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Review Article

Which Videolaryngoscope Should We Use in Airway Management?

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ABSTRACT

Aim of review: This review elaborates on the role of different videolaryngoscopes in modern airway management and whether the outcomes of studies on patients and on manikins help anesthesiologists in determining which videolaryngoscope we should prefer.

Methods: We reviewed the articles comparing the performance of different videolaryngoscopes published in the last decade.

Recent findings: Airway problems that occur during the introduction of general anesthesia in the operating theatre, prehospital, emergency department and intensive care setting are commonly managed by skilled anesthesiologists. However, anticipated and unanticipated difficult airways do occur. Very seldom do these difficult airways result in a "can't ventilate-can't intubate" scenario, with potential death and brain damage as devastating outcomes. Standard Macintosh Laryngoscopy (SML) has its limitations, with Cormack-Lehane grade III-IV and percentage of glottic opening (POGO) scores of 0 being called difficult laryngoscopy. Percent of Intubation success with the direct classic Macintosh blade laryngoscopy (DML), without the use of adjuncts, is often limited to 90% (95% with adjuncts and extra manoeuvers). Videolaryngoscopy offers superiority over direct laryngoscopy as it allows an improved view of the larynx (Cormack-Lehane grade I-II; POGO 50-100%) and results in an almost 100% intubation success rate with decreased intubation time. In the rare event that an intubation attempt with a Macintosh blade videolaryngoscope (VLS) is not successful, acute angled blades can be used, or a combination technique offers an alternative. The market offers several videolaryngoscopes with alternative options (channelled, non-channelled, acute angled and Macintosh blades), each with their own indications. At this moment, there is no videolaryngoscope available which offers a solution for all problems. With our review we hope to determine the "best" scope, based on publications in the last decade.

Summary: Videolaryngoscopes have improved airway management and reduced airway related morbidity and mortality by improving the glottic view (laryngoscopy) and first attempt intubation success. Videolaryngoscopy is useful in video-guided insertion of endotracheal tubes, supraglottic airway devices, temperature probes and nasogastric tubes. However, not all videolaryngoscopes are created equally as there are definite differences which anesthesiologists must be aware of in order to make the best choice for individual patients. This review concluded that the most favored videolaryngoscope was the Pentax-Airway Scope of the channelled videolaryngoscopes and the Karl Storz C-MAC of the non-channelled videolaryngoscopes. However, the C-MAC VLS is the most versatile and can be used for direct and indirect laryngoscopy.

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Airway management is one of the most challenging tasks for any anesthesiologist, especially if it concerns an unanticipated difficult airway. The core business for all anesthesiologists is to establish an effective, patent and safe airway during general anesthesia, whilst avoiding dental injuries and trauma to the oropharynx and larynx.

Direct laryngoscopy using Macintosh blades is standard practice during endotracheal intubation for general anesthesia, although it is not always successful and "can't intubation, can't ventilate" scenarios do occur, potentially leading to lethal consequences due to hypoxia with cardiac arrest and brain damage. Prediction of airway difficulties remains a challenging task. Nørskov et al. (1) found that 93% of difficult intubations in the Danish Anaesthesia Database were unanticipated. Despite the usual practice of preoperative airway assessment (mouth opening, thyromental distance, Mallampati class, ability to prognath the lower jaw, lip bite test), evaluation of neck (circumference and range of motion in flexion-extension) and information about the patient's weight, body mass index (BMI) and history of previous difficulties with intubations, no single parameter shows a high sensitivity to accurately predict a difficult airway. In today's standard practice, clinicians are only able to predict half the patients who present with a difficult airway when direct laryngoscopy was difficult. Therefore, anesthesiologists need to be prepared at all times to be confronted with an unexpected difficult airway and have videolaryngoscopy available as it offers many advantages over direct classic Macintosh blade laryngoscopy (DML). Fortunately, many manufacturers offer a wide range of different videolaryngoscopes to aid clinicians in the improvement of airway management.

In 1990, King and Adams (2) reported an occurrence of 600 deaths per annum throughout the developed world due to complications with classic Macintosh laryngoscopes at the time of intubation. Furthermore, they reported that errors associated with endotracheal intubations accounted for 31% of all deaths and cerebral damage in anaesthesia. The development of better monitoring (capnography, peripheral oxygen saturation) and advanced airway equipment (a large range of new airway devices, including videolaryngoscopes, and adjuncts), has reduced the incidence of "can't intubate, can't ventilate/oxygenate" in patients undergoing anesthesia. Notwithstanding, airway management is not without risk to the patient, nor is it always successful.

