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Review

Styletubation versus Laryngoscopy: A New Paradigm for Routine Tracheal Intubation

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Abstract: Laryngoscopy for tracheal intubation has been developed for many decades. Among various conventional laryngoscopes, videolaryngoscopes (VLs) have been applied in different patient populations, including difficult airways. The safety and effectiveness of VLs have been repeatedly studied in both normal and difficult airways. The superiority of VLs then has been observed and is advocated as the standard of care. In contrast to laryngoscopy, the development of video-assisted intubating stylet (VS, also named as styletubation) was noticed two decades ago. Since then, sporadic clinical experiences of use have appeared in the literature. In this review article, we presented our vast use experiences of the styletubation (more than 55,000 patients since 2016). We found this technique to be swift (the time to intubate from 3 s to 10 s), smooth (first-attempt success rate: 100%), safe (no airway complications), and easy (high subjective satisfaction and fast learning curve for the novice trainees) in both normal and difficult airway scenarios. We, therefore, propose that the styletubation technique can be feasibly applied as universal routine use for tracheal intubation.

Keywords: styletubation; video-assisted intubating stylet; tracheal intubation; laryngoscope; videolaryngoscope; anesthesia; difficult airway; airway management; paradigm shift; new paradigm

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1. History of Laryngoscopy

In the late 19th century, a device/tool to visualize the glottis, invented and subsequently modified by mainly ear–nose–throat (ENT) doctors, was called the laryngoscope (for review, see [1]). To acquire such a glottis view, either direct or indirect, laryngoscopes served a supportive role for ENT doctors to surgically treat patients. Interestingly, the laryngoscope was not used to perform intra-tracheal intubation and general anesthesia until the early 20th century, first reported by Chevalier Jackson and Henry Janeway, respectively. It is worthy to mention that Janeway plays an important role in the transition phase of such laryngoscopes from being a tool used solely by the ENT specialist to a fundamental instrument used by the anesthesiologist. Since then, to see the glottis and to place an insufflation tube into a patient's trachea became a clinical skill, either for airway management or clinical anesthesia.

While use of a conventional direct laryngoscope (DL) with a blade to perform tracheal intubation became popular, the airway managers immediately found occasional incidence of difficulties or failure. Several patient's factors were identified to be associated with the likelihood of traumatized temporo-mandibular joint, mouth, or other soft tissue injuries. Those risk factors include prominent sternal region, narrow space between the incisors, reduced intra-oral space, and the anteriorly positioned larynx in patients [2]. A new type of laryngoscope blade, among several others, was later designed to lessen the difficulty of exposing the larynx to pass an endotracheal tube [3]. Meanwhile, several technical tips and pearls were proposed for tracheal intubation under general anesthesia, e.g., head extension, chin lift, elevating the laryngoscope and displacing the base of the tongue upward, protecting upper teeth, viewing and lifting the epiglottis upward, visualizing the vocal cords, and finally passing the endotracheal (ET) tube. It was mentioned that the DL technique is "essentially an easy manoeuvre if simple anatomical rules are obeyed" [3].

Unfortunately, the anatomical rules are not always obeyed for laryngoscopy. In the last few decades, several technical maneuvers were found to be helpful for direct laryngoscopy when the event of a difficult airway (laryngoscopy and/or intubation) was predicted or encountered. The external laryngeal manipulations, e.g., BURP (backward, upward, rightward pressure) [4–8], laryngeal lift [9], sniff positioning [10–13], and various head–neck elevation or hyperextension positions [14,15], were demonstrated to be beneficial for tracheal intubation. It is worthy to mention that the sniffing position does not always achieve alignment of the classical three axes (TAAT; oral/pharyngeal/laryngeal Three Axes Alignment Theory), e.g., in awake patients with normal airway anatomy [16]. It has been proposed that direct laryngoscopy is inherently a three-dimensional performance [17]. Theoretically, alignment of the three axes (oral, pharyngeal, and laryngeal) may seem ideal because it brings all anatomical structures together into one straight line for better vision. However, instead of a theory, whether in clinical practice TAAT is valid has been challenged [18,19].

2. A Paradigm Shift of Videolaryngoscopy

No matter if the axes theories or the external laryngeal manipulations are valid and useful, the anatomical structures are still limited and restrained the laryngeal visualization by the airway managers during the tracheal intubation procedure. The conventional DL is definitely a difficult skill to master and places a heavy mental load for most medical staff, especially for novice practitioners or those who do not perform it on a regular basis. The same is true for experienced airway managers if they encounter difficult airway scenarios (e.g., obesity, limited cervical spine mobility, unstable cervical spine trauma, upper airway obstruction or bleeding, radiation fibrosis or flaps over neck region, etc.). Such difficulties may eventually cause disasters and are reflected by medico-legal misadventure reports. Difficult tracheal intubation events occurred more in sicker patients, in emergency procedures, and in non-perioperative locations. It should also be noted that "can't intubate, can't ventilate" and "physiologically difficult airway" as non-anatomical reasons for the emergence of clinical emergencies may occur during an endotracheal intubation. Eventually, patients' outcomes remained poor in recent malpractice claims related to difficult tracheal intubation [20].

Apparently, "to see is to intubate" is a prerequisite for the success of laryngoscopy, which can be measured by visualization of the glottis opening, first-attempt success rate, time to complete intubation, failure rate, necessity to have assistance or changing accessary devices, complications, etc. In the real world, despite various pre-operative airway assessment parameters, DL occasionally yields expectedly or unexpectedly poor laryngeal views. When this happens, the end results can be devastating, even with ultimate success in airway management. To overcome such "cannot see, cannot intubate" quandary, a new VL (GlideScope® designed by John Pacey in 2001) was made by installing a robust, high-resolution camera (charge-coupled device) embedded into a conventional laryngoscope blade. Such a VL, therefore, is able to yield a comparable or even superior glottic view in comparison to a DL [21]. Successful intubation was generally achieved even when the DL was predicted to be moderately or considerably difficult [22].

Subsequently, it is not surprising that various kinds of the VL quickly gained global popularity as the primary intubating device in many clinical scenarios, driven by quick to learn, ease of use, positive patient outcomes, etc. Such a VL was originally designed to provide an indirect view of the upper airway. Therefore, in clinically difficult airway management, it is hoped that the VL can improve Cormack–Lehane grade and achieve the same or a higher intubation success rate in less time and effort, compared with the DL [23]. Clinically, use of a VL was observed to be associated with fewer failed attempts and complications such as hypoxemia, whereas glottic views were improved [24]. More important, whether the VL could or should replace the DL in patients with normal or difficult airways and serve as a tool for routine tracheal intubation remains a debate and requires conclusive evidence [25,26]. Recently, in critically ill adults undergoing tracheal intubation in the emergency room and intensive care unit, the use of a VL has been demonstrated to result in more successful first-attempt intubation than the DL [27]. It should be noted that such a conclusion might not be applied to airway management in anesthetizing locations (e.g., operating rooms) or by experienced anesthesiologists.

3. Evolution of Optic/Video Intubating Tools

The comparison between the VL and DL has always been around the primary key clinical outcome parameters as first-attempt success rate, intubation time, and overall success rate. The safety outcome parameters, e.g., cardiovascular events (hypoxemia, severe hypotension, cardiac arrest, or death), esophageal intubation, dental and soft tissue injury, and aspiration, also served as the comparison indices. Although the main advantage of the VL is the ability to provide better visualization of the glottis than the DL does, both techniques may still face certain difficulties. For example, the insertion of the laryngoscopic blade into oral–pharyngeal space and advancement of the endotracheal tube/stylet unit may occasionally be awkward and failing.

The original design of the VL allowed indirect laryngoscopy, better laryngeal exposure of the vocal cords and related airway structures without requiring a direct line of sight. Before the invention of the VL, the rigid fiber-optic laryngoscopy (e.g., Bullard laryngoscope™, patented for use in 1995; WuScope™, patented in 1993; and UpsherScope Ultra™, patented in 1995) was also designed to provide a superb glottis visualization in rather difficult airway scenarios. This kind of airway device served as the rescue airway management tool when difficult airway scenarios were predicted or encountered [28]. Unfortunately, such rescue devices generally require a significant amount of clinical experience to achieve proficiency.

Optical stylets (OSs), first coined the term by Berci and Katz [29], are rigid or semi-rigid tubular devices that fit in an endotracheal tube (ET tube) and transmit images using either fiber-optic bundles inside or complementary metal oxide semiconductor (CMOS) video chips at the distal end of the device (for review, see [30]). Another advanced optical intubating device was the rigid stylet invented by Pierre Bonfils in 1983 [31]. The Bonfils endoscope was applied in a pediatric patient with a difficult airway caused by Pierre Robin syndrome. Such a rigid endoscope, instead of being straight and rigid, employed a fixed curved distal tip at the angle of 40 degrees. With this innovative design, it allowed not only better access to the anteriorly located glottis but was also suitable for applying the retromolar technique of tracheal intubation (for review, see [32]). However, in contrast to the flexible fiber-optic bronchoscope (FOB), the straight design of the rigid stylet was not always applicable for the cases of difficult laryngoscopy, and the device itself had to be introduced with the aid of a Macintosh laryngoscope for compressing the tongue base and the epiglottis (bimanual method).

4. Styletubation

In contrast to the conventional concept of laryngoscopy, the ease of using intubating stylet (e.g., Bonfils endoscope) seems promising, either in regular/routine or expected/unexpected difficult airway scenarios. A new design of simple lighted stylet (lightwand) also was demonstrated to be clinically useful, especially when combined with laryngoscopy [33,34]. Although its transillumination-based design principle could not achieve the same goal as other optically seeing intubating tools, the unique “field hockey stick” configuration of the Trachlight™ stick together with the endotracheal tube proved to be useful and practical. One of the hockey stick examples of the stylet is the Shikani Optical Stylet (SOS; Shikani Seeing Stylet™) (Figure 1).

