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Review

The Evolution of Laryngoscopy

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Abstract

The work of anesthesiologists–intensivists, critical care specialists, and medical emergency teams is multifaceted and complex, with airway management representing a cornerstone and a common denominator of many procedures and interventions. Tracheal intubation has represented, and still represents today, the gold standard for airway control. Laryngoscopy evolution has progressed in parallel with technological development and innovation, resulting in the evolution of new skills and in the expansion of possibilities and safety for patient care. The evolution of laryngoscopy essentially took place between the late 1800s and the first half of the 1900s, with the consecration of the MacIntosh laryngoscope. Almost 50 years later, the world witnessed a pivotal turning point around the 2000s with the introduction of videolaryngoscopes. Along this path, the devices that have succeeded one another introduced new problems, driving the search for new solutions. At present day, tracheal intubation with videolaryngoscopy has achieved success and safety standards that are certainly superior, if not unimaginable, when compared with the early days of the technique. In this review we will retrace the historical aspects of the evolution of laryngoscopy, analyzing the problems that have emerged over time with the various devices and the solutions adopted. We will then examine the evolution of videolaryngoscopes, the impact of these devices on both technical skills and non-technical skills, as well as the debate surrounding their routine use (*universal videolaryngoscopy*) and the choice of the best adjuncts to optimize success during their use, including the application of assistive artificial intelligence to improve both success rates and the learning curve. This journey, after 150 years of evolution, has probably reached today the highest possible level of expression in terms of safety and efficacy.

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1. The Evolution of Techniques to Visualize the Larynx

In 1743 André Levret, a pioneer in Medicine and a French obstetrician, used a reflecting spatula (essentially a vaginal speculum) illuminating the nasal cavities with a candle to remove intracavitary polyps[1]. In 1807, Philip von Bozzini developed a speculum consisting of two metal tubes equipped with mirrors (the *Lichtleiter*), used to reflect light (from the sun or a candle) to visualize the internal cavities of the body, including the upper airway[2]. Benjamin Guy Babbington presented his "Glottiscope" in 1829, once again using a speculum as a tongue depressor illuminated by sunlight or candlelight. Babbington never formally published a scientific paper on his device[3], and it appears that the term "laryngoscope" was used for the first time not by Dr. Babbington himself but by a colleague, Dr. Hodgkin, better known for the description of the lymphoma that bears his name[4]. Years later, in 1855, Manuel Garcia (a singer and also an anatomy teacher) used a double-mirror system, which reflected sunlight or candlelight, to perform the first indirect laryngoscopy in history, describing the vocal cords, the mechanism of breathing, and the genesis of the voice[5]. The first

