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Review Article

Clinical value of video-assisted single-lumen endotracheal intubation and application of artificial intelligence in it

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Abstract: Visualization techniques and artificial intelligence (AI) are currently used for intubation device. By providing airway visualization during tracheal intubation, the technologies provide safe and accurate access to the trachea. The ability of AI to automatically identify airways from images of intubation device makes it attractive for use in intubation devices. The purpose of this review is to introduce the state of application of visualization techniques and AI in certain intubation devices. We reviewed the evidence of clinical implications of the use of video-assisted intubation device in the intubation time, first attempt success rate, and intubation of the difficult airway. Especially, VivaSight single-lumen tube with an incorporated optics allows direct viewing of the airway. VivaSight single-lumen tube has more advantages in tracheal intubation. AI has been applied to fiberoptic bronchoscopy (FOB) and video laryngoscope with automatic airway image recognition, and has achieved certain accomplishment. Further, we discussed the possibility of applying AI to the VivaSight single-lumen tube and proposed future directions of research and application.

Keywords: Single lumen endotracheal intubation, fiberoptic bronchoscopy, video laryngoscope, VivaSight single-lumen tube, artificial intelligence

Introduction

Airway management is the core task for anesthesiologists, and it is important to ensure effective ventilation in the perioperative period [1]. Intubation devices have recently more evolved from relying on physician's experience to relying on intubation device which provide airway visualization during intubation, including video laryngoscope, fiberoptic bronchoscopy (FOB) and VivaSight single-lumen tube (VSLT) (ETView Ltd., Misgav, Israel), video laryngeal mask, video stylet and other intubation devices. FOB is considered the gold standard for resolving difficult airways. Video laryngoscope not only reduces costs, but also plays a significant role in airway management. VSLT has been noted as a new intubation device which provides airway visualization during intubation. So, this article reviews focused on the clinical application of these three intubation devices.

Artificial intelligence (AI) technology has developed rapidly over the past few years, with significant progress in the image classification, segmentation and object detection. These functions can assist doctors in diagnosis or reduce their stress [2]. AI can be applied to identify the airway. However, at present, there are few studies about video laryngoscope and FOB in this area. Most of the studies are mainly focused on recognizing tumors and blood vessels. In particular, there is a research gap in the application of AI in VSLT.

This article reviews the clinical applications of video-assisted intubation devices and the current status of AI in video-assisted intubation devices. The review will eventually provide an outlook and perspective on the possible applications of AI in VSLT in future.

Clinical applications of video intubation device

We reviewed prospective randomized studies, case studies, observational clinical studies, retrospective studies and manikin studies on VSLT, video laryngoscopy and FOB to show their application and clinical implications. The clinical reports of the relevant devices are summarized in **Table 1**.

Clinical applications of VLST

The VSLT is a disposable PVC endotracheal tube with an embedded complementary metal oxide semiconductor video camera and light source at its distal end for continuous airway visualization. The airway images are continuously projected onto a portable monitor screen via a cable. It also has a tube for saline injection to clean the camera [3]. This device can improve the success rate of intubation without direct laryngoscope or FOB, and may be faster than the latter [4]. The videoscopic techniques have a disadvantage that secretions, blood or nebulization can cause visual blurring. The flushing channel of the VivaSight VSL helps to overcome this disadvantage caused by secretions [5].

VSLT is easy to use and doesn't require a long learning period. It has been pointed out that people who had no previous experience with the VSLT were able to intubate effectively to use it with a short-term training [6]. However, this study is manikin-based rather than a clinical study because a randomized clinical trial for cases of cardiac arrest is highly unethical.

