARYNGOSCOPE WORKS

Compared to viewing the larynx from outside the oral cavity by a direct line of sight approach with direct laryngoscopy, video laryngoscopes provide an indirect view by having a camera lens close to the tip of the blade nearer to the larynx. This results in a much wider angle of view compared to direct laryngoscopy.[8] Unlike direct laryngoscope blades, which contain a fiberoptic, xenon halogen, or light-emitting diode light source that runs the length of the blade, video laryngoscope blades contain a recessed light source and a camera generally positioned in the middle of the blade (Figure 3). The light source and camera are powered either from the monitor (Glidescope [Verathon Medical, Bothell, WA]; Storz C-MAC [Karl Storz, Tuttlingen, Germany] or by an internal battery (King [Ambu, Ballerup, Denmark]; Mcgrath [Medtronic, Minneapolis, MN]; Co-Pilot [Magaw Medical, Fort Worth, TX]). The light projected from the video laryngoscope blade and the wide field of view of the camera result in a more panoramic view of the larynx compared to direct laryngoscopy. The type of lens used by the individual device also impacts the field of view; lenses used by different video laryngoscopes are not identical and have different fields of view and varying levels of distortion.[8] As an example, the Mcgrath video laryngoscope lens has a smaller field of view compared to the Glidescope lens.[8]

Figure 1. Image of the Boekel's laryngoscope, invented in 1886. An oil lamp was used as the light source. The operator looked through the hole in the mirror on the right into the larynx, which was illuminated by light being focused through the lens in the middle of the device. Source with permission: http://phisick.com/item/boekels-improved-laryngoscope/.

The majority of video laryngoscopes use a light-emitting diode light source and a CMOS sensor. CMOS sensors convert light signals to electric signals at high speed with low power consumption (Figure 4). Most CMOS sensors use active pixel sensors because they produce less noise and produce high-quality images compared to a passive pixel sensor. The Coopdech video laryngoscope (Daiken Medical, Tokyo, Japan) uses a charge-coupled device (CCD) instead of a CMOS sensor. The Airtraq video laryngoscope (Teleflex Medical, Wayne, PA) uses optical mirrors to generate the image seen via the eyepiece and also offers an optional camera or a smartphone adapter that can be attached to the eyepiece and converts the optical image to a digital image using a CMOS chip.

CCD and CMOS image sensors are the devices most commonly used by cell phones and digital cameras to capture images. Both CCD and CMOS devices function as photodetectors that convert light photons into electric signals (charge-to-voltage conversion).[9] The CCD uses capacitors to collect an electrical charge proportional to the amount of light hitting the device and then converts this charge to a digital image (pixels). The CMOS sensor uses photodetectors to capture light and then amplifies the signal to generate an image. Both sensors also use filters to convert the light signals into a color image. CCD sensors are more expensive and use more power but generate higher quality pictures and are preferred for digital cameras. CMOS technology, on the other hand, is less expensive and uses less power, an advantage in cell phones and video laryngoscopes where very high-quality images are

Figure 2. Images of 2 of the early Glidescope prototypes. Courtesy of John Allen Pacey, inventor of the Glidescope.

Figure 3. Mcgrath video laryngoscope with attached X Blade (left) and Glidescope video laryngoscope with reusable titanium angulated blade (right). Arrows indicate location of recessed light source and camera.