In 2012, Cook and MacDougall-Davis (3) extensively elaborated on complications and failures of airway management with incidences of failed intubation (1:2000 elective patients; 1: 300 obstetric patients; 1:50-100 in the emergency department, intensive care unit (ICU) and prehospital setting), however, the definitions of airway management were far from uniform. Information was provided based on data garnered from litigation in Canada, USA, UK and Australia. Although "can't intubate- can't oxygenate" scenarios occur in fewer than 1:5000 routine general anesthetics, they may require an emergency surgical airway (1:50,000), and are responsible for 1:4 anesthesia-related deaths. Hypoxia, resulting in death and brain damage; and aspiration of gastric contents are the most common causes of death (50%) and brain damage (53%). Risk factors and contributing factors to difficult airways are congenital and acquired malformation of the oropharynx/mouth/face, oral infections, tumors, dental problems and obesity. Kheterpal et al. (4) reported on difficult mask ventilation (2.2%) and impossible mask ventilation (0.15%). To define the incidence of morbidity is more difficult, although a recent review article by El-Boghdadly et al. (5) reported a 62% incidence of postoperative sore throat following general anesthesia. This figure cannot be accepted as normal practice anywhere in medicine.

We know that direct laryngoscopy is not optimal (laryngoscopy fails in 10% of patients; intubation difficulties are legion and fail in 1:5000 cases). Complications are rare but potentially fatal, and side effects (postoperative sore throat incidence is 62%) are far too many and often result in an increased haemodynamic response. Direct laryngoscopy is a fast and inexpensive technique in most patients, but when it comes to a difficult airway (failed laryngoscopy, Cormack-Lehane [C&L] grades III-IV and difficult endotracheal tube [ETT] insertions), anesthesiologists need a rescue method to secure the airway. It would be preferable if a superior alternative were made available at all times to be utilized for standard instrumentation of the airway. Videolaryngoscopy closes the gap with >99% successful intubations, whereas in 10% of direct laryngoscopies there are difficulties associated with inserting the endotracheal tube into the patient's trachea. Through a developmental progression that spans across domains, significant improvements have been made towards the safety of patients undergoing endotracheal intubation: a) adequate evaluation of the airway; b) better planning for adverse effects; c) improved positioning on the operating table (ramped position, especially for the obese patients); d) better preoperative oxygenation technique (e.g. Thrive); e) better equipment (and appropriate use) to manage the airway (e.g. videolaryngoscope, flexible and rigid bronchoscopes, supraglottic airway devices to buy extra time to prepare for the next step; other adjuncts such as viewing stylets and lighted stylets); f) improved training (first in simulation, and later on patients); g) practice standardization with availability of difficult airway trolley; h) adequate staffing and equipment; and i) availability of difficult airway algorithms, standard operating procedures, and policies. These all have contributed to the resolution of several problems associated with difficult laryngoscopy and endotracheal intubation techniques, resulting in an increased rate of intubation success.

The aim of our review was to assess studies which compared the performance of different videolaryngoscopes. The primary outcome was to establish device preference, and to summarise which devices most effectively managed diverse clinical circumstances, based on the published researches. All randomized controlled trials and cohort studies spanning the last ten years which compared the function of at least two laryngoscopes, used in humans or manikins, were included. This manuscript intends to review the existing literature by comparing the outcomes of airway devices for endotracheal intubation, such as DML and a wide range of videolaryngoscopes available on the market. The primary outcome was to determine the frequency in which the (video) laryngoscope was labelled the "clinically preferred" scope by the authors.

What Are the Characteristics of an Ideal Videolaryngoscope?

An efficient videolaryngoscope- compared to a classic direct Macintosh blade laryngoscope- should provide many benefits (6) i) an improved first attempt successful intubation rate for both the skilled and inexperienced intubator to reach 100% intubation success at the second attempt, without the need for adjustment manoeuvers and minimal preparatory steps - ideally, the VLS should be routinely used for both direct and indirect intubation; ii) an improved view (angle of view 60° vs 15° with classic laryngoscope) of the larynx and oropharynx (without fogging of the camera lens) during airway instrumentation (although a good view of the larynx is no guarantee for successful intubation), minimizing the "blind" spot, allowing for detection of any airway trauma and a clear differentiation between the entrance to the trachea and the esophagus; iii) less need for adjuncts or airway escapes (avoiding rigid stylets); iv) easy and reliable insertion of the ETT at an adequate insertion depth, with minimal patient manipulation, avoiding excessive forces, with less morbidity (dental trauma, mucosal trauma, postoperative sore throat), avoiding difficulties associated with difficult airways; v) less haemodynamic response during the intubation act; vi) eliminating the risk of developing hypoxaemia during placement of the ETT with adequate speed of ETT insertion in the trachea (a short intubation time is desirable, although haste and carelessness may cause potential trauma); vii) reliably extrapolated results obtained in manikins may be translated to clinical patients with a fast learning curve; viii) provide enough diversity in different sizes and shapes of blades to accommodate the patient's anatomy, with special angulated blades in case of an anterior positioned larynx; ix) avoid trauma by the device itself (blades should have a rounded vallecular end); x) facilitates safe insertion of ETTs, supraglottic airway devices (SADs), naso- and orogastric tubes, NIM tubes, double lumen tubes, temperature probes, gastroscopes and esophagoscopes; xi) excellent intubation results, irrespective of race, gender, age, BMI, congenital or acquired deviations of the airway; xii) correct use in all circumstances: elective and emergency cases, adults and children, normal and difficult airways, in patients with all kind of positions; xiii) an enhanced potential as a teaching, learning and monitoring tool, even in non-standard positions. The learning curve (including hand-eye coordination) should be steep with most cases having a learning curve of around 20-30 cases; xiv) recording options for teaching and research purposes. Ideally, videoclips should be added to the patient's records, similar as the patient's laboratory results - the information may be useful for future anesthesia interventions; xv) others to see the intubation act, so that helpers can be more proactive, and supervisors see where problems occur; and xvi) multifunctional modular equipment that can be used with adequate connectors to other airway devices (e.g. flexible or rigid bronchoscope can be attached and use the same monitor). Ideally, the VLS should be lightweight and portable, with disposable blades, avoiding cross-infection.