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clinical uses of laryngoscopes are attributed to the physicians Ludwig Turk (Vienna) and Johan Nepomuk Czermack (Budapest). Both doctors described the first clinical applications of laryngoscopy in 1857, both receiving recognition from the French Academy of Sciences, in an academic *ex aequo* that was anything but peaceful and was fought out through a flurry of scientific articles[6,7]. Sir William Macewen, a Scottish surgeon, has been credited with performing the first elective and prolonged intubation (36 hours) on July 5, 1878[8,9], thus defining the so-called "endotracheal anesthesia"[10]. A few years later, in 1895, Alfred Kirstein codified the use of laryngoscopy in Germany, inventing his "autoscope" (an esophagoscope combined with an electroscope)[11] consisting of a spatula reflecting external light (later replaced by an independent external light source) and combining its use for tracheal intubation[12]. Chevalier Jackson, an otolaryngology surgeon and Professor of Laryngology at Jefferson Medical College in Philadelphia, in 1913 modified a suspension laryngoscope (creating a tubular "U"-shaped instrument with a blade and handle)[13] using it first with a light source on the operator's head and then distal to the instrument, which featured a sliding system at the base thus creating space for an endotracheal tube[14] or a rigid bronchoscopic optic[15]. In the same year, the American anesthetist Henry Janeway at Bellevue Hospital in New York created a laryngoscope equipped with a battery-powered light source located inside the instrument handle. Additionally, he created an anchoring system on the blade, which he designed slightly curved to facilitate laryngoscopy, defining, without proper credit, the foundations of modern laryngoscopy and general anesthesia with endotracheal intubation with the first landmark article[16]. After Janeway's laryngoscope, numerous modifications followed until 1941, when Robert Miller, an American physician, designed a blade with a semicircular flange and straight blade, whose use facilitated visualization of the *aditus ad laryngem* during the laryngoscopic maneuver, but with two important limitations. The first was represented by potential trauma to the dental arch, and the second was the laryngeal view obscured by the passage of the tube inside the semicircular channel of the flange. The second problem was partially solved in collaboration with Sir Robert Macintosh, an English physician who modified a urethral dilator (bougie) into a guide that passed inside the Miller blade flange without obscuring the glottic view, over which the tube could subsequently slide (under partial vision)[17]. Sir Ivan Whiteside Magill developed an evolution of Jackson's laryngoscope in 1931, incorporating batteries into the handle and articulating a folding blade[18], in a (new) dispute with Rowbotham for primacy of invention, not only of the laryngoscope but also of Magill forceps, which apparently were originally developed by Rowbotham himself[19]. The true innovation proposed by Sir Macintosh was to redesign a blade with continuous curvature, from articulation with the handle to the distal end, which allowed maintaining excellent approach to laryngeal visualization in a more protective manner for dentition[20], and above all to define and codify the technique of use[21]. Miller's blade ("straight")[22] is still used today, especially in the neonatal population, while Macintosh's curved blade accompanied generations of anesthetists until the early twenty-first century. In the 60 years of Macintosh blade use, apart from variously successful "variations on the theme", such as the articulated segmented blade ("flexiblade"), the Macintosh blade with articulated tip ("McCoy")[23], the only significant innovation was probably represented by the development, by Dr. Paul Venn, of the first tracheal introducer with "coudé" tip, launched on the market in 1972 and since then universally defined as "gum elastic bougie" (in honor of the first "straight" bougie developed by Macintosh)[24–26]. Parallel to the evolution of the laryngoscope, the introduction of new batteries and especially optical fibers allowed improvement of the laryngoscopes' illumination systems, and in 1967 Shigeto Ikeda of Asahi Pentax Corporation developed a prototype fiberoptic bronchoscope[27,28], which allowed bringing the human eye to the bronchial branches, opening new perspectives for tracheal intubation with fiberoptic bronchoscope (described by Calder and Murphy in 1967)[29,30], even in the "awake" patient in spontaneous breathing[31]. The last true innovations in laryngoscopy came in the 1990s, with "hybrids" between rigid and articulated laryngoscopes (Bullard scope[32], Wu-scope[33], UpsherScope[34]), and with Berci's intuition (who in 1988 coupled a video system to a Macintosh laryngoscope[35]) that formally initiated the videolaryngoscope "revolution" at the turn of 2000.

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Weiss in 1998[36] coupled optical fibers to a standard laryngoscope, while Berci and Kaplan, in the same year, published a report of a Macintosh laryngoscope mounting a CCD video camera system. In 2001, American surgeon John Pacey, together with Canadian anesthetist Richard Cooper, developed the Glidescope®, the first true videolaryngoscope in history, with a hyperangulated blade and video system at the blade tip[37]. From 2000 onwards, a large number of videolaryngoscopes have appeared with the most diverse characteristics: from single-use to reusable models, devices with reusable handle/screen and disposable blade/blade cover; Macintosh-like blades and models with hyperangulated blade with proprietary curvature, devices with the possibility of oxygen supplementation and videolaryngoscopes equipped with a channel or semi-guide for tube direction, models dedicated to nasal intubation and models for use with double-lumen tubes. Regardless of specific characteristics, however, the videolaryngoscope revolution has implied a series of technical and non-technical changes, summarized in Table 1.

Table 1. Comparison of traditional laryngoscopy and videolaryngoscopy.