An important aspect of airway management is the difficulty of airway intubation. Obese patients often have a difficult airway. A study of Barak et al. [7] included 72 adult obese patients who underwent laparoscopic sleeve gastrectomy and found that the VSLT was helpful in the endotracheal intubation (ETI) and continuous surveillance of tube position in these morbidly obese patients. Gil et al. [8] studied the assistance provided by VSLT for difficult airway intubation in two cases. In the study of Truszewski et al. [9], the results in all of their designed experimental scenarios demonstrated shorter time to successful intubation and sound gate observation using VSLT compared to standard endotracheal tube with Macintosh laryngoscope (MAC). Karczewska et al. [10] performed a meta-analysis of 12 relevant studies and the results showed that VSLT provided better visualization of the sound gate and shorter intubation time, supporting that VSLT can reduce intubation time and improve success rate in different simulated intubation scenarios. Gawlowski et al. [11] conducted a prospective, randomized, crossover, manikin trial, which included 67 nurses with more than 1 year of clinical experience who had no experience using video laryngoscope or VSLT, and concluded that VSLT was much faster and required less intubation attempts compared to direct laryngoscope.

The VSLT can be used in combination with other airway devices and may provide better results. The bronchial sealer combined with a common single-lumen tracheal tube is favored by clinical anesthesiologists because it is less invasive and easier to operate. However, during the operation process, the blocking capsule is often displaced due to position change or surgical operation, affecting the ventilation of one lung. In such cases, it's necessary to have a realignment adjustment with FOB, which inevitably affects the surgical process and also increases the risk of lung infection as well as the wear and tear of FOB. Qiu et al. [12] reported a case of intermediate tracheal tumor undergoing tracheal resection and reconstruction under video-assisted transthoracic surgery, in which the VSLT was used to guide bronchial blocker placement for single-lung ventilation, and favorable results were obtained. Gaitini et al. [5] checked the feasibility of ETI with VSLT through the Laryngeal Mask Airway (LMA). They concluded that the high first-attempt tracheal intubation success rate of the VSLT for trachea intubation through a LMA makes this technique attractive and promising. However, their study was only performed for normal airways and lacked experiments in difficult airways.

According to the current study, there may be wide potential for clinical applications of VSLT, and more research is needed.

Clinical applications of video laryngoscope

When there are distorted airway anatomy, tissue immobility or limited access to the mouth,