Obviously, we all want the best, most advanced equipment at a reasonable price that offers a wide range of options in airway management at all times and in all circumstances. Economic reality often puts a halt on this dream as each medical device comes at a price, which may not always meet the resources of a particular department. In this review, we have not compared the costs involved in acquiring and maintaining these devices.

Methods

Data Sources and Search Strategy

A certified librarian for the university of Queensland searched PubMed and the Cochrane library between the period of 2005 up to August 2016, using the following keywords: Videolaryngoscope; videolaryngoscopes; videolaryngoscopy; videolaryngoscopies; "video laryngoscope"; "video laryngoscopes"; "video laryngoscopy"; "video laryngoscopies"; airway; airways; complication; complications; problem; problems; problematic; difficult; impossible; intubations; intubation; ventilations; ventilation; "bag-mask"; "bag mask"; "mucosal trauma"; "dental trauma"; death; "cerebral damage"; "brain damage"; "non-ventilation"; "non ventilation"; "non-intubation"; "non intubation"; "non- oxygenation"; "non oxygenation"; types; type; sizes; size; brand; brands; compare; compares; comparison; comparisons; comparative. The initial results were then refined with the filters: Humans only; Abstracts available; Title/abstracts. A citation search by manual review of references from primary articles was also performed.

We included studies, restricted to the English language only, comparing DML with VLS regarding: a) an improved glottis view (Cormack-Lehane grade; percentage of glottic opening [POGO]); b) time to successful intubation; c) first attempt intubation success rate; d) use of manoeuvers and adjuncts; and e) final outcome judged by the authors as "best" (video) laryngoscope.

Which (Video) Laryngoscopes are Studied?

Table 1 lists per manufacturer and the name of the different videolaryngoscopes. For direct laryngoscopy, it is standard practice to use a Macintosh blade laryngoscope. Contrary to videolaryngoscopes, DML are not too dissimilar, hence, we did not search for the manufacturer of the DML.

We grouped the results of each trial that included two or more (video) laryngoscopes in two categories: 1) clinical patients undergoing surgery, and 2) tests on manikins. The number of times the studies listed a "best" (video) laryngoscope was divided by the number of studies that included the named (video) laryngoscope in each group for each laryngoscope. We also calculated the number of patients (clinical studies) and participants (manikin studies) to evaluate whether the scope designed to be the "best" was studied in at least 50% of the publications. Finally, an overall "best favored" (video) laryngoscope was determined.

Results

PubMed results listed 506 articles, and the Cochrane Library listed 404, of which 102 were identified as relevant and imported into EndNote, demonstrating the use of videolaryngoscopy for placement of ETT comparing at least 2 (video) laryngoscopes. Publications that were identified twice, that contained content unrelated to the study focus, or did not meet the inclusion criteria, were excluded from further analyses. Additional publications were retrieved by a hand search of the references.

This review discussed videolaryngoscopes of 13 manufacturers (Table 1). The analysis included 59 trials, with a total of 8,740 patients in 41 clinical trials (7-46) on surgical patients (Table 2) and 859 participants in 18 manikin studies (Table 3) (47-64). Table 2 and 3 list items as follows: per (video) laryngoscope, the number of surgical patients or providers (manikin studies) that participated in studies, which (video) laryngoscope was used, its outcome and the number of times it was listed as "the best" for each of the studies.

Table 4 provides the outcome of the incidence of clinically most preferred VLS used per device. Only the AWS (for the channelled VLS) and the C- MAC (for the non- channelled VLS) were shown to have the favored outcome in surgical patients, i.e. 78% (AWS) and 89% (C-MAC). All other VLSs had a performance of less than 50%.