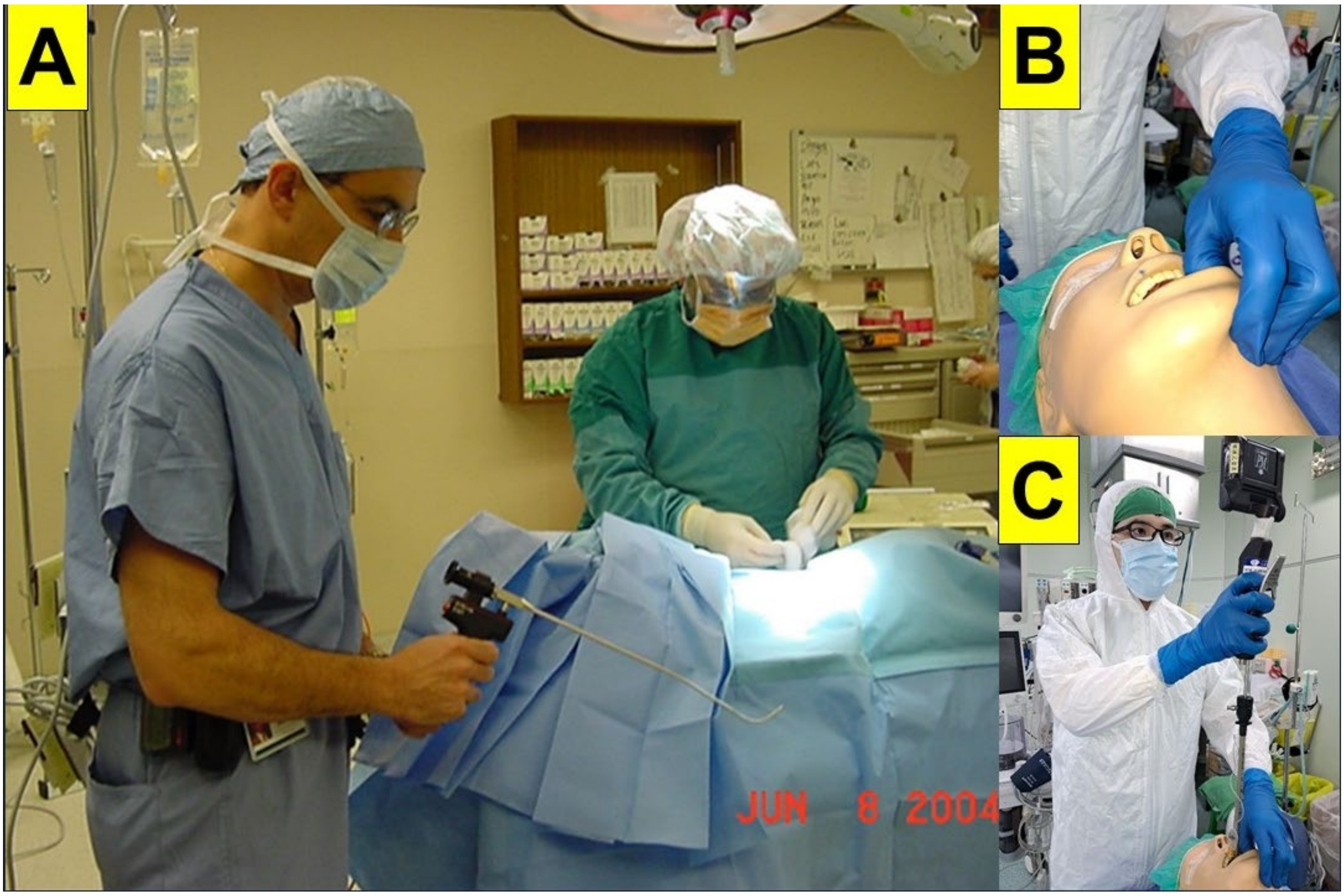

Figure 1. The Shikani technique: (**A**) demonstration with an SOS (Shikani Seeing Stylet™); (**B**) jaw thrust using a non-dominant hand; and (**C**) applying a video-assisted intubating stylet (Storz C-MAC® video stylet) using a dominant hand in a mannequin model.

The SOS (Shikani Optical Stylet™; Clarus Medical, Minneapolis, MN, USA), invented by Alan Shikani and available since 1996, is a new generation of seeing intubating stylet that has a lens at the distal end, a fiber-optic cable inside, and is connected to a camera and a video monitor. Such a design allows continuous visualization of the airway and laryngeal inlet during introduction of the ET tube into the glottis and trachea [35]. The hockey stick design of the stylet facilitates the management of the potential difficult airway, minimizes the risk of trauma to the glottis or dentition, and allows intubation without the absolute need of the rigid laryngoscope blade to retract the base of the tongue. Another modified version of the SOS is the LFS Scope™ (Levitan First-Pass Success scope; invented by Richard Levitan and manufactured by Clarus Medical, 13355 10th Ave N. Suite 110, Minneapolis, MN 55441, USA), a short malleable semi-rigid fiber-optic stylet [36].

Over the past two decades, since the Shikani Seeing Stylet™ and its technique were introduced, a gradual increase in adopting this intubating tool has been observed in the literature. The clinical application of a video-assisted intubating stylet (VS) and the Shikani technique (Figure 2) covered a broad spectrum of airway management scenarios, such as pediatric difficult airways, limited cervical spine mobility, limited mouth opening (but still enough to accommodate an ET tube), head–neck lesions, obesity, etc. [37–44]. Because an operational technique like the Shikani technique with a VS is sharply different form that of a conventional laryngoscopy technique, we, therefore, coined the term "styletubation" to reflect its uniqueness and advantages (Figure 2) [45–48]. In the following text, we will present several related issues to the styletubation technique.

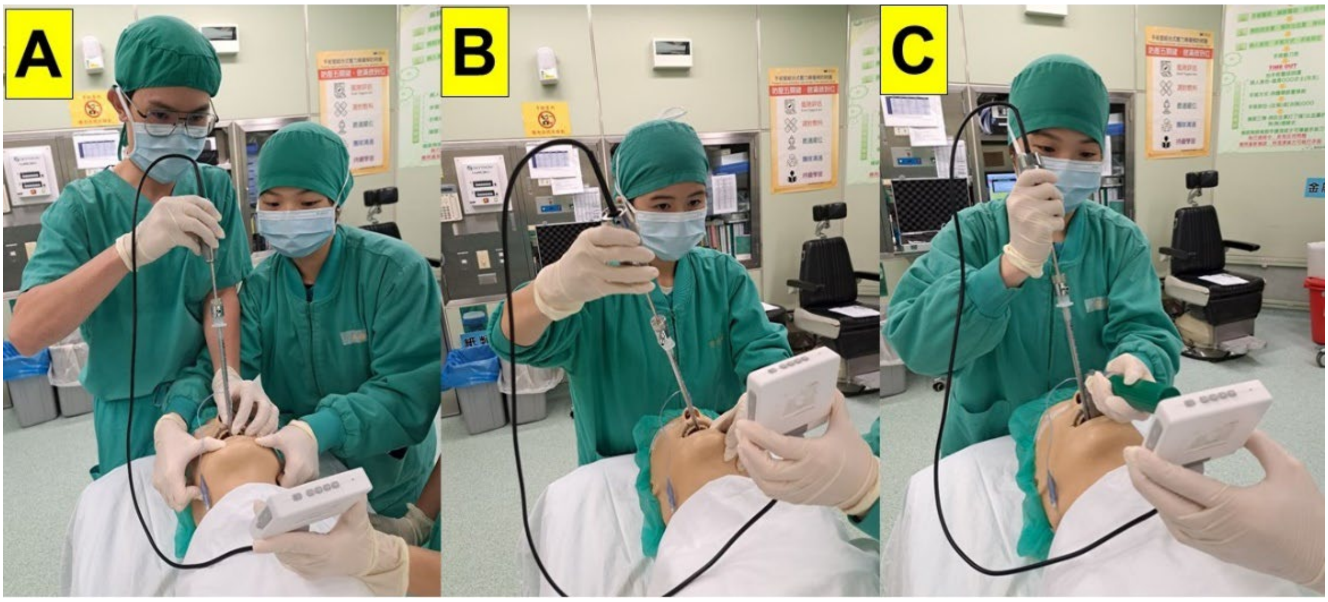

Figure 2. Styletubation technique (video-assisted intubating stylet technique): (**A**) two-person method; (**B**) one-person with jaw-thrust method; and (**C**) one-person with laryngoscopic assistance model. The video-assisted intubating stylet is the S-RVL Video Stylet (Sensorendo Medical Technology, Zhuhai, China). The video monitor is separated from the stylet and connected with a cable.

5. Cases Presentation

5.1. Awake FOB or Styletubation for Emergency Tracheostomy

When appropriate, awake (oral or nasal) intubation should be considered if the difficult airway of the patient is suspected (e.g., difficult ventilation, increased risk of aspiration, short apneic tolerance, expected difficulty with emergency invasive airway rescue) [28]. Typical examples include a huge tumor over head and neck [49,50] or undergoing oral maxillofacial surgery [51]. It should be emphasized that awake FOB is still the gold-standard tracheal intubation for such intractable and difficult airway scenarios, although other modified intubation modalities have been mentioned. For example, the advantageous role of a VS for trans-nasal tracheal intubation has been compared with that of laryngoscopy [52] and FOB [53,54]. Meanwhile, it should be noted that serious critiques on the trans-nasal use of a VS for difficult airway have also been made [55].

For predicted difficult airways, pre-operative trans-nasal or trans-oral endoscopic airway examination (PEAE) [56–58], together with imaging studies, provided useful clinical information to make a plan for tracheal intubation (awake, asleep, or anesthetized intubation). The FOB, among various awake tracheal intubation options, has a reasonable success rate and a favorable safety profile in cases of anticipated difficult airway management [59]. However, difficulties (e.g., impaired glottis visualization by secretions/blood, impingement during ET tube advancement) may occur [60,61]. Figure 3 shows a typical case of a 60-year-old man with past history of right vocal leukoplakia and a granular tumor diagnosed 8 years ago. Later diagnosis was progressive squamous cell carcinoma of the glottis–subglottic larynx (T1N0M0) with radiotherapy (6600 cGy). The MRI sequences confirmed these endoscopic findings on the vocal folds with the glottis–subglottic space reduction. The airway assessment conducted after tracheostomy shows normal by the classic predictors (i.e., mouth opening size, Mallampati score, sternomental distance, and upper lip bite test). The pre-operative nasoendoscopic images show recurrent tumor growth gradually in two years until causing dyspnea and signs of airway obstruction in the ER. To be on the safe side, the airway operator decided to perform awake nasal FOB for tracheal intubation, instead of applying styletubation. Emergent tracheostomy was performed after successful establishment of airway.