Table 1. Clinical reports for the use of FOB, video laryngoscope and VSLT

Studies	Design of studies	Patients	Results	Complications
Szarpak L, Truszewski Z, Czyzewski L and Kurowski A [6]	Randomized crossover manikin trial		Faster intubation with VSLT without chest compressions (P < 0.001) and with uninterrupted chest compressions (P < 0.001)	Dental compression during MAC intubation: 6.5% of intubation attempts.
Barak M, Assalia A, Mahajna A, Bishara B, Braginski A and Kluger Y [7]	Prospective study, n=72	adult obese patients undergoing laparoscopic sleeve gastrectomy	Slower intubation time (29±10) and fewer soft tissue damage with VSLT	Sore throat: 2 in VSLT, 3 in control group. Soft tissue injury for 3 patients in the control group.
Gil MG, Albamonte PS, Hernandez CC, Cobo I, Guijarro R and de Andres Ibanez J [8]	Case report, n=2	Patients with difficult airway and unanticipated tracheal stenosis	Successful detection of airway narrowing to avoid tracheal injury with VSLT	Not reported
Truszewski Z, Szarpak Ł, Smereka J, Kurowski A, Evrin T and Czyzewski Ł [9]	open, prospective, randomized, crossover, not-blinded manikin study		Faster intubation and higher success rate of first attempt with VSLT	Dental compression rate with Macintosh: 88.9%. Dental compression rate with VSLT: 4.5%
Karczewska K, Smereka J, Dabrowski M, Lisiecki A, Golik D, Dunder D, Bialka S, Szarpak L and Ruetzler K [10]	meta-analysis, n=12		Better glottic visualization, shorter intubation time and higher success rates during different simulated intubation scenarios with VSLT	
Gawlowski P, Smereka J, Madziala M, Cohen B, Ruetzler K and Szarpak L [11]	prospective, randomized, crossover, manikin trial		better perform in a complex scenario of airway management with VSLT	Dental compression rate with Macintosh: 82.1%. Dental compression rate with VSLT: 6.0%
Qiu J, Feng M, Zhang C and Yao W [12]	Case report, n=1	Patients with a middle tracheal tumor	Avoided touching the tumor and interrupting ventilation with VSLT	Not reported
Gaitini LA, Yanovski B, Mustafa S, Hagberg CA, Mora PC and Vaida SJ [5]	Feasibility study, n=50	patients with normal airways	The FT-LMA was placed successfully in 49 patients at the first attempt.	Not reported
Herbstreit F, Fassbender P, Haberl H, Kehren C and Peters J [15]	Prospective comparison study, n=93	Patients without increased risk for aspiration of gastric contents	Faster intubation with video laryngoscope	Not reported
Noppens RR, Geimer S, Eisel N, David M and Piepho T [16]	prospective, comparative before-after study, n=274	Critically ill patients requiring endotracheal intubation	More successful intubations on first attempt with the C-MAC® video laryngoscope (34/43, 79%)	3 minor tissue injuries, 3 bleedings, 1 regurgitation/aspiration, 1 glottic swelling, 2 esophageal intubations and 7 other Complications in Macintosh laryngoscopy group, 1 minor tissue injuriy, 2 bleeding, 4 glottic swelling, 3 endobronchial intubations and 4 other Complications in C-MAC® video laryngoscope group.
Vlatten A, Aucoin S, Litz S, Macmanus B and Soder C [17]	Prospective, randomized study, n=56	Patients four years of age or younger who are undergoing elective surgery	Longer time for intubation with the STORZ DCI video laryngoscope	None
Trimmel H, Kreutziger J, Fitzka R, Szüts S, Derdak C, Koch E, Erwied B and Voelckel WG [18]	Multicenter, prospective, randomized, control trial, n=326	Adult emergency patients requiring endotracheal intubation	Higher success rate with the GlideScope Ranger video laryngoscope (96.2%)	No serious complications were observed
Pang L, Feng Y-H, Ma H-C and Dong S [21]	Case report, n=1	Patient undergoing surgical resection of a large, high tracheal tumor causing severe tracheal stenosis.	Fiberoptic bronchoscopy-assisted intubation was successful after several failed conventional endotracheal intubation attempts	Not reported
Peris A, Linden M, Pellegrini G, Anichini V and Di Filippo A [22]	A case-control, before-and-after, retrospective study, n=128	Patients with failure to wean, who had undergone PDT	Faster intubation, fewer needle approaches and fewer rate of complications with VF PDT group	7 hemorrhages, 3 tracheal ring ruptures, 1 case of hypoxia, 1 posterior wall lesion and 1 accidental extubation in the TF PDT group. 3 hemorrhages, 3 tracheal ring rupture, and 1 case of hypoxia in the VF PDT.

Berkow LC, Schwartz JM, Kan K, Corridore M and Heitmiller ES [24]	Retrospective review, n=128	Patients with difficult airways underwent the LMA-AIC-FOB technique	119 (93%) of the 128 patients were successfully intubated by the LMA-AIC-FOB technique.	None
Truszewski Z, Szarpak L, Czyzewski L, Evrin T, Kurowski A, Majer J and Karczewska K [25]	Open, prospective, randomized, crossover manikin trial		Shorteraverage intubation time (56.3 s)	Not reported
Alhomary M, Ramadan E, Curran E and Walsh S [26]	Meta-analysis, n=8		Shorter intubation time with video laryngoscope	

PDT = percutaneous dilatational tracheostomy, VF = video-assisted fiberoptic, VSLT = VivaSight single-lumen tube, AIC = Aintree Intubation Catheter, FOB = fiberoptic bronchoscopy, LMA = Laryngeal Mask Airway, MAC = Macintosh laryngoscope.

it is more difficult to expose the vocal canal and perform tracheal intubation quickly and effectively with a rigid laryngoscope [13]. Video laryngoscope is a combination of traditional laryngoscope with a light source and camera that transmits the captured images to a monitor. It can overcome some of the challenges that exist with ordinary laryngoscope. In the emergency department, it is valuable for the prevention of anticipated difficult airway and cervical spine prophylaxis in trauma patient [14].