Providers of airway management in the manikin studies showed similar results. In 50% of the studies where AWS was involved, the AWS VLS was judged to be the best; whereas in 56% of the manikin studies where the C-MAC VLS was involved, the intubators scored the latter VLS as the best. None of the other VLSs had scores above 50% . Also, for the total number of patients involved, a similar pattern was seen, with C-MAC scoring the favored VLS in 5,567 (91%) of the 6,133 patients where C-MAC was one of the videolaryngoscopes reviewed. In patients undergoing surgery, AWS VLS was one of the videolaryngoscopes studied in 9 of 41 studies (22%); whereas C- MAC VLS was utilized in 18 of 41 studies (44%). The DML was part of the majority of studies (27:41 studies, i.e. 66%). Almost 1 in 5 studies where the DML took part, the classic laryngoscope was still scored the best. Data for VLS that are only occasionally studied were not provided and were not further investigated.

Table 1. A Range of Available Videolaryngoscopes for Airway Management Available on the Market for Clinical Use.

Manufacturer	Videolaryngoscopy brand
Aircraft Medical - Edinburgh, UK	McGraft - Series 5; McGraft-MAC
Connell Energy Technology Co Ltd, Shanghai China	CEL-100
Daiken Medical Co, Osaka, Japan	Coopdech VLP-100 MAC
Karl Storz, Tuttlingen, Germany	DCI Berci-Kaplan DCI; V-MAC; C-MAC; C-MAC D blade; C-MAC-S; C-MAC PM
King Systems Ambu, A/S Ballerup, Denmark	King Vision VLS (channelled and non- channelled)/aBlade/Ambu a-Scope 3
Magaw Medical, Fort Worth, TX, USA	Co-Pilot VL
Pentax- AWS, Hoya Corporation, Tokyo, Japan	Airway Scope AWS-100; AWS-200
Prodol Meditec S.A., Vizcaya, Spain	Airtraq Avant-Airtraq SP
Rush, Tuttlingen, Germany	X-Lite
Truphatek, Israel	TruView
Venner Medical, Kiel, Germany	Venner APA (channelled and non-channelled)
Verathon Medical, Bothell, WA, USA	GlideScope Cobalt, GlideScope Ranger; GlideScope Titanium; GlideScope Groove
Vivid Medical, Palo Alto, CA, USA	VividTrac VT-A100

Discussion

This review concluded, based on the available literatures of the last 10 years, that the clinically most preferred VLS is the Pentax-AWS VLS for channelled VLSs and the Karl Storz C-MAC, for the non- channelled VLSs. However, this warrants several comments, as there are a number of reasons why this may change in the future: a) operator bias; b) time since the device is made available on the market; and c) whether or not the device has been included in studies (i.e. especially for the newest devices).

The possibility of operator bias in clinical use and research (clinical and simulation) exist for several reasons, which may make interpretation of data difficult: i) blinding is not possible for the VLS used and the intubation conditions; ii) bias among anesthesiologists may exist against new equipment and medical devices; iii) not all brands are available in each hospital, given the acquisition costs involved; iv) lack of familiarity of VLS brands due to the wide range of products and hospital preferences; and v) different levels of skill, training and experience of the operator are crucial factors that heavily influence operator acceptance and rejection of VLS. The intubator also needs to be instructed in theory and practice on manikins. Definitions of airway may vary in the different studies and there may be different intubation end-points. For example, the intubation times may vary from the time the laryngoscope is

Table 2. Outcomes of Comparative Studies in Clinical Patients using Different Types of Videolaryngoscopes.