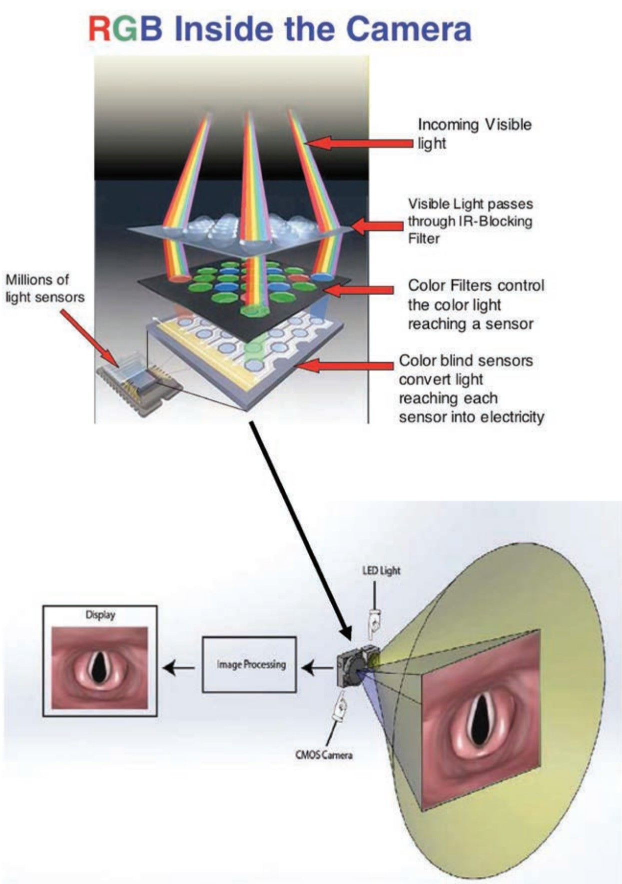

Figure 4. How the CMOS camera in a video laryngoscope converts light into a display image. CMOS indicates complementary metal oxide semiconductor; LED, light-emitting diode; RGB, red, green, blue.

not necessary and longer battery life is advantageous. Both types of sensors are designed as small chips, allowing complex technology to fit into a small device such as a video laryngoscope. The images generated from the CMOS or CCD chip are then sent to the video screen of the video laryngoscope, providing the end user a view on the video screen of the image processed from the middle of the blade by the CMOS chip.

The majority of video laryngoscopes use a color liquid crystal display, either mounted to the video laryngoscopy device itself or attached via a cable to allow mounting on a pole (Table). In general, the separate displays are larger and allow recording and storage via a USB port as well as provide video output to a larger display via an HDMI cable. Some devices also allow still and video recording of images via a USB port (Glidescope, Pentax [Pentax Medical, Montvale, NJ]) or an SD card (Storz only). The optional Airtraq camera uses Wi-Fi to download images to a personal computer or mobile phone app.

Some additional features that are provided by individual video laryngoscope manufacturers include an optional HDMI-DVI cable (Storz), markings on the liquid crystal display to guide endotracheal tube placement (Pentax), a channel through which a bougie can be placed (CoPilot VL), and an optional phone adaptor to attach a cell phone for monitoring and/or recording (Airtraq). None of the currently available devices, unlike some of the older rigid fiberoptic bronchoscopes, allows for suction or oxygen or helium delivery.

Video laryngoscopes vary as far as the type and geometry of the blade. The majority of video laryngoscopes use blades angulated between 60° and 90° to provide a more anterior view, allowing glottic visualization with less neck flexion or extension compared to conventional direct laryngoscopy. Some video laryngoscopes offer the option of Macintosh and Miller-type blades as well, which can be used to perform direct laryngoscopy or indirect laryngoscopy using the video component (Mcgrath, C-MAC, Glidescope Titanium) (Figure 5). The combination of an angulated blade and a video component provides a wider angle of view to the person performing the intubation. The majority of the blades also include some type of antifog heating mechanism either built into the camera (Storz, Glidescope, CoPilot) or via an antifog coating on the disposable blade (Mcgrath) or lens (King) itself.

Although the originally marketed video laryngoscopes were designed with solely reusable blades that required cleaning and disinfection, most video laryngoscopes now offer partially or fully disposable designs. Verathon (Glidescope) offers reusable or disposable blades in its

