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Respiration and the Airway

RESPIRATION AND THE AIRWAY

# Evaluation of six videolaryngoscopes in 720 patients with a simulated difficult airway: a multicentre randomized controlled trial

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## Abstract

**Background:** Videolaryngoscopes are aggressively marketed, but independent evaluation in difficult airways is scarce. This multicentre, prospective randomized controlled trial evaluates six videolaryngoscopes in patients with a simulated difficult airway.

**Methods:** With ethics committee approval and written informed consent, 12 senior anaesthetists intubated the trachea of 720 patients. A cervical collar limited mouth opening and neck movement, making intubation difficult. We evaluated three unchannelled (C-MAC™ D-blade, GlideScope™, and McGrath™) and three channelled videolaryngoscopes (Airtraq™, A.P. Advance™ difficult airway blade, and KingVision™). The primary outcome was first-attempt intubation success rate. Secondary outcomes included overall success rate, laryngeal view, intubation times, and side-effects. The primary hypothesis for every videolaryngoscope was that the 95% confidence interval of first-attempt success rate is ≥90%.

**Results:** Mouth opening was decreased from 46 (SD 7) to 23 (3) mm with the cervical collar. First-attempt success rates were 98% (McGrath™), 95% (C-MAC™ D-blade), 87% (KingVision™), 85% (GlideScope™ and Airtraq™), and 37% (A.P. Advance™, $P<0.01$). The 95% confidence interval of first-attempt success rate was >90% only for the McGrath™. Overall success, laryngeal view, and intubation times differed significantly between videolaryngoscopes (all $P<0.01$). Side-effects were minor.

**Conclusions:** This trial revealed differences in the performance of six videolaryngoscopes in 720 patients with restricted neck movement and limited mouth opening. In this setting, first-attempt success rates were 85–98%, except for the A.P. Advance™ difficult airway blade. Highest success and lowest tissue trauma rates were achieved by the McGrath™ and C-MAC™ D-blade, highlighting the importance of the videolaryngoscope blade design.

**Clinical trial registration:** ClinicalTrials.gov: identifier NCT01692535.

**Key words:** anaesthetic techniques, laryngoscopy; equipment, airway; intubation, tracheal tube

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**Editor's key points**

- Videolaryngoscopes may be useful in patients with difficult airways, but there may be differences in their efficacy.
- Six videolaryngoscopes were compared in patients with simulated difficult airway (application of a cervical collar to limit mouth opening and neck movement) in the ease of tracheal intuabation.
- There were marked differences between six videolaryngoscopes in the efficacy of tracheal intubation.

In the Fourth National Audit Project on major complications of airway management in the UK, the reported incidence of major adverse airway events was 1 in 22 000 anaesthesia patients, but the real incidence was estimated as 1 in 5500 anaesthesia patients.[1] Videolaryngoscopes have been developed by combining features of classic laryngoscopes and fibre-optic bronchoscopes in an effort to increase intubation success rates and to decrease anaesthesia-related morbidity and mortality. A steadily increasing number of videolaryngoscopes are marketed, but a sound evaluation before marketing is often missing.[2–4] Videolaryngoscopes vary with regard to the shape of their blades, camera location, video screen, integration of a channel for tracheal tube guidance, and single-use *vs* multiple-use design.

Many studies on videolaryngoscopes were carried out in manikins,[5–8] in cadavers,[7] or in patients with normal airways. In the setting of predicted, simulated, or genuine difficult airways, studies demonstrated superiority of videolaryngoscopes compared with the classic Macintosh laryngoscope, with better laryngeal views[7 9–15] and higher intubation success rates[10 12–18] with the videolaryngoscopes.

In patients with positive predictors for difficult intubation, such as a Mallampati score of III or IV, the C-MAC™ (93%)[12] and the Berci–Kaplan™ videolaryngoscope (99%)[10] showed higher first-attempt success rates than the Macintosh laryngoscope (84 and 92%, respectively, in the two studies). Other studies confirmed overall success rates of more than 90% in this setting with the C-MAC™,[14 19 20] the GlideScope™,[14 19] and the McGrath™.[20] However, the inclusion criterion for these studies was the presence of one predictor for difficult intubation, and it is known that predictors such as the Mallampati score have high inter-rater variabilities[21 22] and that the sensitivity of single predictors for difficult intubation is low (Mallampati: pooled sensitivity of 49%).[23] The high success rates with the Macintosh laryngoscope of more than 80% show that, indeed, most of the included patients probably did not have a true difficult airway.[10 12]

Other studies evaluated videolaryngoscopes in patients with manual in-line stabilization, reducing neck movement as much as possible. In this setting, Liu and colleagues[24] compared the Airway Scope™ and the GlideScope™ and found high success rates with the use of both devices (100 and 89%, respectively).[24] McElwain and Laffey[15] showed that the Airtraq™ performed better than the C-MAC™ with its Macintosh-style blade,[15] and Enomoto and colleagues[13] found that the Pentax-AWS™ had higher success rates than the Macintosh laryngoscope (100 *vs* 89%, respectively).[13] A study in patients in whom conventional laryngoscopy had failed confirmed success rates of more than 90% with the Pentax-AWS™.[11]