Year	First author	Clinical (N of patients) Manikin (N of providers)	Number and types of (video)laryngoscopes used (see list of abbreviations)*	Better outcomes for VLS based on: A: Improved glottis views (C&L/POGO); B. Faster TSI (Time to Successful Intubation); C: Higher FAIS (First Attempt Intubation Success) rate; D: Less frequent use of manoeuvers or adjuncts (bougie, stylet)	Clinically Preferred Choice of VLS
2005	Sun (7)	Surgery (200)	2: DML -GVL-D	DML:GVL-D→A [C&L grade I] 63%:59%); B (30":46")-6 pts in GVL worse C&L grade	DML
2007	Marrel (8)	Surgery (80)	2: DML -X-Lite	DML:X-Lite→A (improved with X-Lite); B (93":59"); C (80%:90%)	X-Lite
2007	Huang (9)	Surgery (60)	2: GVL-D -Trachlight	GVL-D:Trachlight→B (33":15")-milder hemodynamic response (Trachlight best)	Trachlight
2007	Xue (10)	Surgery (57)	2: DML -GVL-D	DML:GVL-D→similar hemodymanic responses	DML=GVL-D
2008	Enomoto (11)	Surgery (203)	2: DML -AWS	DML:AWS→A ([C&L grade I]: 61%:100%); B (51":54")	AWS
2008	Suzuki (12)	Surgery (320)	2: DML -AWS	AWS significantly improved: A (C&L grade +POGO score plus); B (faster intubation time)	AWS
2009	Walker (13)	Surgery (120)	2: DML -McG5	DML:McG5→A (=); B (30":47")	DML
2009	Lee (14)	Surgery (44)	2: DML -V-MAC	Pressure exerted on maxillary incisors→DML (mean 15, range 0-87 N); V-MAC (mean 2, range 0-45 N)	V-MAC
2009	Ray (15)	Surgery (400)	2: DML -McG5	DML:McG5 A [C&L grade I: 60%:99%); B (22":10"); successful intubation (83%:95%)	McG5
2009	Van Zundert (16)	Surgery (450)	4: DML -GVL-R -V-MAC -McG5	DML:GVL-R:V-MAC:McG5→A ([C&L grade I]: 1.7:1.0:1.0:1.0); B (-: 34":18":38"); C (-:76%:80%:74%); D (McG5 59%; GVL-R 43%; V-MAC 7%)	V-MAC
2009	Maassen (17)	Surgery (150)	3: GVL-R -V-MAC -McG5	GVL-R:V-MAC:McG5→A [mean C&L]: 2.1:2.0:2.0); B (33":17":41"); C (40%:76%:33%); D (McG5 76%; GVL-R 60%; V-MAC 10%)	V-MAC
2009	Liu (18)	Surgery (70)	2: AWS -GVL-D	AWS:GVL→B (34":72"); successful intubation (100%:89%); faster (< 60"-94%:63%)	AWS
2010	Teoh (19)	Surgery (400)	4: DML -AWS -C-MAC -GVL-D	AWS: shortest intubation times/easiest for ETT insertion/most C&L grades 1	AWS
2011	Su (20)	Surg (1196) META	5: GVL-D -C-MAC -McG5 -AWS -X-Lite	A (all VLS>DML); B (all VLS>DML); C (VLS=DML)	GVL-D=C-MAC
2011	Huang (9)	Surgery (60)	2: Trachlight -GVL-D	Trachlight better than GVL-D (faster intubation and less haemodynamic responses)	Trachlight
2012	Lee (21)	Surgery (100)	4: DML -GVL-R -McG5 -V-MAC	Pressure exerted on maxillary incisors→DML>McG5>GVL-D>V-MAC	V-MAC
2012	Ng (22)	Surgery (130)	2: C-MAC -McG5	C-MAC:McG5→A (<); B (50":67"); C (>)	C-MAC
2012	Sø rensen (23)	Ped surg (10)	2: Airtraq -C-MAC	B (C-MAC 29"; Airtraq 15.8")	Airtraq
2013	Riveros (24)	Ped surg (134)	3: DML -Truview -GVL-D	A [C&L-I] (Truview 82% - GVL-D 14%); B (DML 23"; Truview 44"; GVL-D 39")	DML
2013	Taylor (25)	Surgery (88)	2: DML -McG5	A [POGO] (McG5 90% - DML 23%); glottis view improved 1-3 C&L grades;	McG5

Table 2. Outcomes of Comparative Studies in Clinical Patients using Different Types of Videolaryngoscopes. (Continued)