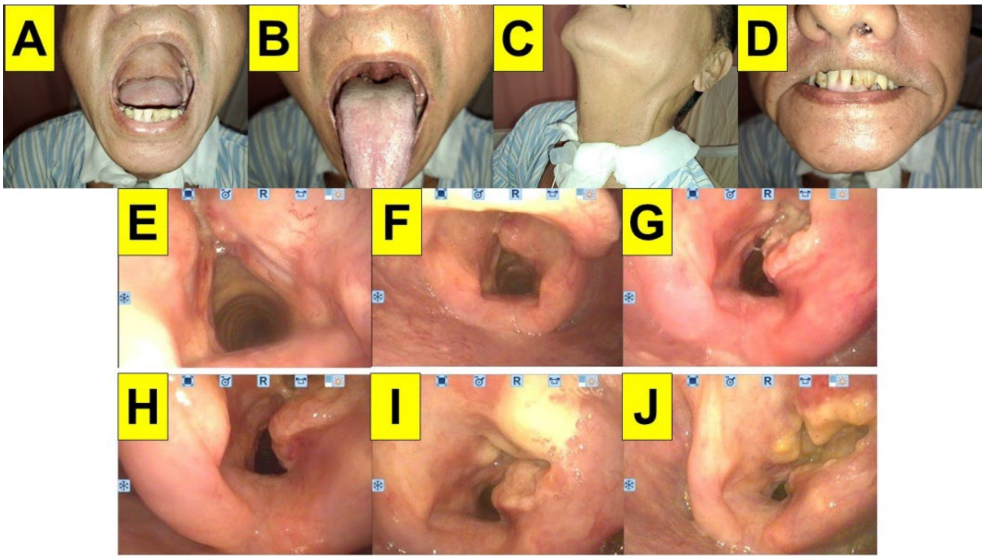

Figure 3. Emergent tracheostomy with awake FOB technique for tracheal intubation in a patient with glottis carcinoma. The airway assessment performed after tracheostomy reveals normal by the classic predictors ((**A**) mouth opening size; (**B**) Mallampati score; (**C**) sternomental distance; and (**D**) upper lip bite test). A series of pre-operative nasoendoscopic images (from (**E**–**J**)) show recurrent tumor growth gradually until causing dyspnea and signs of airway obstruction. Emergent tracheostomy was performed after successful establishment of airway by awake nasal FOB.

In contrast, the styletubation could be adopted as the first-line tool for tracheal intubation in certain difficult airway scenarios. Three typical cases with upper airway obstruction and dyspnea include hypopharyngeal and supraglottic carcinoma (Figure 4). However, the styletubation technique would very much depend on the airway operator's preference, clinical competency, and experiences. Without such self-confidence, awake FOB should be the option for tracheal intubation.

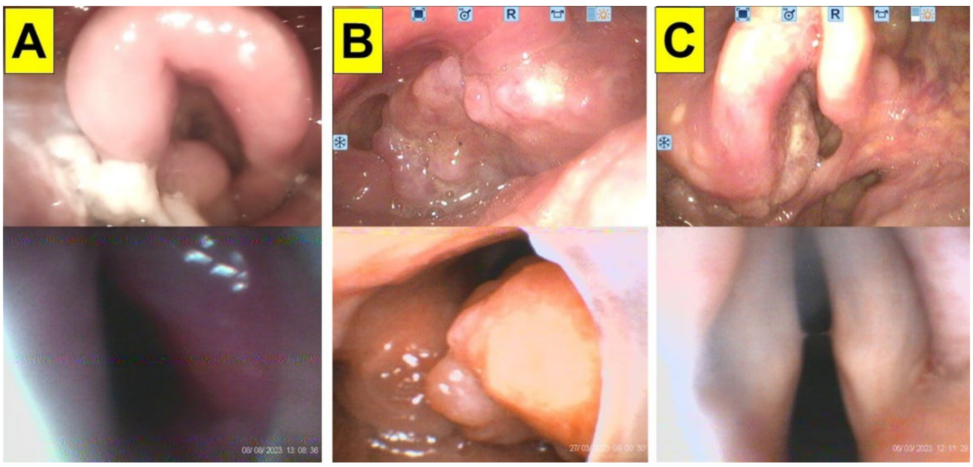

Figure 4. Pre-operative endoscopic examination (PEAE, upper panels) and styletubation (lower panels) applied in three examples of predicted difficult airways. (**A**) A 60-year-old man suffered recurrent left hypopharyngeal squamous cell carcinoma with concurrent chemoradiation therapy (CCRT) one year ago. Emergent tracheostomy was performed due to dyspnea caused by soft laryngeal tissue swelling and airway compression and deviation. (**B**) A 65-year-old man suffered from right hypophyaryngeal squamous cell carcinoma (cT3N0M0) with CCRT. He was admitted for laryngomicrosurgery (LMS) due to dyspnea, choking, dysphagia, and body weight loss. (**C**) A 75-year-old man suffered from supraglottic squamous cell carcinoma (cT3N0M0) with CCRT. He underwent tracheostomy due to dyspnea and stridor.

5.2. Styletubation Grading System for Tracheal Intubation

Numerous pre-operative airway evaluation methods have been used to predict whether potential difficult tracheal intubation might eventually occur in apparently normal patients [62–64]. In addition to the traditional airway physical examinations [65–67], several other individual physical examination findings might be predictive but do not reliably exclude the likelihood for a difficult tracheal intubation by laryngoscopy. Among them, upper lip bite test (ULBT) is reported to be an accurate individual bedside clinical assessment [68–72]. Other individual tests that might be helpful to predict difficult airway include neck circumference, cervical spine mobility, hyomental distance, thyromental distance [73–75], sternomental distance [76], etc. A simplified pre-operative multivariate airway risk index may improve risk stratification for difficulty when laryngeal visualization is to obtain during rigid laryngoscopy (e.g., grade 4) [77].

While modified Mallampati classification (MMC) is an assessment to describe the relative size of the tongue base in relation to the oropharyngeal opening and space [65,66], it is for predicting the difficult airway by rigid laryngoscopy and not for others (e.g., FOB and styletubation). After the larynx is exposed by laryngoscopy, the degree of difficulty for glottis visualization is then described by the Cormack–Lehane classification [78,79]. The scoring system can predict the difficulty of advancement and insertion of an ET tube into the trachea. Further, the percentage of glottic opening (POGO) scale is to assess airway visualization during endotracheal intubation by laryngoscopy, and such a POGO score shows good reliabilities and is able to distinguish patients with large and small degrees of partial glottic visibility [80]. Therefore, the POGO score might provide a better outcome for assessing the difference between various intubation techniques and modalities.

It should be stressed that "to see" (glottic visualization) and "to insert" (advancement of ET tube into trachea) are separate parts of the tracheal intubation procedure. In contrast to the conventional roles of Mallampati score or Cormack–Lehane classification for laryngoscopy, the difficulty grading system of styletubation appears to be quite different. Although all the optic intubating instruments share similar difficulties (e.g., interfered by secretions, blood, vomitus, collapsed soft tissues), the main challenges for the operation of the styletubation technique is the impact by the position status of a patient's epiglottis. Usually, a normal shape and size of the epiglottis can easily be lifted up and pulled away from the posterior pharyngeal wall using the jaw-thrust maneuver. After passing the stylet–ET tube unit under the epiglottis, a well-exposed glottis structure facilitates subsequent advancement and placement of the ET tube into the trachea.

We, therefore, established an LQS (Luk–Qu–Shikani) grading system for such styletubation conditions. The degree of difficulty performing styletubation can be categorized into three levels. The LQS grade 1 is defined as any part of the glottis structure that can be seen in front of the epiglottis, usually with help of the jaw-thrust maneuver (Figure 5). A trained airway operator (novice or experienced operator) can easily and smoothly perform styletubation in patients with LQS grade 1. When the epiglottis can be observed but only be lifted up a little with a marginal space beneath the epiglottis to allow the stylet–ET tube set to pass through, then it is an LQS grade 2 (Figure 6). Usually, styletubation in patients with an LQS grade 2 is not difficult. Rare but difficult, when the epiglottis can not be lifted up at all and completely drops downward against the posterior pharyngeal wall, it is defined as an LQS grade 3 (Figure 7). In patients with an LQS grade 3, difficult airway should be expected, and cautious efforts are needed to operate. Usually, this rare scenario occurred in patients with a certain degree of obesity, stiff neck (e.g., radiation fibrosis, status of flap reconstruction, tumor), ankylosing spondylitis, and cervical spine immobility. In our experiences, the prevalence of grade 1 and grade 2 is about 65% and 35%, respectively. In anticipated difficult airway scenarios, the chance to observe grade 3 is higher.

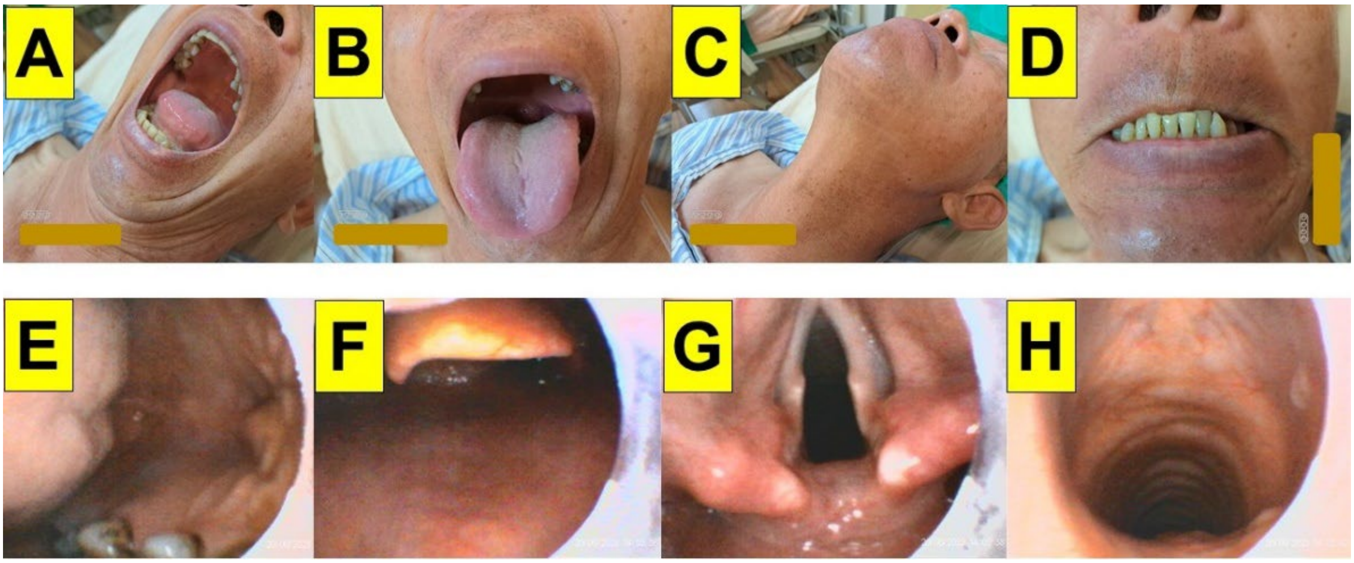

Figure 5. LQS grade 1: a 63-year-old man with a BMI 26.9 kg/m^2 (height 169 cm, weight 77 kg). (**A**) Mouth opening with inter-incisor distance 5.5 cm; (**B**) MMC class II; (**C**) sternomental distance 18 cm; (**D**) ULBT class 1; (**E**) oral entrance view; (**F**) epiglottis view and partial glottis can be seen; (**G**) vocal cord view (POGO 100%); and (**H**) tracheal rings view. (see Video S1 in the Supplementary Materials).