Given that videolaryngoscopes are promoted as tools for the difficult airway, their performance in difficult airways needs to be known. As true difficult airways are rare and possibly life threatening, the performance of intubation devices for difficult airways is frequently evaluated by reversibly creating 'difficult-to-intubate' situations with cervical collars.[9 25–27] These collars restrict neck movement and, importantly, also limit mouth opening (which could not be achieved by manual in-line stabilization). The cervical collar creates airways that are far more difficult to intubate (success rates with the Macintosh laryngoscope around 40%)[25] than airways under manual in-line stabilization only (success rates >80%).[13] With a cervical collar, Byhahn and colleagues[9] evaluated the Macintosh laryngoscope compared with the C-MAC™ and found better glottic views with the C-MAC™.[9] However, larger randomized trials comparing different videolaryngoscopes in patients with genuine difficult airways or in patients with difficult airways simulated with a cervical collar are missing, and it remains unclear which videolaryngoscopes perform best in these situations.

To provide the missing evidence, we compared six videolaryngoscopes in a prospective randomized controlled multicentre trial in patients with a difficult airway simulated with a cervical collar. For every single videolaryngoscope, the primary hypothesis was that the 95% confidence interval (CI) of the first-attempt success rate is ≥90%.

## Methods

This prospective randomized controlled patient-blinded multicentre trial evaluates the performance of six videolaryngoscopes in patients with a simulated difficult airway. It was performed at the University Hospitals of Bern, Lausanne, and Geneva in Switzerland from December 3, 2012 to January 20, 2015. It was approved by each local ethics committee (Kantonale Ethikkommission Bern, approval 106/12; Commission Cantonale d'éthique, Lausanne, approval 444/12; Comité d'Ethique, Geneve, approval 12-251). Patients were included with written informed consent, and the study was registered at www.clinicaltrials.gov (identifier NCT01692535). The detailed study protocol was published as a methods paper before the start of this clinical study.[28]

### Participants and inclusion and exclusion criteria

We prospectively included 720 adult patients with ASA status I–III who were to undergo elective surgery requiring tracheal intubation at one of the participating hospitals. Exclusion criteria were risk of aspiration and known or predicted difficult airway (BMI >35 kg m$^{-2}$, Mallampati >III, thyromental distance <6 cm, interincisor distance <3.5 cm, known difficult mask ventilation/laryngoscopy, and planned or previous history of awake tracheal intubation).

### Study devices

The six videolaryngoscopes (Fig. 1) included three videolaryngoscopes without a guiding channel and three videolaryngoscopes with a guiding channel for intubation. Unchannelled videolaryngoscopes were the C-MAC™ (Karl Storz, Tuttlingen, Germany) with its D-blade and a stylet, the GlideScope™ (Verathon Inc., Bothell, WA, USA) blade 3 with GlideScope™ stylet, and the McGrath™ (Aircraft Medical Ltd, Edinburgh, UK) with MAC blade #3 and a stylet. Channelled videolaryngoscopes were the Airtraq™ (Prodol Meditec SA, Vizcaya, Spain) #2 in women and #3 in men, the A.P. Advance™ (Venner Medical SA, Singapore) difficult airway blade, and the KingVision™ (Kingsystems, Noblesville, IN, USA) blade #3. The C-MAC™ D-blade is reusable; all other blades are single use. Tracheal tubes were cuffed

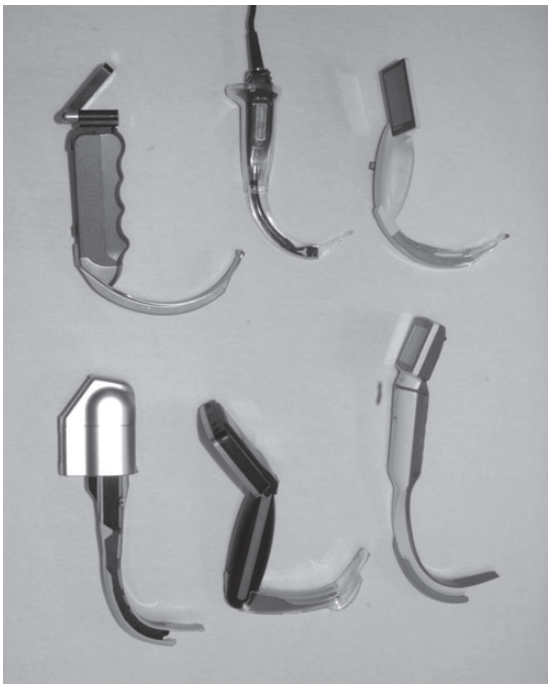

Fig 1 The six videolaryngoscopes evaluated in the present study. Top row from left to right: the unchannelled videolaryngoscopes C-MAC™ D-blade, GlideScope™, and McGrath™. Bottom row from left to right: the channelled videolaryngoscopes Airtraq™, A.P. Advance™, and KingVision™. Note the differences in design, angulation, and length of the blades.