Year	First author	Clinical (N of patients) Manikin (N of providers)	Number and types of (video)laryngoscopes used (see list of abbreviations)*	Better outcomes for VLS based on: A: Improved glottis views (C&L/POGO); B. Faster TSI (Time to Successful Intubation); C: Higher FAIS (First Attempt Intubation Success) rate; D: Less frequent use of manoeuvers or adjuncts (bougie, stylet)	Clinically Preferred Choice of VLS
2013	Mosier (26)	DEM (463)	2: C-MAC -GVL-D	A? B? C (C-MAC 84% - GVL-D 82%)	C-MAC=GVL-D
2013	Kovitwanaborg (27)	Surgery (200)	2: GVL -D-AWS	GVL-D = AWS	GVL-D=AWS
2013	Serocki(28)	Surgery (96)	3: DML -GVL-D -CMAC-D	Difficult Airways-DML:GVL-D:C-MAC-D→A (C&L grade III-IV): 19%: 2%: 0%); B (11":19":18"); C (84%:94%:84%)	GVL-D=C-MAC-D
2014	Sekiguchi (29)	Surgery (90)	3: McGMAC -VLP-MAC -AWS	A [C&L-I] (AWS = McGMAC0; B (AWS: 3"; VLP-MAC 4"; McG5 5")	AWS
2014	Sun (30)	Ped META (14)	DML -diverse VLSs	A (VLSs>DML); B (prolonged TSI in VLSs); Failures (VLSs>DML)	DML
2014	Lili (31)	Surgery (60)	2: DML -GVL-D	DML:GVL-D→A(>); B (<)	GVL-D
2014	Burnett (32)	Surgery (107)	2: C-MAC -KV-1 or 2	C-MAC better than KV→B-C (first attempt and overall intubation success)	C-MAC
2015	Chastel (33)	Surgery (37)	2: DML -Airtraq DT	A (DML 73% vs Airtraq DT 97%) [Double lumen tube]	Airtraq DT
2015	Ota (34)	Surgery (100)	3: DML -AWS	B (AWS: better performance in providers without DML experience)	AWS
2015	Pieters (35)	Surgery (141)	4: DML -C-MAC -GVL-D -McG5	Forces applied on maxillary incisors: DML>McG5>GVL-D>C-MAC	C-MAC
2015	Vassiliadis (36)	Surgery (619)	2: DML - C-MAC	(C&L grade III-IV)-chances of intubation (C-MAC:DML = 3:1)	C-MAC
2015	Wallace (37)	Surgery (164)	2: DML -McG-MAC	Direct laryngoscopy using the McGrath MAC was poor compared to DML	DML
2015	Akbar (38)	Surgery (90)	2: DML -C-MAC	DML:C-MAC→A (lower C&L grades with C-MAC); B (39":33"); D (less with C-MAC)	C-MAC
2015	Ali (39)	Surgery (50)	2: Airtraq -KV-2	KV-2 performed better than Airtraq (B-C)	KV-2
2015	Alvis (40)	Surgery (66)	2: McGMAC -KV-2	McG-MAC:KV-2→A(=); B (7":38"); C (100%:89%)	McG-MAC
2015	Bakshi (41)	Surgery (120)	3: DML -TruV - McG5	Expertise with standard DML does not translate to VLS expertise	DML
2015	Bruck (42)	Surgery (66)	2: C-MAC -GVL-D	A (=); B (=); C (C-MAC 56% - 93% GVL-D)-D (11-5)	GVL-D
2016	Aziz (43)	Surgery (1100)	2: GVL-D -CMAC-D	GVL-D and C-MAC-D perform equally well	GVL-D=C-MAC-D
2016	Yumul (44)	Bariatric (161)	4: DML -C-MAC -GVL-D -McG-5	BMI > 30 $kg.m^{-2}$-A (all VLS>DML); B (C-MAC>DML/GVL-D/McG5); D (C-MAC/GVL-D>DML/McG5)	C-MAC
2016	Heuer (45)	Surgery (104)	3: DML -GVL-D -GVL-direct	A (DML<GVL-D/direct)	GVL-D
2016	Kleine- Brueggeney (46)	Surgery (720)	6: C-MAC -D-GVL -D-McG -5-Airtraq-APA - KV-2	C (McG5/C-MACD >95%; GVL/AT/KV2 85%; APA 37%)	C-MAC-D/McG5

*Non-channelled (video)laryngoscopes: DM=direct laryngoscopy using Macintosh blade classic laryngoscope; C-MAC=V-MAC (Video-MAC)/C-MAC/videolaryngoscope with Macintosh blade; and C-MAC-D blade (for difficult airways; angulated blade); GVL = GVL-D-GVL-R-GVL-MAC = GlideScope: types: a) Cobalt (acute angled blade); b) Ranger (acute angulated blade); c) titanium (Macintosh blade); McG5-McG-MAC=McGrath: videolaryngoscope with acute angulated blade (Series 5) or Macintosh blade (McGrath MAC); VLP-MAC= Coopdech-VLP-100: Macintosh blade videolaryngoscope; CoP=Co-Pilot Magaw videolaryngoscope: Acute angulated blade; APA=Venner AP Advance Videolaryngoscope; KV-1=King Vision non-channelled blade: acute angulated blade; VT-A100= VividTrac VT-A100 Videolaryngoscope: acute angulated blade; TruV=Truview Videolaryngoscope: Macintosh blade; X-Lite.

Channelled videolaryngoscopes: Airtraq=Airtraq & Airtraq Avant; AWS=AWS-100/AWS-200=Pentax Airway Scope AWS-100 or -200 series; KV-2=King Vision - acute angled blade; APA-2=Venner AP Advance Videolaryngoscope; VTrac=VividTrac.

Table 3. Outcomes of Comparative Studies in Simulation Studies on Manikins Using Different Types of Videolaryngoscopes.