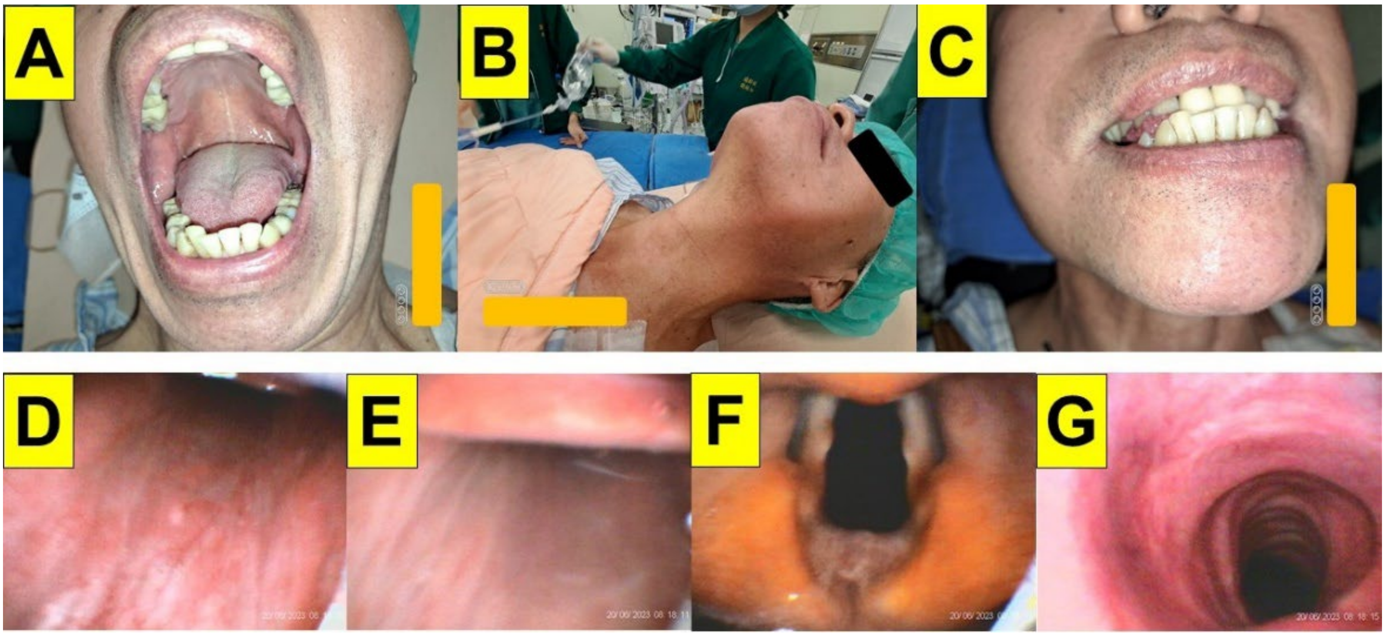

Figure 6. LQS grade 2: a 65-year-old man with a BMI 23.7 kg/m^2 (height 174 cm, weight 72 kg). (**A**) Mouth opening with inter-incisor distance 5.0 cm and MMC class IV; (**B**) sternomental distance 17 cm; (**C**) ULBT class 3; (**D**) view of pharyngeal space; (**E**) epiglottis view with a narrow space against posterior pharyngeal wall; (**F**) vocal cord view (POGO 90%); and (**G**) tracheal rings view. (see Video S2 in the Supplementary Materials).

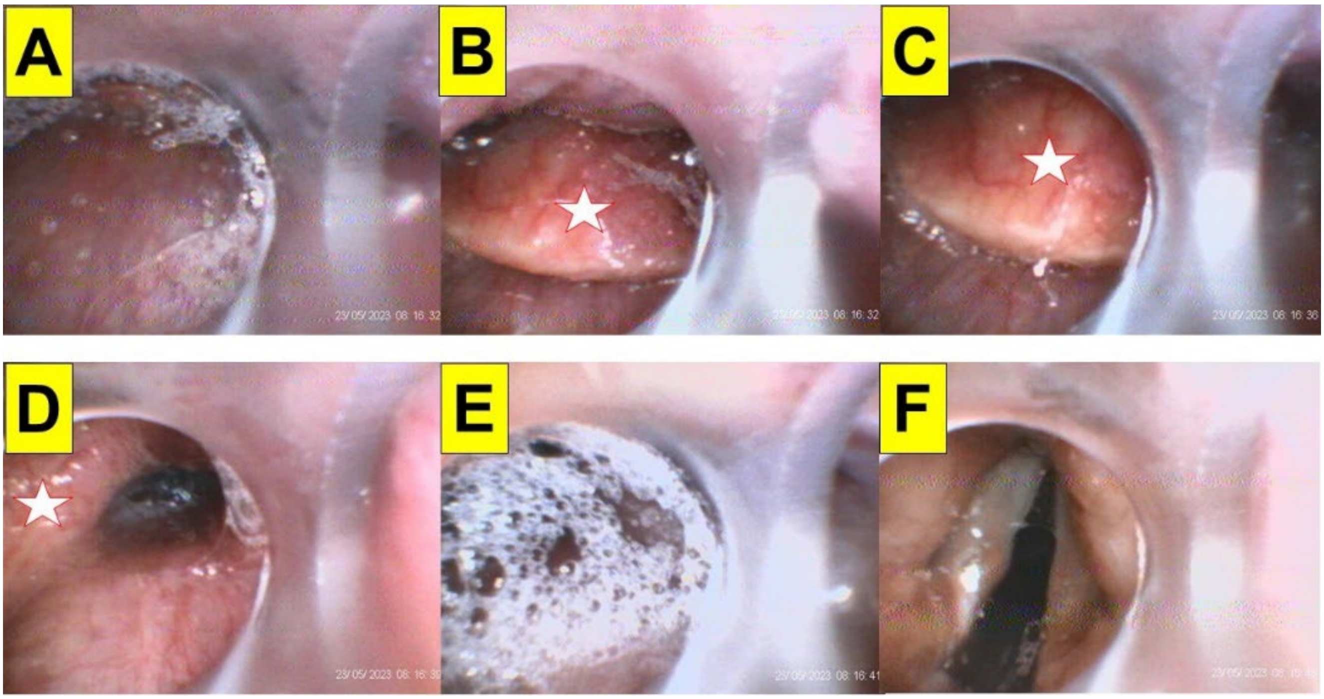

Figure 7. LQS grade 3: a 70-year-old man with a BMI 29.0 kg/m^2 (height 167 cm, weight 81 kg); mouth opening with inter-incisor distance 4.5 cm; MMC class IV; sternomental distance 16 cm; ULBT class 2; (**A**) pharyngeal space view; (**B**,**C**) view of epiglottis; (**D**,**E**) view of esophageal inlet; and (**F**) vocal cord view (POGO 100%). Epiglottis could not be lifted up by the jaw-thrust maneuver, and thick and copious secretions were noted. The epiglottis is denoted by the white star in (**B**–**D**). (see Video S3 in the Supplementary Materials).

5.3. Intubating Time and Ease of Maneuverability as Outcome Parameters

In patients undergoing endotracheal intubation, it has been concluded that the VL is superior to a direct Macintosh DL as the former enlarges the view of the glottis, shortens time to achieve intubation, facilitates intubation with easy manipulation, and causes less risk of complications. Tracheal intubation using a VL has been shown to yield significantly higher intubation success rates and fewer complications than a DL in patients with non-difficult airways [81] and, in particular, may be useful instruments in the management of the predicted difficult airway [82].

Although the VL would be safer to employ in patients with vital requirement of hemodynamic stability, it did show longer intubation times than the conventional DL [83]. Even though the VL offers better glottic entrance visualization and intubation conditions, a good laryngeal view does not guarantee easy or successful tracheal tube insertion and might be VL blade geometry-dependent [84]. Although the time to intubate using a VL is significantly dependent on operator's experience and skills, such time is also influenced by, e.g., the angle of curvature of the stylet [85].

In contrast to other comparators (e.g., first-pass success rate, total success rate, number of attempts, the quality of visualization, complications), "time to intubate" itself has been commonly used as a primary outcome comparator among various intubating modalities. Factors influencing such a comparator include design of the device, patient's factors, clinical scenarios, and airway operator's skills and competency. Numerous clinical studies and meta-analyses show the comparison between a Macintosh DL and various VLs in normal and difficult airway scenarios [86–89]. For example, the time to intubation in normal airways with a DL and VL, respectively, are 9 s and 11 s [90]; 33 s and 34 s [91]; and 35 s and 56 s [92]. In difficult airways, the time to intubation with a DL and VL, respectively, are 38 s and 32 s [93]; 56 s and 41 s [94]; 37 s and 14 s [95]; 60 s and 45 s [96]; 43 s and 45 s [97]; 27 s~50 s [98]; 50 s and 57 s [99]; 47 s and 38 s [100]; 52 s and 63 s [101]; 57 s and 45 s [102]; 16 s and 14 s [103]; and 11 s and 73 s [86].