Mallinckrodt Hi-Contour Tracheal Tubes™ (Covidien, Hazelwood, MO, USA; 6.5 mm for women and 7.5 mm for men).

## Study personnel

All participating consultant anaesthetists were airway management experts and trained with all videolaryngoscopes on both manikins and patients until they, as airway specialists, felt competent with each device. We did not set a fixed number of pretrial intubations because previous clinical experience with the different videolaryngoscopes was not uniform and manual skills are acquired at an individual rate. None of the videolaryngoscopes had been a standard intubation device at any of the centres before the start of the study.

## Randomization and blinding

Patients were randomly assigned to one of the six videolaryngoscopes by computer-generated randomization using sealed opaque envelopes. To ensure that each anaesthetist intubated 10 times with each videolaryngoscope, we block randomized separately for each anaesthetist participating in this study. A member of the study team was responsible for correct enrolment and assignment of patients. Patients were blinded to randomization. The postoperative interview with the patient was carried out by a blinded member of the research team.

## Anaesthesia and intubation

Premedication with midazolam 7.5 mg or lorazepam 1 mg was administered at least 30 min before the start of anaesthesia. Standard monitoring included ECG, non-invasive blood pressure measurements, oxygen saturation, capnography, and volatile anaesthetic concentration. Anaesthesia was induced with propofol 1.5–3 mg (kg body weight)$^{-1}$ and with fentanyl 1–2 μg (kg body weight)$^{-1}$. Neuromuscular block was then achieved with rocuronium 0.6 mg (kg body weight)$^{-1}$ and was controlled by loss of 1 Hz muscle twitching (TOF Watch™; Organon, Dublin, Ireland). The inter-incisor distance at maximal mouth opening was measured before and after adjustment of a size-adjustable cervical collar for adults (Stifneck™; Laerdal, Copenhagen, Denmark), and the size of the collar was adjusted according to the manufacturer's recommendations depending on the anatomy of the patient. The collar was adjusted to permit a minimal mouth opening of 18 mm, and the head was taped to the trolley to inhibit neck movement.

Two intubation attempts with the randomized videolaryngoscope were allowed. The study was terminated once tracheal intubation was achieved, after two unsuccessful attempts, or when airway injury, bronchospasm, technical failure of the videolaryngoscope, or a reduction of oxygen saturation below 90% occurred.

## Measurements

Patient and airway characteristics, such as age, BMI, Mallampati score, and thyromental distance <6 cm, were recorded. Success of the first intubation attempt was the primary outcome parameter. Success was defined as placement of the tube in the trachea within 180 s, confirmed by end-tidal carbon dioxide.[28] Overall success rate (i.e. success in the first or second attempt) was a secondary outcome parameter. Other secondary outcome parameters included the Cormack–Lehane class, percentage of glottic opening (POGO) score,[29] Intubation Difficulty Scale (IDS),[30] intubation times, reasons for intubation failure, adverse events, and side-effects. An interim time was recorded at the moment when the vocal cords were seen. Additionally, as an amendment to the published protocol, anaesthetists graded the ease of device insertion, quality of the view, and ease of tube advancement on a subjective scale (excellent/good/fair/poor).

## Hypothesis and calculation of sample size

We defined a success rate of 0.9 as the clinically acceptable lower limit for a device that is designed for management of difficult airways.[28 31] Thus, our primary hypothesis for every single videolaryngoscope was that the lower limit of the 95% CI of first-attempt success rate is at least 0.9. With these values, we calculated the necessary sample size as 107 per device, given an $\alpha$ level of 0.05 and a power of 0.8. We decided to include 120 patients per device (total of 720 patients) to compensate for drop-outs and missing data.

## Statistical analysis

Intention-to-treat analysis according to randomization was performed. Binary data were analysed using the $\chi^2$ test, or by Fisher's exact test if more than 20% of expected values were below 5. Ordinal data were evaluated using the Kruskal–Wallis test. Continuous data were checked for normality by Q-Q plots, histograms, and Shapiro–Wilk W-test. Normal data were analysed by Student's unpaired *t*-test (two groups) or one-way ANOVA (more than two groups). Non-normal data were analysed by independent samples Kruskal–Wallis test.

Pairwise *post hoc* comparisons by logistic regression were corrected for multiplicity with the Bonferroni–Holm method.

Binary data are presented as numbers (%), whereas continuous data are presented as the mean (SD) if normally distributed and otherwise as the median (25th and 75th percentile). The range is reported where indicated. A probability of $P<0.05$ was considered statistically significant. Data were analysed using Stata V.13.1 (StataCorp, College Station, TX, USA).