Traditional Laryngoscopy	**Videolaryngoscopy**
Alignment of axes – line of sight	Non-alignment of axes – look around the corner
Laryngoscopic vision limited by line of sight	Better laryngoscopic vision
Vision = intubation	Vision does not necessarily = intubation
Mechanical articulation of the blade	No articulated mechanical parts
Different types of blades and sizes	Different types of blades and sizes
Less illumination	Better illumination
Tunneled vision	Vision on incorporated and/or separate screen
Individual operator-patient relationship	Shared patient-team vision
Need for double tube position check	Better/immediate tube position check
Indirect teaching (operator feedback)	Direct teaching (shared vision)
Eye-hand-tube coordination	Eye-screen-hand-tube coordination
3D vision	2D vision
Obligatory position	Better intubation ergonomics
Defined learning curve	Learning curve under definition

The recent COVID-19 pandemic then represented an important push in the evolution and diffusion of videolaryngoscopes: the observation that a videolaryngoscope allowed doubling the distance from the patient's airway, a source of viral infection, from about 17 to about 35 centimeters[38] and the awareness that the external video allowed better vision through personal protective equipment, as well as its sharing with the team[39], meant that the pandemic indirectly promoted the diffusion of videolaryngoscopes, whose number strongly increased comparing pre- and post-pandemic censuses[40].

What is certain is that, within two decades, with a pandemic that favored and promoted the diffusion of these instruments, the approach to laryngoscopy and intubation has radically changed.

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After almost one hundred years of searching for line of sight, the new millennium has seen us return to Manuel Garcia's indirect laryngoscopy, replacing mirrors and candles with video cameras and LEDs, leading us to "see (better) around the corner" (*look around the corner*) and shifting the center of gravity of difficulty to the passage of the tube between the vocal cords of a very well-visualized larynx.

2. The Airway Around the Corner

Videolaryngoscopy has represented not only a technological but also a cultural evolution: by redefining airway visualization and facilitating it, it has determined:

- Reassessment of the concept and predictive parameters of difficulty: while maintaining mouth opening (interincisor distance[41]), macroglossia, rigidity of neck structures post-radiation or post-surgery, classic predictive parameters of difficulty such as atlo-occipital extension, thyromental distance or mento-hyoid distance have taken on a different meaning with videolaryngoscopes, since the alignment of oral, pharyngeal, and tracheal axes is no longer the mechanism underlying visualization. There are not many studies that have analyzed predictive parameters of "pure" videolaryngoscopic difficulty, but certainly several have identified the institution and experience in use as an important predictive factor for intubation success with videolaryngoscope[42–44].
- Definition of two learning curves: that of the naïve user (who starts from videolaryngoscopy) and that of the Macintosh user, who have to "forget" the direct laryngoscopy technique to learn the new videolaryngoscopy technique. The classic work of Mulcaster[45] identified 47 as the number of laryngoscopy attempts with a Macintosh laryngoscope as a cutoff for optimal learning of the technique. Similarly, another work by the Italian group of Cortellazzi[46] identified 76 as the number of attempts with videolaryngoscope to achieve the same objective. This difference certainly reflected the era in which the study was carried out (early phases of videolaryngoscope diffusion), thus less background and the need for a shift from the concept of line of sight to that of look around the corner. More recent studies, in an era where universal videolaryngoscopy is now discussed[47], indicate that the number of attempts to acquire skills with the hyperangulated blade videolaryngoscope in subjects already familiar with airway management drops to 12[48].
- Facilitation of teaching: Classic laryngoscopy required direct feedback from the user, who in the early phases of the learning curve certainly might not be able to correctly report the difficulty, often determining the need for the trainer to intervene directly, sometimes intervening directly on laryngoscopy and intubation. Certainly videolaryngoscopy, considering the possibility of sharing vision (or limiting it to only the teacher, who observes the screen while the student uses the Macintosh blade in direct vision) represents an enormous possibility in teaching terms, so much so that recent meta-analyses indicate videolaryngoscopes as the preferential teaching instrument[49]. The topic is not exempt from debate, with supporters of classic laryngoscopy focused on the need, imposed by the "old technique," to better know anatomy, structures, and the physiology of intubation[50]. Probably the combined approach (user on laryngoscope and teacher on screen) also fills this teaching gap.
- Facilitation of evolution toward teamwork and valorization of non-technical skills: The possibility of transforming laryngoscopy from a 1:1 relationship between the operator and the patient to team visualization implies an important series of advantages that reverberate both on airway control success and on patient safety[51]. Shared vision of the moment of laryngoscopy and intubation allows targeted help from the assistant, sharing observation of anatomy and any pathological findings, choice of tube size, shared verification (or doubt) of correct endotracheal tube positioning (so much so that recent PUMA guidelines indicate the videolaryngoscope as the second instrument after capnography for verification of correct tracheal intubation)[52]. In a sense, the videolaryngoscope acts as a *nudge*, a gentle push toward sharing and teamwork, coordinating team actions and, ultimately, improving patient safety.