In our experiences, when either experienced staff or novice trainees applied styletubation, it usually took about 5 s to 10 s (from lip to trachea) to accomplish the trachea intubation in patients with normal airways. Although it can be performed in 3 s in an easy airway scenario and 30 s to 60 s for teaching purposes, we regard 10 s of such "time to intubation" to be reasonable, easy, smooth, and elegant. We adhere to the tenet of "seeing around the corner" while applying the styletubation. All the signposts along the patient's airway from mouth to trachea are encouraged to observe with the styletubation technique. Even in patients with normal airways, incidental findings along patient's airway could be observed every once in a while (e.g., large tonsils, laryngeal tumor, vocal polyps or cyst, tracheal tumor). In expected difficult airways, such standardized maneuverability of styletubation ensures a smooth and successful tracheal intubation. Figure 8 shows examples in three patients with time to intubation by 5 s, 7 s, and 15 s, respectively. It is worthy to mention that in our experience, the first-pass successful rate is almost 100% for styletubation, while it varies widely and rather is low for a DL and various VLs (e.g., 86%~93% [94]; 70%~93% [97]; 42%~72% [92]; 37%~98% [98]; 44%~90% [99]; 85%~100% [100]; 78%~67% [101]; 92%~85% [102]; 90%~85% [103]; and 26%~92% [86]).

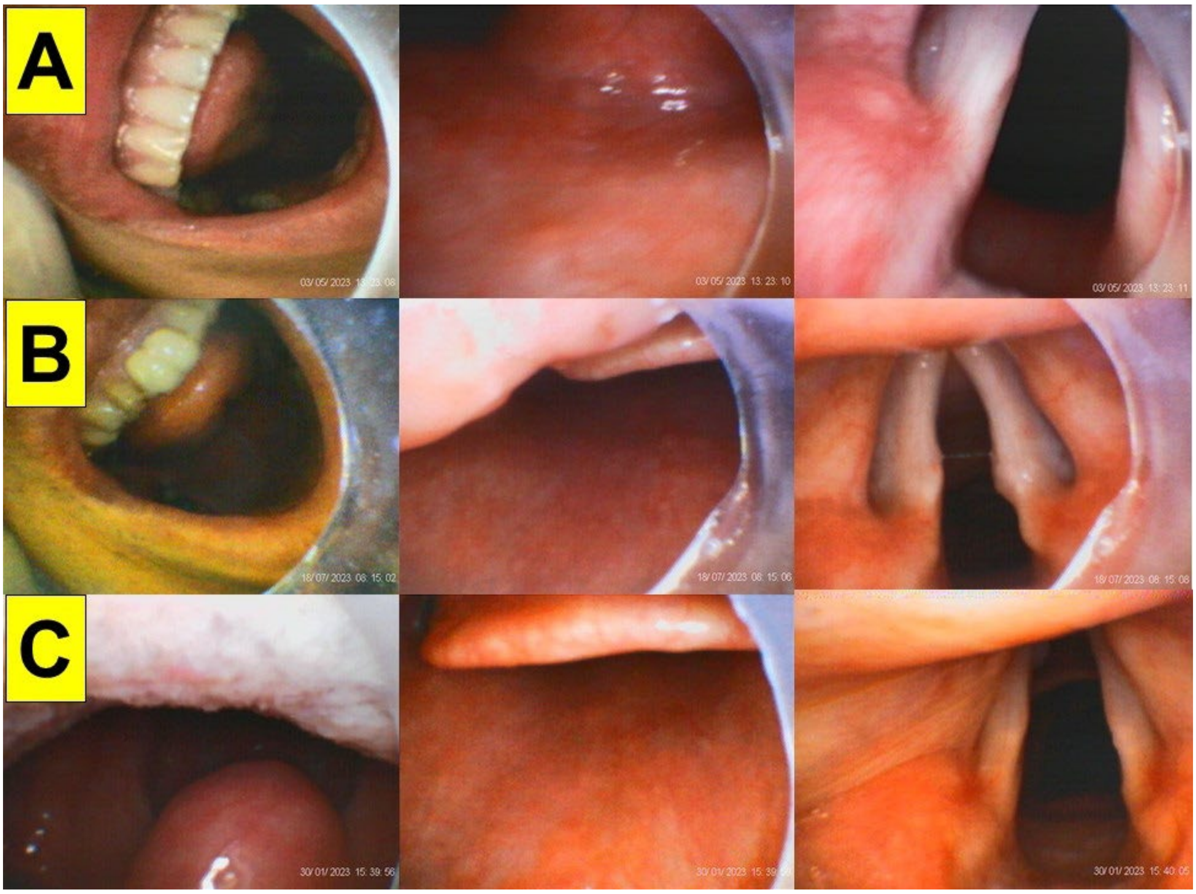

Figure 8. Time to intubation by styletubation (from lip to trachea). Left panels: oropharyngeal view; middle panels: epiglottis view; and right panels: vocal cords view. (**A**) A 26-year-old woman with a BMI 24.1 kg/m^2 (height 155 cm, weight 58 kg); mouth opening with inter-incisor distance 4.5 cm; MMC class II; sternomental distance 17 cm; ULBT class 1; LQS grade 1; POGO 100%; and intubation time 5 s. (**B**) A 60-year-old man with a BMI 24.2 kg/m^2 (height 170 cm, weight 70 kg); mouth opening with inter-incisor distance 4.0 cm; MMC class II; sternomental distance 16 cm; ULBT class 1; LQS grade 2; POGO 100%; and intubation time 7 s. (**C**) A 61-year-old man with a BMI 23.3 kg/m^2 (height 167 cm, weight 65 kg); mouth opening with inter-incisor distance 5.0 cm; MMC class II; sternomental distance 17 cm; ULBT class 1; LQS grade 2; POGO 100%; and intubation time 15 s. (see Videos S4–S6 in the Supplementary Materials).

5.4. Ankylosing Spondylitis

Among various scenarios of difficult airway management, a patient's limited cervical spine mobility is one of the toughest and most excruciating conditions. Patients who suffered cervical spine injuries usually are on immobilization devices (e.g., halo ring, crowns, or vest) or cervical collars (neck brace). Other cervical spine immobilization scenarios include application of stereotactic head frame for neurosurgical procedures or practice. When laryngoscopy is on intended use under such difficult airway conditions, the airway managers often expected to encounter limited oropharyngeal-laryngeal exposure. Difficulty inserting the laryngoscopic blade, poor glottic visualization, or failure to orient and advance the ET tube into the trachea are not uncommon.

There has been high hope for the plausible role of a VL to perform better in cervical spine immobility conditions (e.g., reduced the risk of intubation failure) [86,104]. However, most comparative study results came from simulated scenarios (e.g., applying a cervical collar or manual in-line stabilization applied by an assistant during intubation) [105–107] and airway mannequin models [108,109]. It should be stressed that the VL maneuver per se may cause harm to fracture the cervical spine [110]. It has been modeled that laryngoscopy itself might cause cervical motion and compressive strains on cervical spinal cords. The effects may exceed potentially injurious values with routine intubation forces [111,112]. Variables included laryngoscope-specific cervical extension, airway displacement/deformation needed for tracheal intubation, in addition to different cervical spine and airway tissue viscoelastic properties [113]. In contrast to a DL/VL, designed to improve success rate, enhance operator's feeling of ease, and reduce patient's cervical spine movement, awake FOB is still considered as the gold-standard technique for airway management in such scenarios [114,115]. Other modalities of the intubating tools (e.g., Bonfils endoscope, lightwand) have also been studied in this scene [116–119].

One of the examples of a severe degree of limited cervical spine motion is the case of ankylosing spondylitis (AS). In few sporadic case reports, the roles of different intubating tools have been studied in patients with AS [120–122], including combined VL with video stylet [123]. Here, we present a case of AS undergoing corrective orthopedic spine surgery (Figure 9). The patient has past history of ankylosing spondylitis with severe cervical hyperlordosis and progressive thoracic kyphosis. Orthopedic operation included pedicle subtraction osteotomy (PSO), posterior instrumentation (PI), and posterior lumbar interbody fusion (PLIF). His cervical mobility was severely restricted. After careful assessment, we applied styletubation for tracheal intubation under standard induction of anesthesia. The time to intubation is 16 s with first-pass success (Figure 10).

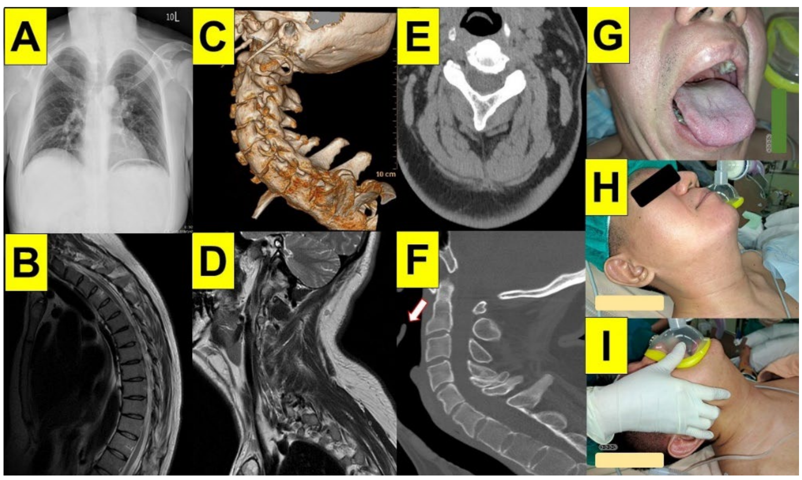

Figure 9. Styletubation for tracheal intubation in a patient with ankylosing spondylitis and thoracic kyphosis. Pre-operative imaging studies show chest X-ray (**A**), kyphosis of thoracic spines (**B**), hyperlordosis of cervical spines (**C**,**D**,**F**), view of epiglottis (**E**), modified Mallampati classification III with inter-incisor distance 4 cm (**G**), and sternomental distance 13 cm (**H**,**I**). Cervical spine mobility is severely restricted. (Same patient as in Figure 10).