Year	First author	Clinical (N of patients) Manikin (N of providers)	Number and types of (video)laryngoscopes used	Better outcomes for VLS based on: A: Improved glottis views (C&L/POGO); B. Faster TSI (Time to Successful Intubation); C: Higher FAIS (First Attempt Intubation Success) rate; D: Less frequent use of manoeuvers or adjuncts (bougie, stylet)	Clinically Preferred Choice of VLS
2009	Tan (47)	Manikin (20)	2: GVL-D - AWS	Difficult airways: GVL-D:AWS→intubation time (17":10")	AWS
2009	Berg (48)	Helicopter (21)	2: DML -Storz VLS (C-MAC-PM)	Difficult airways-CML:VLS→A (C&L improved with VLS); B (VLS longer); C (DML<VLS)	C-MAC-PM
2010	Koyama (49)	Manikins (35)	3: DML -Airtraq - AWS	AWS highest successful intubation rate / fastest intubation	AWS
2010	McElwain (50)	Manikins (31)	4: DML -C-MAC -GVL-D - Airtraq	DML:C-MAC:GVL-D:Airtraq→A[C&L grade I]: 65%:94%:97%:100%); C (12":16":33":22")	Airtraq
2011	Butchart (51)	Manikin (30)	2: APA -GVL-D	APA:GVL-D→time to optimal view (=); B (25":46"); intubation success (=)	APA
2011	Wetsch (52)	Manikin (25)	6: DML -C-MAC -GVL-R -AWS -Airtraq -McG5	Trapped car accident-DML outperformed all VLS-but all VLS have better view	DML
2011	Hodd (53)	Manikin (90)	3: DML -APA-GVL-R	APA: fastest device in difficult airway; best view; least potential airway damage	APA
2011	Piepho (54)	Manikin (30)	3: DML -GVL-R-McG5	Similar times until 1st ventilation and success rate. Better glottis view only with McGrath	McGrath-5
2011	Darshane (55)	Manikin (20)	4: DML -GVL-D -TruV - Airtraq	DML:GVL-D:TruV:Airtraq→all VLS has worse scores-A (Airtraq best); B (DML fastest)	DML
2012	Saito (56)	Manikin (50)	3: DML -AWS-VLP-100	AWS>VLP>DL providing shorter visualization time + higher intubation success	AWS
2012	Healy (57)	Manikin (30)	4: DML -GVL-D -C-MAC -DCI	A (DML < 3 VLS); B (DML/C-MAC > GVL-D/DCI)	C-MAC
2012	Wetsch (58)	Manikin (23)	6: DML -Airtraq -AWS -GVL-R -McG5 -C-MAC	(immobilized cervical spine) - Overall intubation success: (DML/C-MAC/Airtraq: 100%; AWS (87%)-McGr5 (72%)	DML/C-MAC/ Airtraq
2013	Tung (59)	Manikin (34)	3: DML -GVL-D -GVL -Groove	DML:GVL-D: GVL-Groove→A [C&L1] (74%:94%:100%); B (17":18": 22"); C(88%:100%:32%)	GVL-D
2015	Choi (60)	Manikin (95)	4: DML - AWS-1 -C-MAC -GVL-D	A (=); B (AWS-1 + CML > GVL-D) [Face-to-face intubation]	AWS + DML
2015	Kriege (61)	Manikin (72)	3: DML -GVL-D -McG5	DML: GVL-D:McG5→A (20%:90%:80%); B (27":47":66");Fogging GVL-D:McG5(0%:45%)	
2016	Pieters (62)	Manikins (253)	7: DML -C-MAC-D -GVL-D -VLP-100 -McG5 -AWS	Major differences between tracheal intubations (patients vs manikins) Macintosh blades result in shortest intubation times & user satisfaction	C-MAC
2016	Pieters (63)	Manikin	10: DML -9 different VLSs	Oral illumination with LED light C-MAC provides the best light intensity (110 cd/m^2)	C-MAC
2016	Cierniak (64)	Technical	4: C-MAC -VTrac -McG-MAC -KV-1	C-MAC: widest viewing angle; largest diagonal size display; strongest lamp intensity	C-MAC

Table 4. Outcomes of Videolaryngoscopy Studies (in Surgical Patients and Manikins).

VLS	Number of studies in surgery			Number of studies in manikins			Total number of surgical patients	Total number of participants In manikin studies
	Total	Favored VLS	% Favored VLS	Total	Favored VLS	% Favored VLS		
C-MAC	18	16	89%	9	5	56%	6133	5567
AWS	9	7	78%	8	4	50%	2579	1383
GlideScope	22	9	41%	15	1	7%	5888	3342
Airtraq	5	2	40%	5	2	40%	817	54
McGrath	16	4	25%	6	1	17%	4096	1274
DML	27	6	22%	14	4	25%	788	136

inserted into the mouth until a) the ETT enters the vocal cords; b) the inflation of the cuff; or c) the time to obtaining the first capnogram. Rating glottis visualization (Cormack- Lehane grade, POGO) can be difficult and is not always clearly evident given their subjective nature.