Video laryngoscope is not only easy to learn, but also can be used as a teaching tool. Herbstreit et al. [15] concluded that the C-MAC video laryngoscope was a valuable tool for teaching medical ETI skills. It increases the success rate of tracheal intubation and reduces the time required for intubation. Further research on the long-term benefits of video laryngoscope is warranted.

In clinical practice, critically ill patients in the intensive care unit (ICU) are vulnerable with rapidly changing conditions, and resuscitation requires emergency physicians to conduct rapid and accurate tracheal intubation. Noppens et al. [16] studied the effect of the C-MAC® video laryngoscope on laryngeal view and intubation success rate in comparison with direct laryngoscope. A total of 274 critically ill patients requiring ETI were included in their study. The result showed the use of the C-MAC® video laryngoscope improved laryngeal imaging and increased the first-attempt tracheal intubation success rate in patients with predicted risk factors of difficult intubation in the ICU setting. Video laryngoscope appears to be a useful device in the ICU, where potentially difficult tracheal intubations are often needed.

There are some studies which point out some limitations of video laryngoscope. The study of Vlatten et al. [17] has demonstrated that the STORZ DCI video laryngoscope provided an improved view to the glottis in children with normal airway anatomy, but required a longer time for intubation. Trimmel et al. [18] designed a multicenter, prospective, randomized, control trial with a study period over 18 months. They have found that there are two reasons why a physician may not be able to utilize video laryngoscope in emergency medical service conditions. First, although the video laryngoscope helps the physician see the airway adequately, it fails to advance the catheter toward the larynx and trachea. Second, anatomical structures are inadequately outlined when blood or fluid becomes an issue, or when bright ambient light impairs the view on the screen.

As a result of these studies, video laryngoscopy is an important video intubation device to help anesthesiologists solve clinical problems. Besides the low cost, it is also very effective in resolving difficult airways, shortening intubation time and improving intubation success rates, either alone or in combination with other devices.

Clinical applications of FOB

Awake tracheal intubation involves placing a flexible bronchoscope or video laryngoscope in an awake patient with spontaneous breathing [19]. In the 1980s, the FOB was introduced for operations on a monitor, with the ability to capture clear images at any time. After the development in the following decades, current generation of FOB is fully portable with a battery light source. They contain a built-in monitor or allow connection to a lightweight portable monitor [20]. It is now considered to be the gold standard for difficult airway management.

Pang et al. [21] reported a successful case of fiberoptic bronchoscope-assisted tracheal intubation in a patient undergoing large tracheal tumor resection with difficult airway. The case suggests that direct tracheal intubation may be possible in patients with large tracheal tumors with the help of FOB. By studying 128 patients who underwent fiberoptic-guided percutaneous dilatational tracheostomy (PDT) over an 18-month period, Peris et al. [22] demonstrated that FOB significantly shortened the operative time and reduced the risk of perioperative complications.

As the most widely used clinical device for adjunctive intubation, FOB can be used in conjunction with other device to solve more complex problems. The laryngeal mask introducer can be used as a resuscitation device for ventilation or as a conduit for insertion of an endotracheal tube, which often requires the assistance of a FOB [23]. However, there is a possible displacement of the endotracheal tube when the laryngeal mask is removed. Berkow et al. [24] designed a retrospective review containing 128 cases and proposed better results by using LMA, Aintree Intubation Catheter (AIC) and FOB. In the 128 patients who were intubated using combined LMA, AIC and FOB, 119 cases were successfully intubated without complications. Therefore, they believe that the method they proposed is safe and effective.

Comparisons of VSLT, video laryngoscope and FOB

FOB is considered the gold standard for the distressed airway, so it can be used as a standard for comparison.

Truszewski et al. [25] compared the effects of FOB and VSLT on tracheal intubation. In scenario without chest compression, the group using VSLT had a higher rate of successful first-attempt intubation and a shorter intubation time, showing a statistically significant difference. But in patients with continuous chest compression, the difference was not statistically significant with the combination of mechanical Lucas-2 (Physio-Control, Redmond, WA) chest compression system.