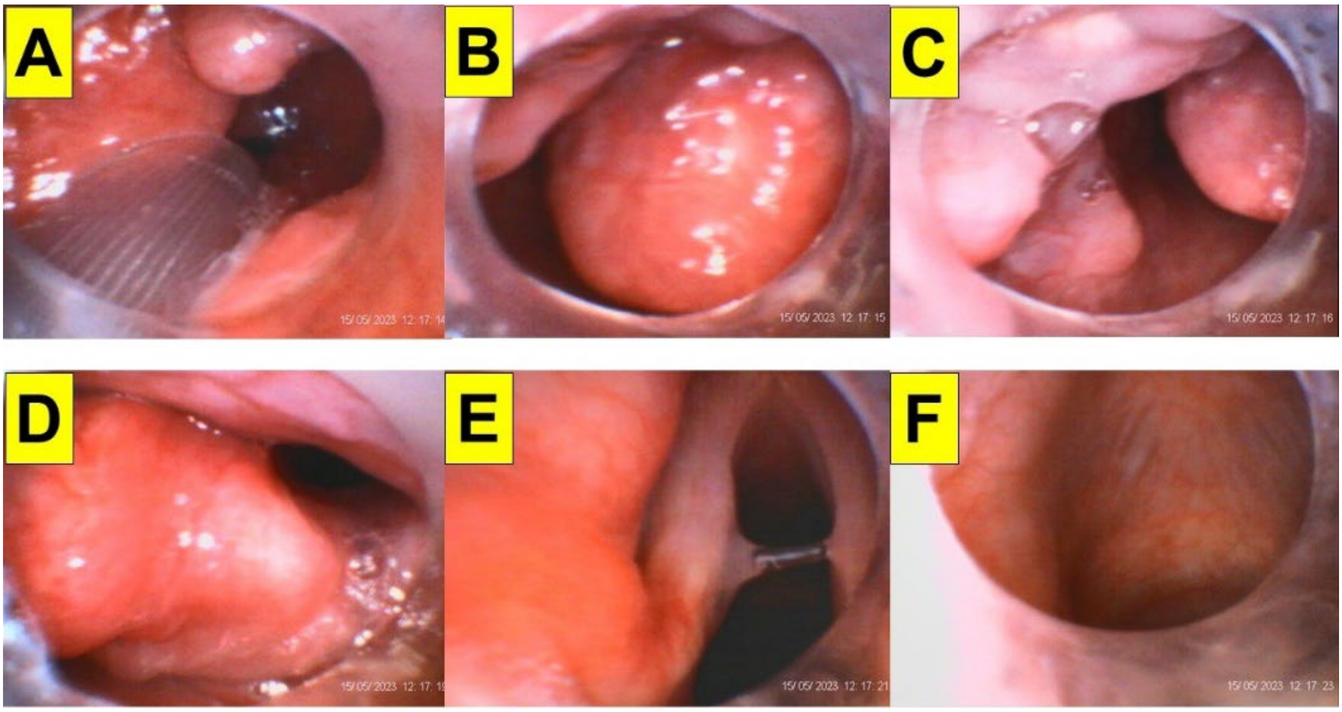

Figure 10. Styletubation for tracheal intubation in a patient with ankylosing spondylitis, cervical hyperlordosis, and thoracic kyphosis. A 33-year-old man with a BMI 26.5 kg/m^2 (height 160 cm, weight 68 kg), mouth opening with inter-incisor distance 4.0 cm; MMC class III; sternomental distance 13 cm; ULBT class 2; LQS grade 2; POGO 100%; and intubation time 16 s. (**A**–**C**) Pharyngeal view with collapsed and immobile epiglottis, and LQS grade 2 based on the location status of the epiglottis. (**D**,**E**) Visualization of the vocal cords. (**F**) View of tracheal ring. (Same patient as in Figure 9.) (see Video S7 in the Supplementary Materials).

5.5. Obesity

Due to the anatomic anomalies, glottis visualization can be poor and tracheal intubation is often problematic in morbidly obese patients. Functionality and performance of the VL in obese patients could be improved, e.g., better overall satisfaction score, intubation time, number of intubation attempts, and necessity of extra adjuncts [124–128]. When compared to a standard DL, the VL required fewer intubation attempts, significantly reduced the time to secure the airway, and improved the glottic view in obese patients undergoing bariatric surgery [97,129].

Other intubating tools, e.g., rigid Bonfils fiberscope, when compared to the VL, can be successfully used for awake intubation in morbidly obese patients when difficult airways are anticipated [130]. In obese patients, the use of the Video Intubation Unit and VS significantly improves the visualization of the larynx, thereby improving the intubation conditions [47,131,132]. Here, we demonstrate such a role of styletubation in an obese patient (Figure 11). This 42-year-old woman with a BMI 63.6 kg/m^2 underwent one anastomosis gastric bypass (OAGB). The pre-operative airway assessment showed more than acceptable for smooth trans-oral tracheal intubation after induction of anesthesia. The time to intubation was 18 s with first-pass success. The result is similar to our previous report regarding the role of styletubation in the obese population [43,47]. It is worthy to note that ramp positioning with sniffing position and keeping the patient's neck until horizontal alignment between the sternal notch space and the external auditory meatus is helpful for laryngoscopy in obese patients [133,134].

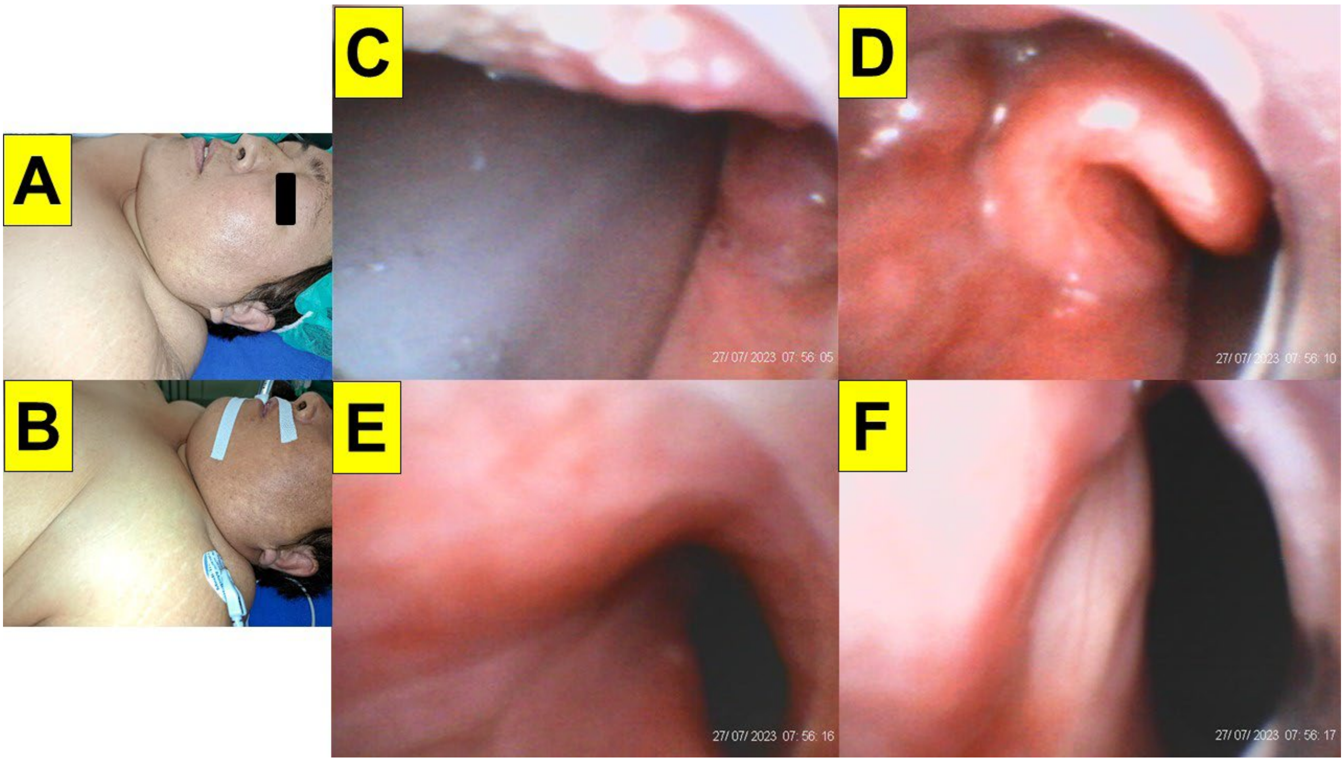

Figure 11. Styletubation for tracheal intubation in an obese patient undergoing bariatric surgery. A 42-year-old woman with a BMI 63.6 kg/m^2 (height 161 cm, weight 165 kg), mouth opening with inter-incisor distance 5.0 cm; MMC class II; sternomental distance 16 cm; ULBT class 1; LQS grade 2; POGO 100%; and intubation time 18 s. (**A**,**B**) Pre- and post-intubation. (**C**,**D**) LQS grade 2 based on the location status of the epiglottis and partial glottis visualization. (**E**) Visualization of the vocal cords. (**F**) View of tracheal ring. (see Video S8 in the Supplementary Materials).

5.6. Rapid Sequence Induction/Intubation

Although visualization of the vocal cords could be improved by using a VL compared with direct laryngoscopy, whether better visualization consistently improves first-attempt success rate during rapid sequence oro-tracheal intubation remains to be an issue [135–137]. Such application of a VL has been studied in the settings of emergency department [101,138], out-of-hospital field [139–141], intensive care units [101], and simulated cardiopulmonary resuscitation manikin studies [142,143]. The inconsistent results of the role of a VL are probably based on the airway operator's training skill, experience, and clinical competency.

Cricoid pressure (CP) did not significantly improve the glottic visualization at laryngoscopy but increased the time to intubation and significantly decreased the first-pass success rate [135]. A recent large randomized clinical trial performed in patients undergoing anesthesia with RSII failed to demonstrate the non-inferiority of the non-CP procedure in preventing pulmonary aspiration [144]. Therefore, we routinely abandon CP (or Sellick maneuver) while applying styletubation for rapid sequence induction/intubation (RSII). Here, we present a case of using styletubation for RSII (Figure 12). This is a 59-year-old man with past history of atrial fibrillation, hypertension, ankylosing spondylitis (with stiff neck and limited cervical spine mobility), and deep vein thrombosis. He was admitted to our emergency room due to cerebellar hemorrhage and scheduled for emergent sub-occipital decompressive craniectomy with intracranial pressure monitoring. Anesthetic induction agents were administered for RSII. The styletubation took only 9 s to complete with first-pass success. No CP was applied.