Table. Video Laryngoscope Designs

Video Laryngoscope	Light Source	Video Camera	Display	Blade Type(s)	Recording/Video Output Capability to Separate Monitor	Battery/Power Source	Minimum Mouth Opening/Width of Blade
Glidescope (Verathon Medical)[10] Titanium Cobalt AVL Ranger	LED	CMOS	Separate 6.4" LCD color display	60° angulated blades and Macintosh-like blades, unchanneled blade	USB port, allows video/still image recording; video output cable; optional HDMI-DVI cable	Rechargeable internal battery and AC adaptor	Blade width 13 to 25 mm, depending on blade style
C-MAC (Karl Storz)[11]	LED	CMOS	Separate 7" LCD color display	Macintosh and Miller blades, angulated D blade, unchanneled blade	SD memory card stores video/still images; video output cable	Rechargeable internal lithium battery and AC adaptor	D blade: 12-mm blade width
Mcgrath (Medtronic/ Covidien)[12]	LED	CMOS	2.5" LCD color display attached to device, moveable	Curved Macintosh-like blades, angulated X Blade, unchanneled blade	None	3.6 V lithium battery, single use, replaceable	11.9-mm blade width
King Vision Scope (Ambu Corporation)[13]	LED	CMOS	2.4" LCD fixed display attached to device	Angulated blades, offers both channeled and unchanneled blades	Video outport, requires optional cable	Three AAA batteries	13-mm mouth opening
Pentax AWL (HOYA Services Corporation)[14]	LED	CMOS	2.4" LCD display fixed to device, option to attach to external display	Angulated blades, unchanneled blade	Micro-USB cable to attach to separate monitor	Two AA batteries	12- to 17-mm blade width depending on blade size
CoPilot VL (Magaw Medical)[15]	LED	CMOS	Separate 4.3" color display	Angulated blade, blade contains channel to pass bougie only	None	Rechargeable lithium battery, AC adaptor	17-mm mouth opening
Airtraq Avant Airtraq SP (Teleflex Medical)[16]	LED	CMOS in optional camera attachment only	None embedded in device (viewfinder only), optional snap-on 2.4" camera or separate video display available	90° angulated blade, channeled blade	Optional Wi-Fi camera allows video recording and storage to PC via app; can connect eyepiece to endoscope camera	Rechargeable battery or 2 AA batteries, depending on model	18-mm mouth opening
Coopdech Video Laryngoscope (Daiken Medical)[17]	LED	CCD	3.5" LCD color display attached to device	Macintosh and Miller styles, angled J blade, unchanneled blade	Allows video output via separated purchased cable	Rechargeable lithium ion battery and AC power adaptor	28-mm maximum blade width

This table contains a summary of the most common video laryngoscopy devices commercially available but is not a comprehensive list of all devices.

Abbreviations: CCD, charge-coupled device; CMOS, complementary metal oxide semiconductor; HDMI-DVI, high-definition multimedia interface-digital video interface; LCD, liquid crystal display; LED, light-emitting diode; PC, personal computer; SD, secure digital; USB, universal serial bus.

Figure 5. Top, Karl Storz C-MAC blades: Macintosh 3, 4, 2, and D blades from left to right. Bottom, Verathon Glidescope Titanium blades: size 3 (top left) and 4 (bottom left) angulated blades, Macintosh 3 (top right) and 4 (bottom right) blades.

Titanium line and disposable blades with a reusable cable in its Cobalt AVL and Ranger lines. Storz (C-MAC) also offers both reusable blades and disposable blades (with a reusable cable). The Mcgrath, Pentax AWS, CoPilot VL, and King video laryngoscopes have reusable handles with single-use disposable blades, and the Airtraq is fully disposable with an optional reusable camera attachment.

Some video laryngoscopes contain built-in channels through which the endotracheal tube is passed (Airtraq, King Vision Scope, Pentax AWS). Other video laryngoscopes offer only an unchanneled blade (Glidescope, C-MAC, Mcgrath, CoPilot VL, Coopdech). Only the King Vision Scope offers both channeled and unchanneled disposable blade options. There are advantages and disadvantages to both types of blades. A channeled blade provides a pathway for the endotracheal tube but limits the ability to manipulate the tube if necessary and provides a less steep viewing angle compared to an unchanneled blade. Unchanneled blades, especially the angulated designs, routinely require a stylet molded to match the curve of the blade to achieve tube delivery into the trachea. Verathon and CoPilot manufacture a proprietary stylet to be used with their device, but other malleable endotracheal tube stylets can also be used. If a nonproprietary stylet is used, the curvature of the styletted endotracheal tube should match the curve of the particular video laryngoscope blade selected to maneuver the tube around the tongue and bring the endotracheal tube into the line of sight provided by the video screen. Several of the video laryngoscope manufacturers recommend the use of a stylet in conjunction with an unchanneled blade. A study by van Zundert et al[18] demonstrated that 50% to 70% of video laryngoscope intubations using an angulated blade required a stylet.

VIDEO LARYNGOSCOPY USAGE AND OUTCOMES

Laryngoscopy and intubation is performed by many health care professionals with variable airway management experience and is considered a single-provider, technically demanding procedure that requires psychomotor skill, has a learning curve, and takes time to acquire, master, and retain.[19] Video laryngoscopy provides a wider field of vision, allows imaging of laryngeal structures beyond the reach of conventional direct laryngoscopy, and is now considered by many to be a first-line intubation technique for routine, difficult, and rescue intubations. Our current knowledge and evidence is limited by insufficient investigation of individual and comparative system performance. A significant amount of information comes from expert opinion, case series, retrospective nonrandomized studies (even mannequin based), or meta-analyses and less from large-scale randomized studies on routine and difficult intubation patients.