## Results

Seven hundred and twenty patients were included without drop-outs after randomization (Fig. 2). Each of 12 participating anaesthetists performed 10 intubations with each videolaryngoscope in random order. Patient and airway characteristics are given in Table 1. Using a cervical collar, neck movement was inhibited and mouth opening was significantly reduced from 46 (7) to 23 (3) mm ($P<0.01$), creating a difficult airway (Table 1). The 95% CI of the mean of the difference of mouth opening without and with the cervical collar was 22–23 mm. There was no difference in mouth opening with the cervical collar between the devices ($P=0.30$).

### Primary outcome parameter: first-attempt success rate

The 95% CI of first-attempt success rate was >0.9 only for the McGrath™, leading to rejection of the primary hypothesis for all videolaryngoscopes except the McGrath™ (Table 2). First-attempt success rates differed significantly between videolaryngoscopes ($P<0.01$) and ranged from 37% with the A.P. Advance™ difficult airway blade to 98% with the McGrath™ (Table 2). Oesophageal intubation occurred in one C-MAC™, two GlideScope™, three Airtraq™, and six A.P. Advance™ patients ($P=0.02$).

Failures because of problems with tube advancement were relatively more frequent with unchannelled devices (tube advancement problems in 76% and viewing problems in 24%) than with channelled devices (tube advancement problems in 45% and viewing problems in 55%; $P<0.01$). The technical problems encountered included loose contacts and problems with the screen.

*Post hoc* pairwise comparisons revealed that the A.P. Advance™ had a significantly lower first-attempt intubation success rate than all other videolaryngoscopes (all $P<0.01$). Additionally, the McGrath™ had a significantly higher first-attempt intubation success rate than the GlideScope™, the Airtraq™, and the KingVision™ (all $P<0.03$), and a similar success rate to the C-MAC™ D-blade. Even when excluding the A.P. Advance™ from the analysis, the first-attempt success rate still differed significantly between the remaining five videolaryngoscopes ($P<0.01$).

### Laryngeal view

Cormack–Lehane classes and POGO scores differed significantly between devices (Table 2). *Post hoc* pairwise comparison revealed