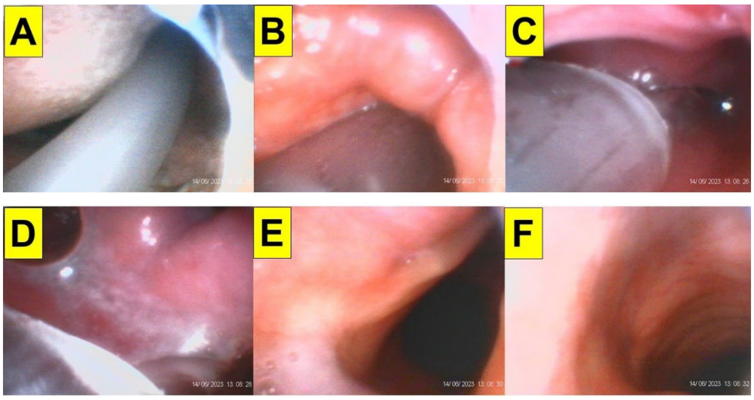

Figure 12. Styletubation for rapid sequence tracheal intubation in a patient undergoing emergent neurosurgery. A 59-year-old man with a BMI 30.1 kg/m^2 (height 165 cm, weight 82 kg), mouth opening with inter-incisor distance 3.5 cm; MMC class III; sternomental distance 10.5 cm; ULBT class 3; LQS grade 2; POGO 100%; and intubation time 9 s. (**A**,**B**) Oropharyngeal views. (**C**,**D**) LQS grade 2 based on the location status of the epiglottis and partial glottis visualization. (**E**) Visualization of the vocal cords. (**F**) View of tracheal ring. (see Video S9 in the Supplementary Materials).

5.7. COVID-19 Pandemic

During the COVID-19 pandemic, the airway management strategies were developed to protect the airway managers and to provide a safe, accurate, and swift airway management of patients with COVID-19 [145–147]. Both tools of the VL and DL have been dedicated for use in patients with COVID-19 where tracheal intubation is feasible [148,149]. It is also noticed that the tracheal intubation procedure might be hampered by personal protective equipment [150–153].

The plausible role of video-assisted intubating stylet for tracheal intubation during the COVID-19 pandemic was tested in the manikin model [154]. In the real world, we applied the styletubation technique for airway management in patients contracted with COVID-19 in our medical center after 2020 [37,40,41,43,155,156]. Here, we present a case (Figure 13) who developed bilateral pneumonia and acute respiratory distress syndrome (ARDS), congestive heart failure after he contracted the COVID-19 virus during the pandemic period. He needed tracheal intubation for mechanical ventilation support in the negative-pressure isolation ward. The airway manager wore personal protective equipment (PPE) and applied the styletubation technique to perform tracheal intubation. The whole procedure was smooth, swift, and accurate.

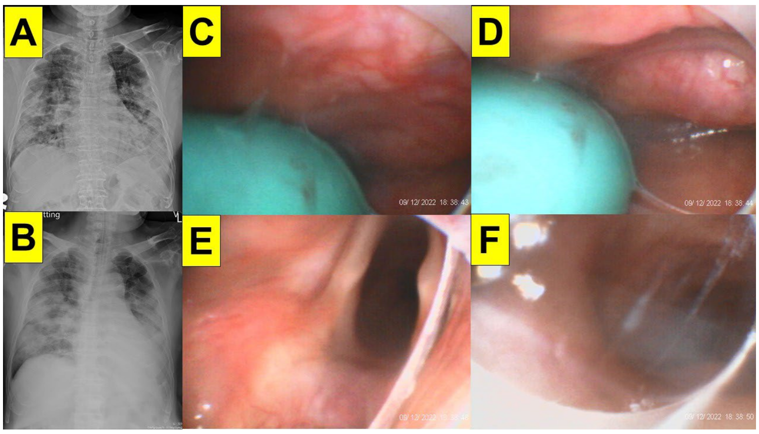

Figure 13. Endotracheal intubation with styletubation in a patient with COVID-19. An 83-year-old man with a BMI 29.0 kg/m^2 (height 153 cm, weight 68 kg). Pre-intubation airway assessment was not able to be performed. LQS grade 2; POGO 100%; and intubation time 12 s with first-pass success. (**A**) Chest X-ray taken before intubation. (**B**) Chest X-ray taken after intubation. (**C**,**D**) Pharyngeal views. LQS grade 2 based on the location status of the epiglottis. (**E**) Visualization of the glottis structures. (**F**) View of tracheal ring. (see Video S10 in the Supplementary Materials).

5.8. Combined VL and VS

When laryngoscopy reveals a Cormack–Lehane high grade (3 or 4), certain options such as external laryngeal maneuvers (e.g., BURP), few adjuncts (gum elastic bougie, stylet) or other different airway modalities (e.g., FOB, second-generation supraglottic airway) could be applied for proper management. Not surprising, when difficult airway or repeated failure to intubate occurred, airway operators might use combined methods of various airway tools [157–161]. When Bonfils intubating fiberscope was applied, usually laryngoscopy (e.g., VL) was used to assist to open enough airway space and to achieve the best possible laryngeal view [162]. Such that, both views from the Bonfils scope and VL were brought together onto one single monitor. It is proposed that such a combined technique can be used for difficult tracheal intubation [163].

When an optic rigid intubating stylet was designed and introduced clinically [35], this optic stylet was proposed to use as a laryngoscopy adjunct, when the epiglottis is not seen during laryngoscopy [164]. On the other hand, laryngoscopy was found to be an adjunct to facilitate the application of VS [42,165,166]. Figure 14 shows a case of applying videolaryngoscopy to facilitate styletubation and also confirms the proper position and depth of the ET tube placement. It is worthy to mention, with such a combined technique, the intubation was performed with first-pass success and smooth and swift tracheal intubation (7 s). In particular, the depth of ET tube placement by styletubation was able to be confirmed by videolaryngoscopy.

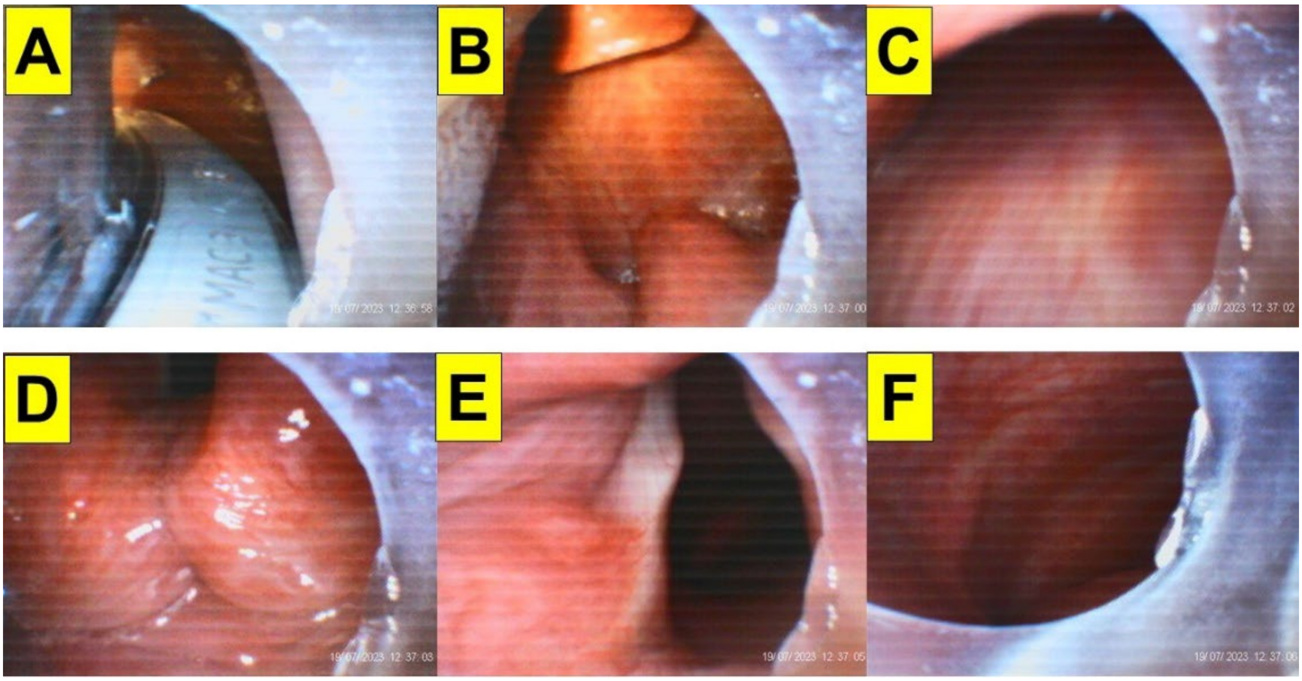

Figure 14. Videolaryngoscopy-assisted styletubation. A 67-year-old man with a BMI 30.8 kg/m^2 (height 161 cm, weight 80 kg); mouth opening with inter-incisor distance 4.5 cm; MMC class III; sternomental distance 13 cm; ULBT class 2; LQS grade 2; POGO 100%; and intubation time 7 s. (**A**) Videolaryngoscopic view (Cormack–Lehane grade 3, shown in the videolaryngoscopic screen). (**B**,**C**) LQS grade 2 based on the location status of the epiglottis. (**D**,**E**) Visualization of the glottis structures. (**F**) View of tracheal ring. (see Video S11 in the Supplementary Materials).

5.9. The Learning Curve

During the last two decades in Taiwan, the role of the VL has been increasing in airway management and has a lower rate of failed intubation in certain clinical scenarios (e.g., difficult airways) and clinical settings (e.g., operating rooms, emergency rooms, intensive care units). When compared with the DL and VL, we found that styletubation appears to have satisfactory first-pass success rate, time to intubation, and rate of complications. While experienced airway operators may be skillful in various intubating tools and techniques, it is understandable that the novices (medical students, residents, and non-anesthesiology trainees) might encounter difficulties during learning and practice. Therefore, various training modules and assessments of tracheal intubation (e.g., VL and DL) for medical personnel have been reported [167–170]. Training inexperienced novice personnel with a VL, e.g., following a short teaching program, improves the success rate and time for tracheal intubation in patients with normal airways [171] or in airway manikins with various simulated clinical scenarios [172].

Different intubating device designs (e.g., DL, channeled VL) may also affect novices' learning curves (e.g., initial success rate, intubating time) [170]. Learners' behaviors, personalities, and prior experiences might also affect the learning curve and success rate of various intubating tools. In contrast to the DL and VL, whether the styletubation is easier to learn by the novice trainees is not clear. Several study results show that the learning curve for novice personnel to acquire the skills of VS was quicker and steeper in real patients [173] or airway manikins [119,174–177]. A relatively small number of hands-on experience is required (less than 10 trials) to properly master such a skill without causing oro-dental trauma. Figure 15 shows a novice trainee (first-year resident of the ear–nose–throat department) operating the styletubation and results in first-pass success but had a little bit longer of an intubation time (63 s). Individual differences in skill learning and competency do exist among all the trainees.