Although an in-depth analysis is beyond the scope of this article, there are some areas where video laryngoscopy has shown superior, enhanced performance and safety over direct laryngoscopy. Video laryngoscopes have consistently shown improved glottic exposure and laryngeal view compared to direct laryngoscopy, increased rate of first-pass intubation success, decreased rates of esophageal intubations, and increased overall intubation success rate, both for expert and inexperienced providers, inside as well as outside the operating room.[20–22] Video laryngoscopy has been shown to decrease hemodynamic responses to tracheal intubation, as well as to decrease the forces of intubation and the pressure exerted over teeth, with potential reduction in dental trauma.[23] A recent Cochrane systematic review demonstrated an improved glottic view and decreased airway trauma in the predicted or known difficult airway.[24] This same review, however, demonstrated no difference in time to intubation, hypoxia, or other respiratory complications with video laryngoscopy compared to direct laryngoscopy.[24] A meta-analysis in the pediatric population showed improved glottic visualization with video laryngoscopy but prolonged intubation times and an increase in intubation failure rate.[25] In the critical care setting, De Jong et al[26] performed a meta-analysis and reported that video laryngoscopy was superior to direct laryngoscopy and reduced difficult intubation, increased first-attempt success, decreased high-grade (limited) laryngeal exposure, and decreased the incidence of esophageal intubation. There was no benefit of video laryngoscopy regarding a decrease in the incidence of hypoxemia, cardiovascular collapse, or airway injury. In the emergency setting, many studies report better laryngeal exposure and greater intubation success, as well as higher first-pass success rate and lower incidence of esophageal intubation, with video laryngoscopy.[22,27–29]

Patients with cervical spine pathology or immobilization do not allow alignment of the oral, pharyngeal, and tracheal axes and may have limited mouth opening that can make intubation more difficult. A recent meta-analysis by Suppan et al[30] demonstrated better overall laryngeal views compared to a Macintosh blade, but only one of the devices studied (Airtraq) showed statistically significant reduction in time to intubation and improved first-pass success. Although not definitive, some studies have demonstrated decreased cervical spine extension with video laryngoscopy compared to direct laryngoscopy.[31] In the trauma population, some studies suggest that video laryngoscopy may reduce cervical spine movement, whereas other studies found no difference compared to Macintosh laryngoscopy.[32]

Video laryngoscopy technology has also played a role in the placement of specialty devices, such as double lumen tubes, nerve integrity tubes for nerve monitoring, orogastric tubes, gastroscopes, and temperature and transesophageal probes.[33] Video laryngoscopy has also been shown to be an important tool for airway exchange and extubation procedures. A recent study showed that video laryngoscopy is currently the most frequently used rescue technique after failed intubation and has the highest success rate among alternative techniques.[34]

Another advantage of the use of video laryngoscopy is its implication for education and training. It provides an improved anatomical display of airway structures, thereby allowing instructors, trainees, and the operative team to share the same view, enabling real-time guidance and training. Certain devices also have the potential to record still images and video, allowing for later review of anatomy and intubation performance. This is a step forward in training and education in laryngoscopy and may have a positive impact with improved proficiency in acquisition and retention of intubation skills.[35,36] The external display of images has also been employed for "tele-intubation" and assistance for out-of-hospital intubations.[37] Video laryngoscopy is now a topic for examination in anesthesiology by the American Board of Anesthesiology.[38]

LIMITATIONS AND COMPLICATIONS OF VIDEO LARYNGOSCOPY

As with any new technology, video laryngoscopy is associated with its own set of limitations, challenges, and complications. Treki and Straker[39] place these limitations into three main categories: operator-dependent, equipment-dependent, and patient-dependent factors. Although the precise learning curve and standardized method of training has yet to be defined, it appears that the interval to achieve competence is shorter for video laryngoscopy compared to direct laryngoscopy.[40] At present, there is insufficient comparative evidence among different types of video laryngoscopy devices (channeled versus unchanneled, blade geometry type) to determine which device is best suited for which specific circumstances and pathology.[21]