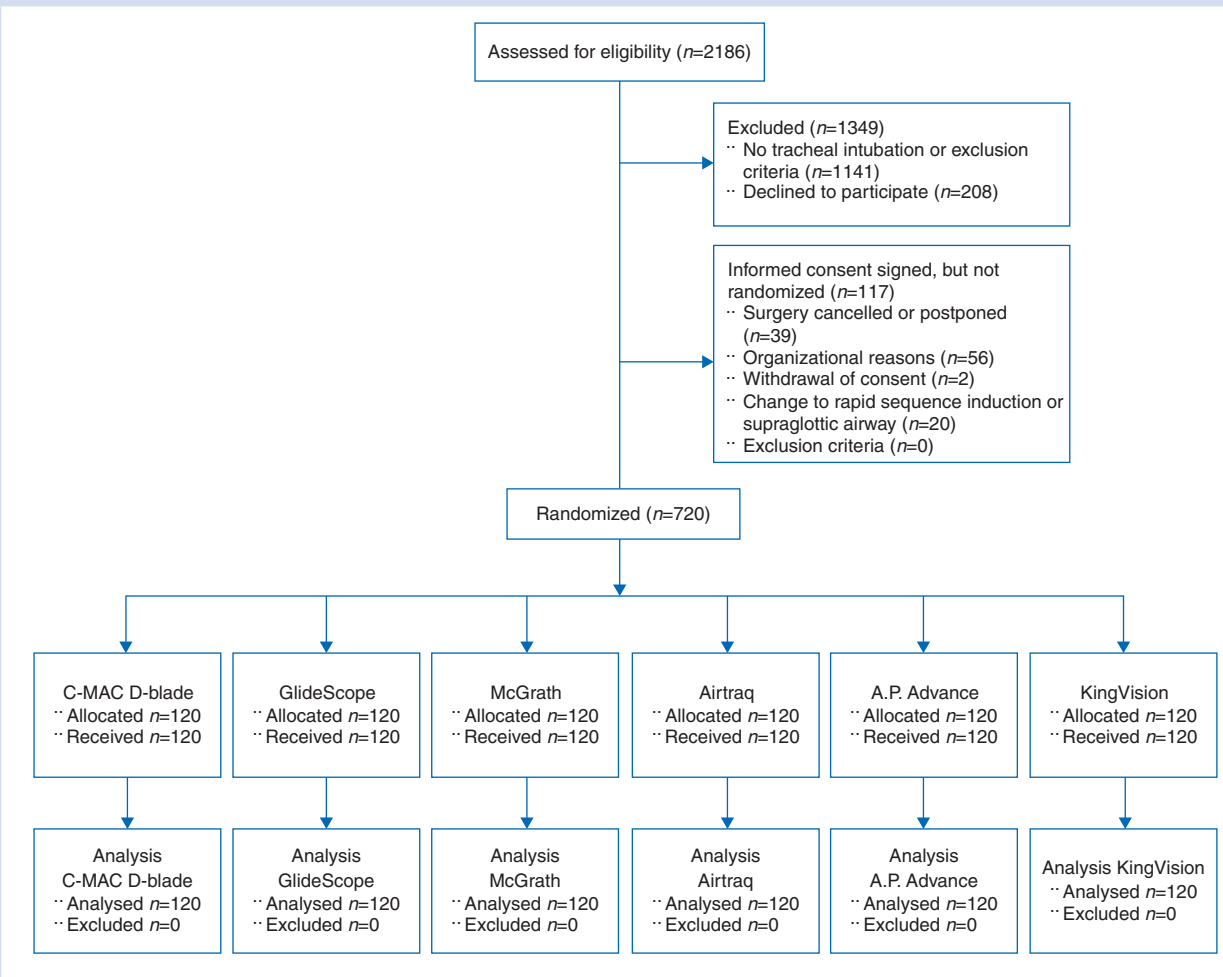


Fig 2 Study flowchart.

Table 1 Baseline patient and airway characteristics, presented as numbers or mean (SD). Missing data for Mallampati: two McGrath™, three Airtraq™, one A.P. Advance™, and two KingVision™

| Characteristic | Devices without a guiding channel | | | Devices with a guiding channel | | |
|---|---|---|---|---|---|---|
| | C-MAC™ D-blade (*n*=120) | GlideScope™ (*n*=120) | McGrath™ (*n*=120) | Airtraq™ (*n*=120) | A.P. Advance™ (*n*=120) | KingVision™ (*n*=120) |
| Sex male/female (*n*) | 71/49 | 63/57 | 67/53 | 67/53 | 77/43 | 69/51 |
| Age (yr; mean [range]) | 49 [19–100] | 52 [21–83] | 50 [18–86] | 49 [18–87] | 49 [18–89] | 47 [18–86] |
| ASA I/II/III (*n*) | 31/67/22 | 28/74/18 | 25/78/17 | 32/63/25 | 28/76/16 | 38/68/14 |
| BMI (kg $m^{-2}$) | 25 (4) | 25 (4) | 25 (4) | 25 (4) | 25 (4) | 26 (5) |
| Mallampati I/II/III/IV (*n*) | 72/44/4/0 | 62/50/7/1 | 56/53/7/2 | 63/49/5/0 | 65/47/7/0 | 64/49/5/0 |
| Thyromental distance <6 cm (*n*) | 5 | 5 | 5 | 6 | 8 | 8 |
| Mouth opening without collar [mm; mean (SD)] | 46 (7) | 45 (6) | 45 (7) | 46 (7) | 47 (7) | 45 (6) |
| Mouth opening with collar [mm; mean (SD)] | 23 (3) | 22 (3) | 23 (3) | 23 (3) | 23 (3) | 23 (3) |
| Difference in mouth opening caused by cervical collar [mm; mean (SD)] | 23 (6) | 23 (6) | 22 (6) | 23 (6) | 23 (7) | 22 (6) |

Table 2 First intubation attempt, presented as number, as percentage, or as median (25th; 75th percentile). No reason for failure was reported for one C-MAC™ D-blade, one GlideScope™, three Airtraq™, 13 A.P. Advance™, and three KingVision™ patients. No Cormack–Lehane grade was reported for one C-MAC™ D-blade, three GlideScope™, one McGrath™, nine Airtraq™, 24 A.P. Advance™, and four KingVision™ patients. *$\chi^2$ test. *Post hoc* logistic regression and pairwise comparison with Bonferroni–Holm corrections: *P*<0.01 for A.P. Advance™ *vs* all other videolaryngoscopes, and *P*<0.05 for McGrath™ *vs* GlideScope™, Airtraq™, and King Vision™. †Kruskal–Wallis test. *Post hoc* ordered logistic regression and pairwise comparison with Bonferroni–Holm corrections: *P*<0.01 for A.P. Advance™ *vs* all other videolaryngoscopes. ‡Fisher's exact test

| | Devices without a guiding channel | | | Devices with a guiding channel | | | |
|---|---|---|---|---|---|---|---|
| | C-MAC™ D-blade (*n*=120) | GlideScope™ (*n*=120) | McGrath™ (*n*=120) | Airtraq™ (*n*=120) | A.P. Advance™ (*n*=120) | KingVision™ (*n*=120) | *P*-value |
| First-attempt success {*n* (%); [95% CI]} | 114 (95); [89–98] | 102 (85); [77–90] | 117 (98); [92–99] | 102 (85); [77–90] | 44 (37); [28–46] | 104 (87); [79–92] | <0.01* |
| Cormack–Lehane grade I/IIa/IIb/III/IV (*n*) | 76/36/7/0/0 | 80/29/3/2/3 | 64/45/9/1/0 | 74/30/4/0/3 | 19/28/22/8/19 | 63/41/7/1/4 | <0.01† |
| Percentage of glottic opening [median (percentiles)] | 90 (80; 100) | 100 (83; 100) | 90 (80; 100) | 90 (80; 100) | 60 (10; 80) | 90 (80; 100) | <0.01† |
| Failure because of technical problems/poor view/intubation difficulty (*n*) | 0/0/5 | 0/5/12 | 0/1/2 | 3/7/5 | 2/34/27 | 0/6/7 | 0.05‡ |

significantly worse views with the A.P. Advance™ compared with all other videolaryngoscopes (all *P*<0.01). No statistically significant difference was found for Cormack–Lehane class or POGO score if data from the A.P. Advance™ were excluded from the analysis.