The true revolution associated with videolaryngoscope use, however, was realizing, accepting, and consequently finding a new technique that allowed directing the tube between the vocal cords moving along a line no longer straight but characterized by at least two curvatures (Figure 1).

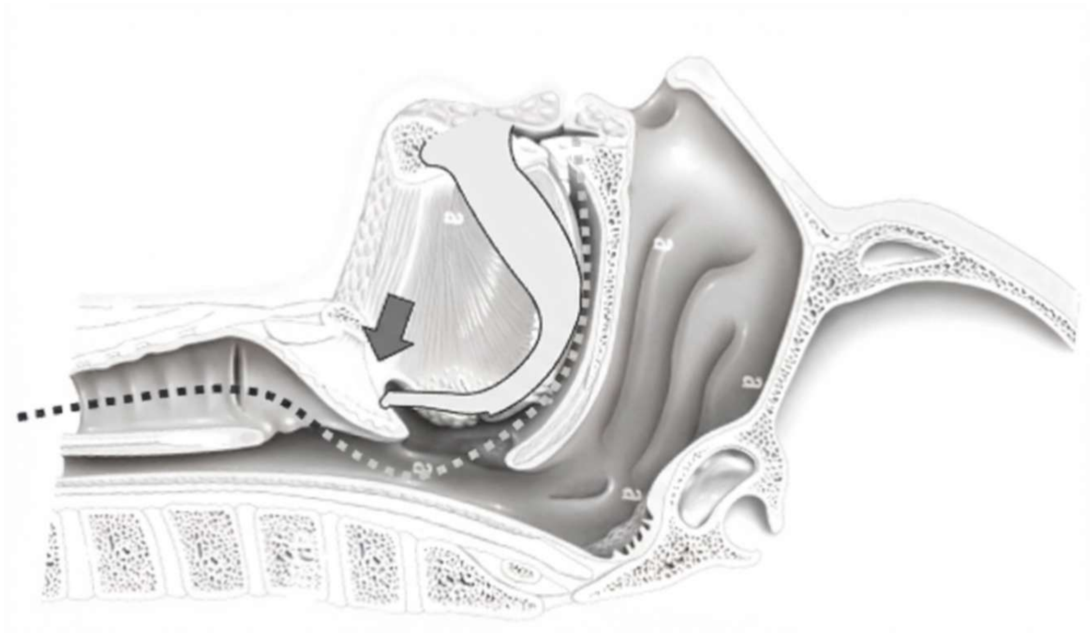

Figure 1. The curvature of oral, pharyngeal, and tracheal axes during videolaryngoscopy.