By including eight studies with 429 patients in a meta-study on video laryngoscope and FOB, Alhomary et al. [26] found that the intubation time using video laryngoscope was shorter. However, there was no significant difference between the two in terms of failure rates and first-attempt success rates. Patient satisfaction was also similar. In one of the cited papers, Xue et al. [27] proposed several questions. First, they found that video laryngoscope was not reported in case studies with local anesthesia, but FOB was. Second, they believed that the experimental intubation method would prolong the intubation time in the FOB group and affect the final conclusion. These questions are also worthy of reference for other experiments.

However, only partial image of the trachea would be clearly visible on video laryngoscopy. As a camera-integrated device in the catheter, VSLT can provide all the images in the airway during intubation without additional equipment. So, we believe that VSLT is promising for practical applications.

Applications of AI in video intubation device

In this section, we introduced the related research on the application of AI in video laryngoscope and FOB. These studies mainly include transfer learning, image recognition and classification, and image segmentation. Paderno [28] proposed that in each study, the study objectives (detection, classification or segmentation) are often not clearly stated or differentiated. The statistical definitions of correct and incorrect diagnoses are subjectively determined by each author, which can lead to significant variations in diagnostic performance metrics (e.g., accuracy, sensitivity, specificity and AUC). Therefore, in the early stages of this field, research teams should focus on standardization of data collection.

Applications of AI in video laryngoscope

Since there is limited research in this area, migration learning is a good way to address the low amount of high-quality labeled data. Patrini et al. [29] used 6 different convolutional neural networks (CNNs) pre-trained on natural images to perform learning feature extraction. After obtaining important features, support vector machines and CNN-based methods were used to classify frames into information-rich and non-information-rich frames, such as blurred, saliva or specular reflections, and underexposed frames. With this approach, they developed a deep learning-based strategy to automatically select information-rich laryngoscope video frames, thereby reducing the amount of data to be processed for diagnosis.

AI algorithms can automatically identify the pharynx and trachea on the basis of video laryngoscope, thus assisting the doctor in intubation and positioning. Wang et al. [30] developed a deep convolutional neural network that can automatically detect laryngeal adductor reflex events in laryngeal endoscopy videos. Experimental results showed promising performance towards automated, objective, quantitative analysis of laryngeal endoscopy videos. Hamad et al. [31] proposed a deep learning based fully automated video segmentation system for segmenting the vocal cords in laryngeal endoscopy videos. Adamian et al. [32] developed a novel computer vision tool for automatic quantitative tracking of vocal fold motion from video laryngoscope and demonstrated the potential of this software as a diagnostic aid in unilateral vocal fold paralysis. Matava et al. [33] used machine learning models to detect, classify and label vocal cords and tracheal anatomy in real time. They used a clinical dataset of 775 laryngoscope and FOB videos. By transfer learning following additional training, the accuracy of ResNet and Inception for identifying the vocal cords was improved (with a confidence of 0.96 and 0.93, respectively). Inception was able to process the live video feeds at 10 FPS while ResNet processed at 5 FPS.

There is also a lot of research in identifying laryngeal cancers. In 2019, Xiong et al. [34] explored the role of deep learning as a supplementary means to diagnose laryngeal cancer. By using a database of 13721 patient images/videos, they constructed a deep convolutional neural network based diagnostic system to detect cancer at different stages. When compared to human experts in an independent test set, the DCCN's performance on detection of laryngeal cancer and precancerous laryngeal lesions achieved a sensitivity of 0.720, a specificity of 0.948, an AUC of 0.953, and an overall accuracy of 0.897, which was comparable to those of human experts with 10-20 years of work experience. In 2020, Ren et al. [35] developed a deep-learning-based computer-aided diagnosis system for distinguishing laryngeal neoplasms (benign, precancerous lesions and cancer) to improve the clinician-based accuracy of diagnostic assessments of laryngoscope findings. In their independent testing dataset, an overall accuracy of 96.24% was achieved. Furthermore, the CNN-based classifier outperformed physicians for most laryngeal conditions in randomly selected test dataset. In 2021, Cho et al. [36] developed a computer-assisted diagnosis system for common laryngeal diseases using deep learning-based disease classification models. The system was established based on CNN models and used a total of 4106 images (cysts, nodules, polyps, leukoplakia, papilloma, Reinke's edema, granulomas, palsies and normal cases). Results showed that the trained deep neural networks outperformed trainees' visual assessments in discriminating cysts, granulomas, nodules, normal cases, palsies, papillomas and polyps, so it could be applied as a supplement to laryngoscope for clinical assessment by providing additional diagnostic clues and references.