## Overall success rate

Overall success rates differed significantly between the videolaryngoscopes and ranged from 40% with the A.P. Advance™ to 98% with the C-MAC™ D-blade and the McGrath™ (Table 3). When excluding data from the A.P. Advance™, overall success rate still differed significantly between the remaining five videolaryngoscopes (*P*=0.04).

## Subjective grading of handling

Results of the subjective grading of handling differed between the videolaryngoscopes (*P*<0.01; Table 3). Overall, taking all six videolaryngoscopes into account, the view was rated as excellent in 59%, and tube advancement in 37% (*P*<0.01).

## Intubation times

Time to view the vocal cords, time to advance the tracheal tube into the trachea, and overall intubation times showed a broad range and differed significantly between devices (*P*<0.01; Table 3). Times also differed when data from the A.P. Advance™ were excluded from the analysis (*P*<0.01).

**Table 3** Overall performance, presented as number, percentage, or median (25th; 75th percentile) [range]. Missing data for insertion of the device into the oropharynx and quality of view: one C-MAC™ D-blade, three GlideScope™, one Airtraq™, eight A.P. Advance™, and three KingVision™ patients. Missing data for ease of tube insertion: three C-MAC™ D-blade, three GlideScope™, one Airtraq™, nine A.P. Advance™, and four KingVision™ patients. CI, confidence interval. *$\chi^2$ test. *Post hoc* logistic regression and pairwise comparison with Bonferroni–Holm corrections: $P<0.01$ for A.P. Advance™ *vs* all other videolaryngoscopes. †Kruskal–Wallis test. *Post hoc* ordered logistic regression and pairwise comparison with Bonferroni–Holm corrections: $P<0.04$ for C-MAC™ D-blade and for McGrath™ *vs* all channelled videolaryngoscopes. ‡Kruskal–Wallis test. *Post hoc* ordered logistic regression and pairwise comparison with Bonferroni–Holm corrections: $P<0.01$ for A.P. Advance™ *vs* all other videolaryngoscopes. ¶Kruskal–Wallis test. *Post hoc* ordered logistic regression and pairwise comparison with Bonferroni–Holm corrections: $P<0.01$ for A.P. Advance™ *vs* McGrath™ and Airtraq™, and $P=0.03$ for Airtraq™ *vs* GlideScope™. §$\chi^2$ test. *Post hoc* logistic regression and pairwise comparison with Bonferroni–Holm corrections: $P<0.01$ for A.P. Advance™ *vs* C-MAC™ D-blade, McGrath™, and KingVision™, and $P<0.03$ for GlideScope™ *vs* C-MAC™ D-blade and McGrath™. ‖Kruskal–Wallis test. *Post hoc* ordered logistic regression and pairwise comparison with Bonferroni–Holm corrections: $P<0.01$ for A.P. Advance™ *vs* all other videolaryngoscopes. #Kruskal–Wallis test. *Post hoc* logistic regression of log-transformed data and pairwise comparison with Bonferroni–Holm corrections: $P<0.01$ for A.P. Advance™ *vs* all other videolaryngoscopes, and $P<0.03$ for KingVision™ *vs* all other videolaryngoscopes. **Kruskal–Wallis test. *Post hoc* logistic regression of log-transformed data and pairwise comparison with Bonferroni–Holm corrections: $P<0.05$ for Airtraq™ *vs* all other videolaryngoscopes, $P<0.01$ for KingVision™ *vs* A.P. Advance™ and GlideScope™, and $P<0.04$ for McGrath™ *vs* GlideScope™ and A.P. Advance™. ††Kruskal–Wallis test. *Post hoc* logistic regression of log-transformed data and pairwise comparison with Bonferroni–Holm corrections: $P<0.01$ for A.P. Advance™ *vs* all other videolaryngoscopes, $P<0.01$ for Airtraq™ *vs* C-MAC™ D-blade, Glidescope™, and KingVision™, and $P<0.01$ for McGrath™ *vs* GlideScope™