The result of this situation, especially in the initial phases of videolaryngoscope use, was the materialization of a paradoxical situation in which, faced with excellent (and superior to Macintosh) laryngoscopic vision, intubation could be difficult or unsuccessful due to impossibility of directing the tube between the vocal cords, especially when using a hyperangulated blade. Although not intuitive, the explanation was very simple: in the transition from Macintosh, which by aligning the axes defined a linear and straight path for the tube (whose movement moreover was directly coordinated by the operator's gaze), the intubating world had to move to a situation in which the tube had to undergo a series of curvatures, with the further complexity related to the fact that this passage occurred by coordinating the movement of the tube and the operator's hands through the screen. This may explain the initial increase in the steepness of the learning curve, and yet explain a series of failures, and above all why the use of the hyperangulated blade videolaryngoscope requires the use of an adjunct, such as a malleable preformable stylet, a preformed rigid one (choice of various production companies), a tracheal introducer, or a stylet or introducer with articulated tip. Alongside these devices, further technical elements consist of choosing a smaller blade size, so as to move the fulcrum point back and gain space and depth of field in the hypopharynx[53]; again in using smaller diameter tubes (possibly to be changed subsequently on a tube exchanger guide) and in reducing (video) laryngoscopic traction at the moment of passing the tube between the vocal cords, so as to reduce the angle that forms between the hypopharynx and the tracheal axis (Figure 1). Interestingly, the existence of these difficulties during the Macintosh-Videolaryngoscopy transition phase, together with the fact that many studies were case series or manikin studies, determined an interesting phenomenon from a scientific point of view. A first systematic review on the use of videolaryngoscopes published by the English group of Lewis in 2017 discouraged, in some way, the use of videolaryngoscopes. The results, especially on first-pass success, intubation time, desaturation episodes, and esophageal intubation, were not as positive[54] as one might have expected based on the laryngoscopic visions that videolaryngoscopes had by then accustomed anesthetists to. Similarly, a large study published in JAMA by the French group from Montpellier on Intensive Care patients[55] presented really poor results for videolaryngoscopes, with greatly lengthened intubation

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times that, intuitively, resulted in a greater number of complications in fragile ICU patients (the so-called "physiologically difficult airway")[56]. However, the French study can give us the right reading key for what we know today. The physicians enrolled in the study were in large part physicians in training, half of which were not even anesthesiologist-intensivists: once again, experience and videolaryngoscopes travel closely side by side and explain the poverty of results. When in fact in 2022, Hansel's group (which included Lewis himself) published a second systematic/Cochrane review[57], after years of routine use and experience with videolaryngoscopes, and especially after a pandemic that had favored their widespread diffusion, the results were reversed, with an overwhelming success of videolaryngoscopes on all endpoints, from intubation success to the time to obtain it, to desaturation episodes and complications, including unrecognized esophageal intubation. After Hansel's study, the results were further confirmed by other important publications. In intensive care, where we find the most fragile patients with physiologically difficult airway (that is, where the anatomical factor may be normal, or that however, even if altered, becomes secondary to reduced apnea tolerance, hemodynamic instability, absence of reflexes, and the many problems of the critical patient)[58], the INTUBE study[59], and in particular the sub-analysis on videolaryngoscopy[60], highlighted the superiority of these devices. And again, Prekker's study in the New England Journal of Medicine[61], reversing Lascarroux's results, consecrated the use of videolaryngoscopes in Intensive Care. Further systematic reviews have definitively sanctioned the superiority of videolaryngoscopy both in the operating room[62] and outside it[63], determining the maturity of the airway manager community for the switch toward universal videolaryngoscopy[64].

3. The Best Adjunct

Having clarified the differences in technique and approach, and consolidated the learning and training path for videolaryngoscope use, the literature debate today is focused on the search for the best adjunct device for videolaryngoscopy. Originally, various manufacturers supplied the videolaryngoscope with a dedicated rigid stylet, with curvature that generally reflected the shape of the videolaryngoscope's blade. Alongside this technique, various users resorted to using a soft, malleable stylet, which they shaped according to the laryngoscopic view or again with 90 degrees hockey-stick type distal curvature. Some manufacturers also presented stylets with articulated distal tip, hypothesizing that this function could contribute to an increase in intubation success [65]. More recently, the bougie, or tracheal introducer, has experienced a sort of second youth. Born in 1973 with the idea that the coudé tip could facilitate intubation by approaching difficult laryngoscopic views (Cormack-Lehane 2, 2e, 3), the original introducer has undergone various evolutions, especially in the transition from reusable to disposable. Today there are many introducers on the market, but the ones better performing with a videolaryngoscope seem to be those made out of polyethylene (with different density variables), as this material allows having a certain shape memory, unlike Teflon, PVC, and other material blends. The main advantage of the introducer, in itself, is represented by greater length and smaller diameter when compared to an endotracheal tube [66], which allows separating the negotiation of the passage of the introducer (small diameter) between the vocal cords from the tube (larger diameter), as shown in Figure 2.