Applications of AI in FOB

Similar to the advantages of migrating learning described in the section on video laryngoscope, the same applies here for FOB. Tan et al. [37] proposed a novel transfer learning method based on the top of DenseNet: sequential fine-tuning (SFT). Compared to the traditional method, which has an accuracy of only 70% to 74%, their method achieved better performance, with an accuracy of 82%. Because of the advantages of transfer learning, they used only 81 normal cases, 76 cases of tuberculosis and 277 of lung cancer in the dataset.

Useless frames are generated during FOB due to coughing, contaminant occlusion and other reasons. These useless frames waste computing power and may lead to lose of some key frames. McTaggart and Higgins [38] developed an automated system consisting of two different methods to classify each frame in an endobronchial video sequence as informative or non-informative. The first method extracts image features through image processing algorithms and then uses support vector machines to classify them, with an accuracy of 78.8%, a sensitivity of 93.9% and a specificity of 62.8%. The second approach uses convolutional neural networks and it can achieve an accuracy of 87.3%, a sensitivity of 87.1% and a specificity of 87.6%.

AI algorithms can automatically identify blood vessels and trachea on the basis of FOB, thus assisting doctors during intubation and positioning, and accurate localization can improve patient outcomes [39]. Bandyopadhyay et al. [40] presented an automated method for enhancing and segmenting the major blood vessels depicted in FOB videos. Experimental data showed that their method can obtain results superior to those of existing popular vascular segmentation methods. They also considered the preliminary application of deep learning in this task. Although this method is less sensitive compared to other methods, it has higher specificity and accuracy.

Fibroscopy with AI technology can be used to automatically identify tumors in the airway. Yamunadevi and Ranjani [41] proposed an efficient and adaptive fuzzyGLCM based segmentation method to get the accurate recognition of the lung carcinoma. Their results showed the validity and efficiency of their algorithm in identifying lung carcinoma using the FOB images.

Directions for the future research

This article briefly describes 3 video intubation devices and the research on AI technology for assisting physicians in video laryngoscope and

FOB. Since the FOB, video laryngoscope and VSLT can provide the image of trachea, with only the position of insertion being different, it is believed that the application of AI in VSLT is reliable. Because VSLT has been proposed for only a relatively short period of time and has not been widely promoted clinically, relevant studies and data are currently scarce. Transfer learning may play an important role in the early stages of the field. Based on the development of the application of AI in FOB and video laryngoscope, it is presumed that the initial development stage of the application of AI in VSLT will also focus on real-time monitoring of airway location or foreign bodies such as tumors, blood clots and sputum in the trachea. About the idea that intelligent medical devices may only assist doctors in the early stage to complete some scattered simple low-risk work, we believed that with the development of technology and the improvement of new technology system, a complete intelligent medical system will be formed eventually.

Summary

With the development of technology, the level of tracheal intubation visualization continues to advance. It not only reduces the surgical damage to the patients, but also reduces physician's stress. They can significantly improve the first-attempt success rates and reduce patient injury during the procedures. The application of AI may elevate the performance of intubation device to a new level.

According to the studies as mentioned, it can be found that easy operations and reduction of intraoperative injuries have always been important issues in tracheal intubation research. It becomes apparent that visualization and AI technology play an important role that cannot easily be overlooked. However, in the process of applying AI technology to enhance the performance of intubation devices, further large-scale, multi-center and cross-platform validation studies are needed to ensure the robustness of AI technology and control potential unknown risks, as the reliability of intubation devices are concerned in clinical practice [42].

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Disclosure of conflict of interest

None.

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