| | Devices without a guiding channel | | | Devices with a guiding channel | | | |
|---|---|---|---|---|---|---|---|
| | C-MAC™ D-blade (*n*=120) | GlideScope™ (*n*=120) | McGrath™ (*n*=120) | Airtraq™ (*n*=120) | A.P. Advance™ (*n*=120) | KingVision™ (*n*=120) | *P*-value |
| Overall success {*n* (%); [95% CI]} | 117 (98); [92–99] | 110 (92); [85–95] | 118 (98); [93–100] | 112 (93); [87–97] | 48 (40); [32–49] | 110 (92); [85–95] | <0.01* |
| Insertion of the device into the oropharynx, excellent/good/fair/poor (*n*) | 69/40/9/1 | 47/48/19/3 | 71/42/7/0 | 41/47/27/4 | 26/43/29/14 | 26/54/26/11 | <0.01† |
| Quality of view, excellent/good/fair/poor (*n*) | 79/31/7/2 | 78/33/4/2 | 74/38/7/1 | 78/33/7/1 | 38/50/14/10 | 68/41/6/2 | <0.01‡ |
| Ease of tube insertion, excellent/good/fair/poor (*n*) | 41/42/26/8 | 36/41/26/14 | 52/41/22/5 | 61/37/16/5 | 25/37/26/23 | 41/47/24/5 | <0.01¶ |
| Soft tissue lesion or bleeding (*n*) | 9 | 27 | 6 | 19 | 43 | 14 | <0.01§ |
| Intubation Difficulty Scale | 0 (0; 1)<br>*n*=117 | 0 (0; 1)<br>*n*=110 | 1 (0; 1)<br>*n*=118 | 0 (0; 1)<br>*n*=112 | ∞ (1; ∞)<br>*n*=48 | 1 (0; 1)<br>*n*=110 | <0.01‖ |
| Time to view the vocal cords {s; median (25th; 75th percentile) [range]} | 17 (12; 23) [6–46] | 19 (14; 29) [3–100] | 18 (13; 24) [6–53] | 20 (12; 28) [5–110] | 30 (21; 55) [9–142] | 26 (16; 32) [7–117] | <0.01# |
| Time to advance tube {s; median (25th; 75th percentile) [range]} | 36 (28; 61) [8–154] | 40 (29; 71) [10–157] | 33 (26; 51) [6–147] | 27 (19; 36) [6–148] | 50 (27; 88) [14–138] | 31 (24; 46) [4–140] | <0.01** |
| Intubation time of successful attempt {s; median (25th; 75th percentile) [range]} | 56 (45; 85) [20–177] | 60 (48; 98) [17–180] | 53 (42; 77) [20–179] | 47 (36; 60) [18–175] | 93 (54; 144) [33–180] | 59 (46; 78) [31–180] | <0.01†† |

### Intubation difficulty scale

The median IDS score was 0 or 1 for all devices, with no differences between the devices except for the A.P. Advance™. Given that more than 50% of the intubation attempts with the A.P. Advance™ were failures, the median IDS for the A.P. Advance™ was, by definition, infinite (Table 3).

### Adverse events

The most frequent adverse event was soft tissue lesion or bleeding (Table 3), ranging from six patients (McGrath™, 5%) to 43 patients (A.P. Advance™, 36%; $P<0.01$). This included even minor tissue trauma. Two cuff leaks occurred after intubation, both related to a videolaryngoscope with a guiding channel (one Airtraq™ and one KingVision™). There was no dental trauma, aspiration, or bronchospasm during anaesthesia.

### Side-effects

There were no statistically significant differences between the videolaryngoscopes for side-effects such as hoarseness (11–18%), sore throat (10–19%), dysphagia (2–8%), or postoperative nausea and vomiting (9–14%; all $P>0.05$). There was a statistically significant difference for pain during swallowing (9% with C-MAC™ D-blade and McGrath™ to 22% with the A.P. Advance™; $P=0.02$), but *post hoc* pairwise comparisons missed statistical significance. Even though blinded to the device, fewer patients in the A.P. Advance™ group (81%) than in all other groups (94–98%) would choose to participate again in the study ($P<0.01$).

### Comparison between the study centres

We evaluated a possible influence of the study centre on the primary outcome parameter. Logistic regression with study centre and device as factors revealed a statistically significant difference in first-attempt success rate in favour of Geneva compared with Bern (odds ratio = 3.71, 95% CI 1.78–7.76; $P<0.01$), but not compared with Lausanne. However, the model revealed no significant interactions between study centre and device (all $P>0.21$), and in all study centres the order of performance of the six videolaryngoscopes was the same.

## Discussion

The present study evaluated the performance of six videolaryngoscopes in 720 patients with a simulated difficult airway that was created by a stiff cervical collar that restricted neck movement and reduced mouth opening to 23 (3) mm. First-attempt success rates differed significantly and were 98% (McGrath™), 95% (C-MAC™ D-blade), 87% (KingVision™), 85% (GlideScope™ and Airtraq™), and 37% (A.P. Advance™). We predefined a benchmark for first-attempt success rate as a 95% CI of at least 90%. This was achieved only by the McGrath™ (95% CI 92–99%) and was very narrowly missed by the C-MAC™ with its D-blade (95% CI 89–98%). Overall success, laryngeal view, and intubation times differed significantly between videolaryngoscopes, and regarding most outcome parameters, the C-MAC™ D-blade and the McGrath™ performed best and the A.P. Advance™ worst.