Patient-related predictors of difficulty for video laryngoscopy also differ. Direct laryngoscopy failure is usually due to inadequate exposure and view of the glottic opening because of factors such as limited cervical spine motion, small mouth opening, short thyromental distance, and high Mallampati score. Some studies also show limitations in morbidly obese patients. Because video laryngoscopy does not require alignment of the oral-pharyngeal and laryngeal axes, failure may be due to limited mouth opening, the presence of a large tongue, a tumor in the oropharynx, vision blurred by fogging, or the presence of a soiled airway (secretions, blood, or vomitus).[41] Several studies have demonstrated that the improved glottic visualization achieved with video laryngoscopy does not automatically translate into easy tracheal intubation. Intubation failure despite a good glottic view has been reported in many studies, and failure to pass the endotracheal tube is the most common cause of failed intubation with video laryngoscopy.[28,42]

Regarding airway injury, there is conflicting data. Although video laryngoscopy may have advantages related to known factors for airway trauma (fewer attempts at intubation, less force on teeth, and less hemodynamic impact), there are increasing reports of injuries to the upper airway associated with their use.[43–45] Mucosal tears and perforations of the soft palate, palate-pharyngeal folds, and tonsillar pillars have been reported.[44–46] The need for a rigid stylet as well as the blind spot that exists during introduction of the endotracheal tube can predispose to these injuries. The majority of injuries occur during advancement of the tracheal tube rather than insertion of the video laryngoscope blade, especially if a rigid stylet is also used; traumatic injuries have also been described with devices that have an intrinsic guiding channel.[44]

SHOULD VIDEO LARYNGOSCOPY REPLACE DIRECT LARYNGOSCOPY? THE ROLE OF DIRECT LARYNGOSCOPY VERSUS ALTERNATE METHODS OF TRACHEAL INTUBATION

It is important to emphasize that no single airway device, even video laryngoscopy, carries a 100% success rate because not all causes of difficulty or failure are the same. All of the published airway algorithms stress the need for back-up plans.[1,2]

Video laryngoscopy may facilitate intubation when direct laryngoscopy has failed or is predicted to fail. Whether the video laryngoscope should be employed for first-line use or reserved as a rescue option when first-line methods have failed is controversial. If video laryngoscopy is reserved only as a rescue option, familiarity with the technique and devices might limit one's ability to rescue when direct laryngoscopy has failed.

Several studies have reported successful use of direct laryngoscopy after failed video laryngoscopy, a strong argument for continuing to perform and maintain competence in direct laryngoscopy.[47–49] Studies comparing the number of laryngoscopy attempts and time to intubation are quite heterogeneous and use different metrics; thus, it is unclear whether video laryngoscopy carries a clear advantage over direct laryngoscopy.[47–49] Although video laryngoscopy may replace direct laryngoscopy as a first-line technique, especially for difficult intubation, direct laryngoscopy still plays a role in airway management. In the emergent and trauma setting, the increased rate of oxygen desaturation and longer time to intubation reported with video laryngoscopy could potentially impact patient outcomes.[32,37,42] Airway managers need to be skilled in a variety of airway techniques and airway devices to successfully plan and carry out multiple back-up plans in a variety of locations where available airway equipment may vary.[50]

Despite evidence of the increase in use and acceptance of video laryngoscopy, major gaps still exist in our knowledge that should be addressed before this technology can be considered the standard of care. Among them is the financial impact of the use of video laryngoscopy. Specialty societies such as the Difficult Airway Society now recommend that video laryngoscopy should be immediately available whenever intubation is performed,[51] but given the high acquisition cost, it remains to be seen if this change in practice can be applied across the world.

CONCLUSIONS

The ideal intubation device would be safe, efficient, reliable, portable, affordable, cost-effective, usable in all age groups and in any location, and easy to teach and master compared to traditional direct laryngoscopy methods. Video laryngoscopy is a very recent invention in the quest to find alternatives and overcome the intrinsic limitations of the direct approach to laryngeal exposure and intubation. Video laryngoscopy is considered a paradigm shift from conventional laryngoscopy and has changed how intubation is taught, learned, and even supervised. There is not enough evidence to date to recommend a particular device, manufacturer, or blade design over others or whether channeled or unchanneled devices are more beneficial in certain circumstances.

Video laryngoscopy systems have been added to most major airway guidelines as a primary or alternate first-line approach to intubation as well as for use as a rescue device.[1–3]

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