Various studies have analyzed the comparison between the two techniques, with two meaningful and paradigmatic papers by the American group of Brian Driver. The first paper, designed as a single-center study compared stylet vs introducer on first-pass success with (video)laryngoscope in the emergency department[67], whereas the second one, designed as multi-centric, explored the same endpoint but in intensive care unit[68]. While the emergency department study demonstrated clear superiority of the introducer over the stylet (96% vs 82%), the results of the multicentric intensive care study failed in reaching the same figures (80.4% vs 83%). Excluding any difference between resuscitation and emergency department patients in anatomical terms, the only explanation lies, once again, in users' expertise. The first study, single-center, was conducted by a group of users experienced with videolaryngoscope and introducer, unlike the second, multicenter, where various degrees of competence and expertise probably influenced a greater results' variability. In expert hands, and according to logic criteria, the introducer should be superior to the stylet, as, not a case, today the videolaryngoscope-introducer association is recommended from the first attempt on a patient with anatomically and/or physiologically predicted difficult airway[69,70]. The question, however, is far from finding definitive solutions. The real problem remains that the introducer, like the Macintosh laryngoscope, was designed to operate and favor the linear approach of the search for a line of sight, while hyperangulated blade videolaryngoscopes kept in place anatomical curves and angles. Tout court application of a bougie to a videolaryngoscope means applying a *linear solution* in a *curved problem*, which is probably the reason behind the active debate including dynamic bougies, articulated introducers, and studies on different forms and approaches to maximize intubation success[71–74].

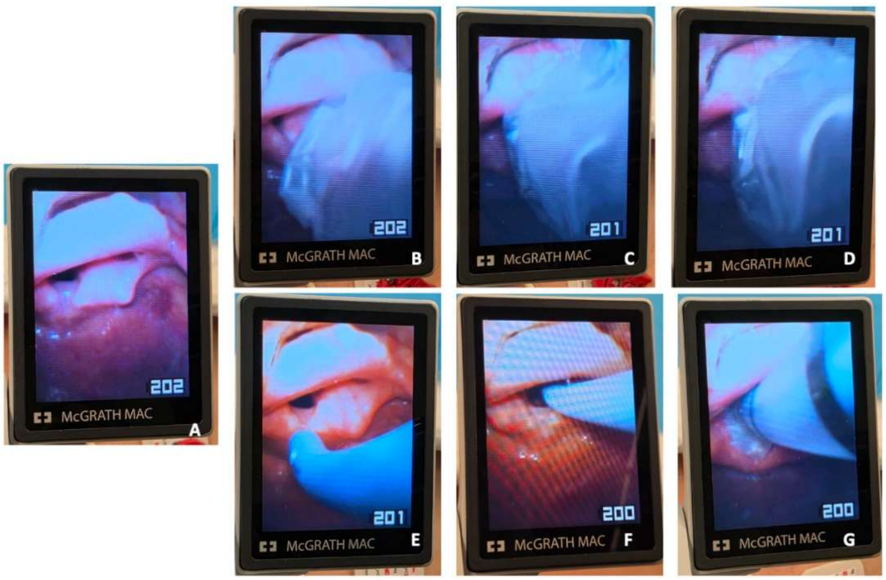

Figure 2. Videolaryngoscopy without (b,c,d) and with (e,f,g) tracheal introducer. Starting from the same videolaryngoscopic exposure (a), use of a styletted tracheal tube results in partial/complete obscuration of laryngeal view inlet (b,c) including the moment of tube passage between vocal cords (d). When a tracheal introducer is used, a better laryngeal exposure may be obtained (the introducer in correct position lifts the epiglottis – e,f) and tube passage between vocal cords results clearer (g).

4. Videolaryngoscopes, Strategy, and Human Factor

Analyses of the Danish Anesthesia Database[75], data from the National Audit Project 4 (an extensive one-year audit conducted in England by RCOA and AAGBI)[76], medico-legal UK sources[77], and American Closed Claims Projects[78] unanimously suggest that the so-called *human factor* plays a pivotal role in airway-related accidents occurrence. The absence of strategy and planning, lack of adequate and assertive communication, stress-associated physiological effect of cognitive biases, especially in emergency, represent in fact the common denominator of all documented incidents[79]. Recent guidelines for airway management[80], the PUMA project (Project for Universal Management of Airways – www.universalairway.org)[81] and human factor-oriented research emphasize the importance of non-technical skills, simulation, checklists, cognitive aids and teamwork as the key for a successful approach to improve airway management safety and success[82,83].