Different models exist from the same manufacturer. It is normal that progress is made in manufacturing of new devices, which provide improved versions. Nevertheless, many studies compare "old" and "new" versions of different VLSs in the same trial, which make interpretation less reliable. Many publications fail in reporting which type of VLS brand is actually used in the trial. Each manufacturer of VLS advocates how to best use their devices and promotes specific adjuncts and manoeuvers (manipulation of the larynx by external application of BURP and cricoid pressure, adjustment of jaw thrust, use of specific bougies and stylets). Intubation times may vary depending on the use of stylets and different models of VLSs result in different outcomes pending technical parameters. Screen technology (LED, OLED, LCD) determines pixel density and resolution of screen and camera display; intensity of the endoscopic light; and automatic zeroing. As medical devices do not require the same rigorous testing and clinical trials as pharmaceutical drugs, registration and entry into the market is easier. Hence anesthesiologists might use them in clinical practice without sufficient knowledge. This may also influence data acquisition when trialled.

The competitive nature of the medical equipment industry promotes sales based on evidence that is not always rigorously verified. New devices might be "better", but as they are not well studied, they are not represented in this study.

Manikins do not always reflect clinical performance and are void of hemodynamic stimulation. We concur with the identified limitations of the use of the results of airway research manikins and fully support the standpoint of Cooke (66), whereby manikin studies should be followed by pilot research and finally randomized controlled trials in humans. Our review did not report comparisons in the quality of the researches, but fully acknowledge the limitations of the manikins.

Future studies are needed to inform of their effectiveness. Mouth opening is an issue in VLS. The bulkier AWS cannot always be used due to limited oropharyngeal access. Furthermore, there is limited space adjacent to the AWS scope for extra instrumentation (e.g. Magill forceps, orogastric tubes, temperature probes). The C-MAC VLS has the unique advantage that it is based on a Macintosh laryngoscope which allows enough room to use extra instrumentation and can be used for both direct and indirect laryngoscopy (65). The C-MAC VLS offers even more, as it can be used as a tool for direct and indirect laryngoscopy (6). This VLS offers several beneficial options that may help in realizing a patent airway and satisfactory gas exchange during endotracheal intubation for all indications (normal and difficult airways) including: a) an improved view of the glottis (avoiding failed laryngoscopy) without the need for aligning the oral, pharyngeal and laryngeal axes (20, 25, 30); b) higher first attempt and overall intubation success rate; c) fast time to successful intubation; d) less frequent need of adjuncts and manoeuvers (16, 17); e) least number of complications (less forces exerted on maxillary incisors and hence less dental trauma; less mucosal trauma due to the "blind" spot (6, 14, 21, 35, 65); in most cases stylets are not essential) (16, 17); and e) beneficial physical characteristics such as: i) wide angle of view (6); ii) strongest lamp and brightest illumination of the oropharynx (63); iii) recording and image storage options with high number of pixels (6); iv) multimodular system which provides options to use the monitor display for other functions (fiberoptic or rigid scope); v) system that provides a wide range of interchangeable blades (reusable, disposable, Macintosh and angled blades) (6); vi) portable and lightweight system; vii) reliable airway visualisation without fogging (61); viii) that allows direct and indirect laryngoscope using the same blade (6). Videolaryngoscopy will be acceptable to clinicians for all forms of practice as it offers advantages in difficult intubations while not imposing a penalty when intubation is practiced on normal airways. The fact that C-MAC VLS uses a Macintosh laryngoscope (developed in 1943) proves that there is still an indication for the latter and can be used in most normal airways, although the Macintosh-blade videolaryngoscope gives the operator added advantage which can make all the difference between a failed and a successfully managed airway.

This review aimed to critically evaluate and compare functionality of laryngoscopes in modern airway management, both on patients and on manikins, and acknowledge that the roles of videolaryngoscopes in airway management of surgical and emergency patients may be different. Each particular videolaryngoscope's features may offer advantages or disadvantages, depending on the situation the anesthesiologist has to deal with. To get the best out of videolaryngoscopy, intubators must select the devices according to indication. If the VLS is chosen to be used as a rescue device when intubation with direct laryngoscopy is unsuccessful, it would be advisable to choose a VLS with an extra curved blade (with or without a tube channel), which increases the chance of seeing "round the corner". If the VLS is being used for general everyday practice, it may be best to choose a VLS, which has the option of using both a Macintosh-shaped blade and an extra-curved blade.

Conclusion

During routine airway insertion, it may be best to choose a videolaryngoscope with the option of both Macintosh-shaped blade and an angulated blade. In case of difficult airways, angled curved blades are very helpful during the insertion of an endotracheal tube, although this should only happen in a minority of cases.

The videolaryngoscopes AWS (channelled) and C-MAC (non-channelled) are labelled as the "most favored" options for airway management in this review, based on the most frequently listed VLS as "clinically preferred" in comparative studies, comparing at least two laryngoscopes. However, no one videolaryngoscope offers a solution for all airway problems. Depending on the clinical scenario, each videolaryngoscope offers different advantages and disadvantages, with intubators selecting the optimal device according to the situation, their expertise and competence.

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