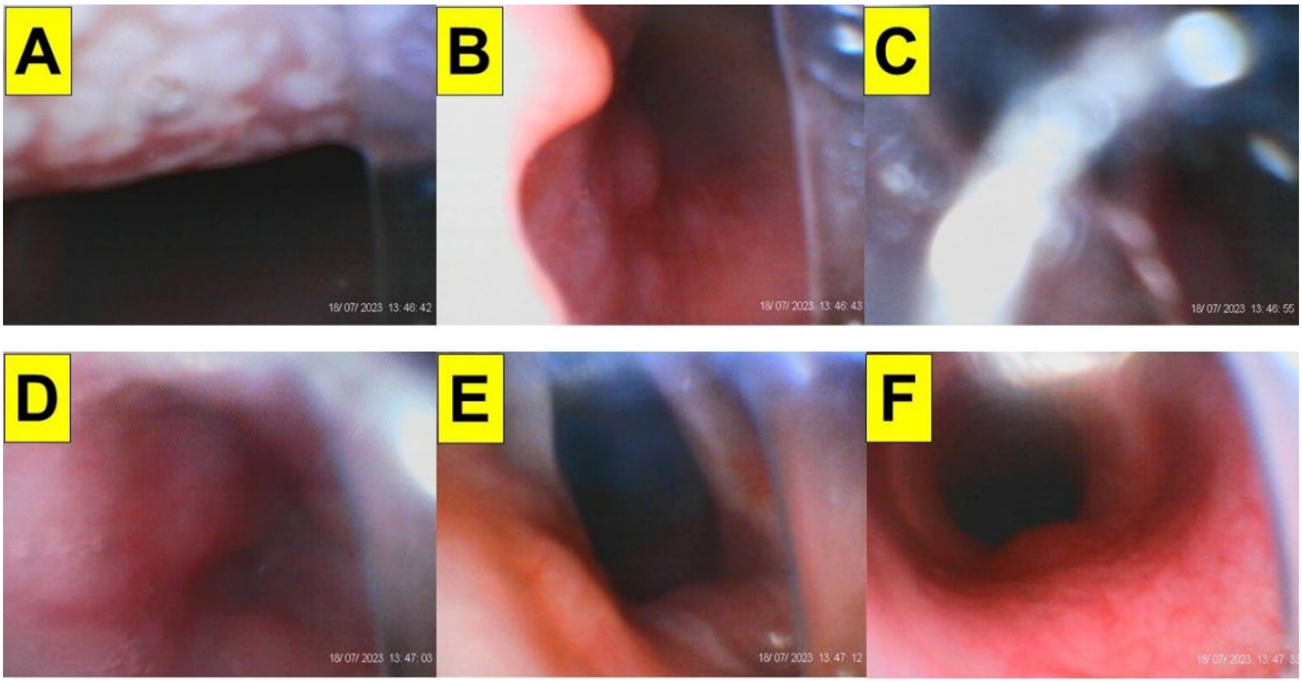

Figure 15. A novice trainee's first-time performance using styletubation. A 23-year-old woman with a BMI 19.8 kg/m^2 (height 157 cm, weight 49 kg); mouth opening with inter-incisor distance 4.0 cm; MMC class II; sternomental distance 15 cm; and ULBT class 1. (**A**–**C**) Views of the oropharyngeal space. (**D**) View of the pyriform recess. (**E**) View of the vocal cords (POGO 100%). (**F**) View of trachea inlet. The time to intubation is 63 s caused by tactless maneuver of the stylet, terrible sense of direction, and obscured view by the secretions. (see Video S12 in the Supplementary Materials).

6. Time for Universal Practice of Styletubation?

The introduction of both lightwand (Trachlight™, Laerdal Medical Inc., Armonk, NY, USA) and video-assisted intubating stylet (Clarus Video System, Clarus Medical, LLC, 13355 10th Ave North, Suite 110, Minneapolis, MN 55441, USA) into Taiwan for tracheal intubation was in 2002 and 2009, respectively. Since then, the clinical experiences of applying such intubating tools slowly built up and became known for local anesthesiologists. Since then, few clinical reports have been published in Taiwan and Asia [118,178–185]. It was not until 2016 that styletubation was universally practiced for routine tracheal intubation in Hualien Tzu Chi Medical Hospital (HTZGH). It is an 1000-bed tertiary medical center in a remote region on the east coast of Taiwan. In its 18 operating rooms, all are equipped with the VS, including Storz, UE, TuoRen, and Trachway. Also, the VS was equipped in clinical settings outside the operating rooms, such as emergency rooms, intensive care units, and clinical competency centers. Table 1 shows the universal coverage of routine tracheal intubations conducted with styletubation. Except for teaching or other purposes, the DL and VL were not routinely used any more by the anesthesia faculty staff. Excluding those who needed to undertake the nasal FOB (e.g., head/neck/oral surgery, pharyngeal/laryngeal lesions, etc.), the styletubation technique is the common and routine technique universally adopted for tracheal intubation in HTZGH (Table 1). The styletubation technique has, therefore, been applied for both normal and difficult airways [37–48,155,156]. In Table 2, comparisons of device features and clinical performance between the VL and styletubation are presented.

Table 1. Use coverage of styletubation (from 2016 to 2022) in Hualien Tzu Chi Medical Hospital, Hualien, Taiwan.

	2016	2017	2018	2019	2020	2021	2022
Total anesthesia number	16,077	17,831	17,998	193,07	19,721	19,244	19,765
GA number	153,39	16,893	17,497	18,481	19,009	18,574	19,061
LMA–GA number	5544	5134	5816	5902	5863	5714	4932
ET—GA number	5953	6504	6920	6966	7418	6982	7602
VL	0	0	20	100	635	336	305
Styletubation	5953	6504	6900	6866	6783	6646	7297

GA: general anesthesia; LMA: laryngeal mask airway; ET: endotracheal tube; VL: videolaryngoscopy; and styletubation: video-assisted intubating stylet technique.

Universal application of the VL for routine tracheal intubation has recently been advocated [25,26,186–190], although some pro and con arguments still exist [191]. Recent clinical evidence creates a favorable argument for "universal" use of the VL in anesthesia to improve efficiency, effectiveness, and safety of tracheal intubation. When the VL (e.g., versus the DL) was adopted as first choice for tracheal intubation in the operating rooms setting, such routine and universal use was associated with a significant lower rate of difficult airways, less use of airway rescue techniques and operator-reported difficulties [26]. Many factors affected the controversial results of such a role of the VL, e.g., human factors (experiences and competency of the airway operator) [192], patient factors (known or unexpected difficult airway), design of the devices, teaching models (simulation tools), etc.

In contrast, the role of styletubation for universal and routine tracheal intubation has never been studied or reported. A recent meta-analysis does not support the use of video stylets as the first choice for patients with neck immobilization [193]. Contradicted results from a meta-analysis study validated efficacy of video stylets (and VL) for tracheal intubation in the situation of cervical spine immobilization [194]. The results of an airway manikin study also support the advantageous role of video stylets in normal airway and cervical spine immobilization scenarios [119].

There are several limitations of the present narrative review article. In contrast to the highest level of evidence of the systematic reviews and meta-analyses, this narrative review article may still provide a new insight of the field of airway management and serve as a source of quick up-to-date reference for readers with interest in styletubation and laryngoscopy. However, our narrative review does have inherent shortcomings in terms of non-standardized and completeness of the literature searching, potential human bias in the appraisal of retrieved articles, and validity and objectivity of interpretation of findings. Although we have a vast array of clinical case experiences (more than 55,000 cases since 2016) of applying styletubation, we did not conduct a retrospective comparative study of styletubation against laryngoscopy. Some of the difficulties of such a study design include different competencies and preferences of the airway operators, un-controlled clinical conditions and scenarios, completeness of medical records and airway evaluation, etc. While we presented several clinical scenarios for using styletubation in this article (e.g., Section 5), the sample size is small, and it is impossible to make any statistical analysis on its significance. In fact, this clinical observational study was conducted by a small group of airway operators in a single medical center. Therefore, the generalizability of the study conclusion may be limited, and use and interpretation of the results should be carefully considered to avoid any unnecessary overstatements.

Table 2. Comparison between videolaryngoscopy and styletubation.

	VL	**Styletubation**
Affordability	Expensive (USD 7000~10,000)	Moderate (USD 600~5000)
Availability	Globally	Regionally
Accessibility	Yes	Yes
Maintenance	Easy	Easy
Learning curve (experienced and novice)	Fast	Very fast
Team performance	Excellent	Excellent
Rescue for difficult/failed intubation	Practical	Practical
Combined use with other tools	With FOB	With DL/VL/FOB
Use in ER, ICU, prehospital rescue by EMS	Often	Gradually increasing
View quality on video monitor	Excellent	Excellent
Required use of a laryngoscope blade	Yes	No
Required mouth opening	Yes	Yes
Required lifting force	Yes	No
Required alignment of airway axes	Yes	No
Often need external laryngeal manipulation	Yes	No
Glottic visualization	Excellent	Excellent
Difficulty inserting ET tube	Possible	Rare
Required stylet	Possible	No
Impact of collapsed epiglottis	Heavily	Heavily
Impact of secretions, blood, vomitus on the lens	Heavily	Heavily
First-attempt success rate	High	Perfect
Time to intubate	Varied	Fast
See around the corner of the airway structures	Yes	Yes
Esophageal intubation incidence	Possible	Very rare
Autonomic stimulation	Very much	Mild
Airway-related complications	Quite often	Very rare
Suitable for awake intubation	Yes	Yes
Operator's subjective satisfaction	High	Extremely high

VL: videolaryngoscope; DL: direct laryngoscope; FOB: fiber-optic bronchoscope; ER: emergency room; ICU: intensive care unit; EMS: emergency medical service; and ET tube: endotracheal tube. USD: US dollar.

In conclusion, with our vast experiences of styletubation (in more than 55,000 patients from 2016 to 2023), we found this technique to be swift (the time to intubate from 3 s to 10 s), smooth (first-attempt success rate: 100%), safe (no airway complications), and easy (high subjective satisfaction and fast learning curve for the novice trainees) in both normal and difficult airway scenarios. We, therefore, propose that the styletubation technique can be feasibly applied as a universal routine for tracheal intubation.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/surgeries5020015/s1, Video S1 (Figure 5), Video S2 (Figure 6), Video S3 (Figure 7), Videos S4–S6 (Figure 8), Video S7 (Figure 10), Video S8 (Figure 11), Video S9 (Figure 12), Video S10 (Figure 13), Video S11 (Figure 14), and Video S12 (Figure 15).

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Informed Consent Statement: Written informed consent was obtained from all patients or their legally authorized representatives.

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