Videolaryngoscopes in this context may be a double-edged sword. On one hand they exhibit a manifold role as the best tool to maximize intubation first-pass success, an effective and powerful teaching method[84] and last but not least a natural facilitator of team interaction during airway management. These features clearly allow a significant potential in reducing airway-related

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accidents. On the other hand, videolaryngoscopes, making intubation somehow easier and within reach of less experienced personnel, may induce evaluation errors and lead to no-way-back choices (such as neuromuscular blocking agents administration) where the preponderant patient's difficulty is ventilation and oxygenation. Prediction, to be performed in a *context-sensitive* manner[85], remains of cornerstone importance as a tool to establish choices and strategies. When correctly located in the frame of a strategy, videolaryngoscopes are natural providers of team intubation, improving success and reducing cognitive biases; they are no magic bullet, given that they cannot provide oxygen in an anesthetized patient[86,87]. There are conditions and patients in which choices for airway control may be different from tracheal intubation, even with videolaryngoscope. The old question "*will my patient be difficult to intubate*?" should be modernly turned into an awareness ("*I must define the strategy to manage this patient's airway*") carrying a new question: "*can I suppress the patient's spontaneous breathing?*". Any guideline proposing an *a priori* harsh separation between predicted and unpredicted difficulty)[88] probably remains outdated, and oxygenation and oxygenability should remain the only priorities[89]. Should the decision be for anesthetized intubation, administration of neuromuscular blockers becomes a consequential and unavoidable step of the strategy[90]. Conversely, if the only available plan B is maintaining spontaneous breathing, the choice of device (laryngoscopy, videolaryngoscopy, flexible bronchoscope, tracheotomy/cricothyrotomy under local anesthesia, ECMO cannulation)[91] becomes secondary to the choice of maintaining the patient's spontaneous respiratory activity and airway muscular tone. Awake intubation with videolaryngoscope, where possible and indicated, is equally performing in terms of success if compared with the gold standard of flexible bronchoscopy, with greater executor compliance and less patient discomfort, with overlapping times and success percentages[92–94]. Probably, awake videolaryngoscopy represents a more familiar technique when compared with the flexible bronchoscope intubation for most anesthetists, and it may have contributed to the growing diffusion of the awake tracheal intubation idea, with the indirect result of improving patient safety[95,96].

5. Conclusions

Difficult laryngoscopy is now probably rarer, and certainly many of those "classically" predictive factors for laryngoscopic difficulty have consequently been downsized. At same time, we have no evidence of specific predictive factors of videolaryngoscopic difficulty, except for reduced interincisal distance and the evidence of new cutoffs for the values we were accustomed to measuring. However, it is indisputable that videolaryngoscopes have changed the pattern of intubation difficulty[97]. The use of these devices can in itself be a trigger for cognitive biases and decision errors, insofar as awareness of a more effective instrument can raise the prudence threshold and lower that of "weight" of prediction faced with particularly challenging but not predictably extremely difficult cases. Conversely, their correct and prudent use and placement in the context of a decision-making algorithm results in valorizing non-technical aspects and team potentials, facilitating interaction, communication, evidence of error, and targeted help. New and interesting promises and prospects come from the growing development and exponential interest toward artificial intelligence [98], which could have an important role from difficulty prediction, real-time intubation assistance and teaching facilitation[99]. At present, the key research nodes concern identification of the best technical approach and definition of the best adjunct instruments, to overcome the difficulty of passing the tracheal tube even faced with brilliant laryngoscopic vision, the price to pay in the transition from Macintosh linearity to the curvilinear world of videolaryngoscopes. In the near future we can expect an improvement in optical performance, a thinning of blades, an implementation of sensors, monitoring, and probably real-time cognitive support, but the objective of (video)laryngoscopy remains the same as MacEwen, Jackson, and Macintosh: see the vocal cords, intubate the trachea, and guarantee our patient's oxygenation.

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