First-attempt success rates were highest with devices that featured a blade that was easy to introduce into the mouth and small enough to allow for adjustments within the oral cavity. Unchannelled blades are usually less bulky and allow for independent manoeuvring of the tracheal tube. In contrast, bulkier videolaryngoscopes and channelled videolaryngoscopes rely on perfect positioning of the videolaryngoscope in front of the glottic opening. The design of the blade (shape, curvature, and position of the video camera) influences the performance of the device. For example, a large portion of the video screen of the A.P. Advance™ shows the plastic part of the laryngoscope tip and not the relevant airway anatomy, which could contribute to its poor performance.

Interestingly, manikin studies with the A.P. Advance™ difficult airway blade presented success rates of 97–100%,[5 32 33] whereas first-attempt intubation success decreased from 100 to 60% when a difficult airway was created.[5] Providing the first clinical data of the A.P. Advance™ in humans, we cannot confirm these success rates of preclinical studies, which also questions airway studies performed with manikins only.[5]

In contrast, single-comparison studies in humans reported first-attempt success rates of 88–93% for the C-MAC™,[9 12 20] up to 100% for the GlideScope™[19 27 34] and the Airtraq™,[35] and 69% for the McGrath™ MAC blade.[20] Studies in patients with positive predictors for difficult intubation showed overall success rates of more than 90% with the C-MAC™,[14 19 20] the GlideScope™,[14 19] and the McGrath™.[20] Another study showed a success rate of 94% in patients after failed intubation with the GlideScope™.[34] Direct comparisons of these studies are difficult because of heterogeneity of clinical settings, airway situations (predicted *vs* simulated *vs* genuine difficult airway), and different levels of experience. Therefore, we included the six videolaryngoscopes in a single study. A recent meta-analysis showed a superiority of the Airtraq™ over the Macintosh laryngoscope to reduce the risk of intubation failure, whereas the C-MAC™, the GlideScope™, and the McGrath™ missed statistical significance.[36] This meta-analysis included studies with cervical spine immobilization, whereas our study included patients who had severely reduced mouth opening in addition to cervical spine immobilization. This demonstrates that the performance of videolaryngoscopes depends on the exact circumstances of the difficult airway and that the optimal videolaryngoscope might differ for various types of difficult airway situations.

Several studies compared different videolaryngoscopes with the classic Macintosh laryngoscope and agree on a higher success rate of the videolaryngoscopes compared with the Macintosh laryngoscope.[12–18 37] Likewise, the meta-analysis of Suppan and colleagues[36] showed that the risk of intubation failure in patients with immobilization of the cervical spine was lower with videolaryngoscopes compared with the Macintosh laryngoscope. Laryngeal view consistently improved with videolaryngoscopes compared with the Macintosh laryngoscope,[7 9 13–15 38] but this does not necessarily lead to improved intubation success. The well-known phenomenon 'you see that you fail' describes the fact that the ability to see the glottis does not automatically facilitate tracheal intubation.

Likewise, in our study, intubation failures were often because of problems with tube advancement. In general, the view was rated as 'excellent' in 59%, but tracheal intubation in only 37%, demonstrating that tube advancement is often a crucial problem with videolaryngoscopes. In direct laryngoscopy, the oropharyngeal curve and the pharyngoglottotracheal curve need to be aligned to permit a direct glottic view.[39] In indirect laryngoscopy with videolaryngoscopes, these curves are not necessarily aligned. Stylets to mimic the curve of the blade are mandatory for intubation with angulated blades without a guiding channel, but even with optimally shaped stylets tracheal intubation can be cumbersome.

Intubation times differed between devices, but these statistically significant differences were clinically irrelevant and similar

to those reported by others.[5 12 20 27] Interestingly, the time needed to obtain an optimal view of the glottis was longer with the channelled videolaryngoscopes. However, once the blade position was optimized, tracheal intubation was fastest with the channelled Airtraq™, which is in agreement with a previous study.[40] All videolaryngoscopes showed a broad range of intubation times. We therefore performed a *post hoc* analysis and recalculated first-attempt success rates by applying a more restrictive definition of success with a cut-off time of 60 s. With this definition, first-attempt success rates were as follows: C-MAC™ D-blade 55%, GlideScope™ 43%, McGrath™ 64%, Airtraq™ 65%, A.P. Advance™ 9%, and KingVision™ 48% ($P<0.01$). Thus, first-attempt success rates decreased significantly and all devices had a first-attempt intubation success rate below 70%, which we consider unacceptable. We conclude that tracheal intubation in difficult airways often takes time, and therefore, optimal preoxygenation is paramount. Although obese and pregnant patients might not tolerate an apnoea phase of 180 s even with optimal preoxygenation, none of the 720 patients included in our study desaturated below 90%.

### Limitations

Given that this trial studied simulated difficult airways, conclusions regarding genuine difficult airways must be drawn with caution. Studying difficult airway management by reversibly creating a difficult airway with cervical collars is common research practice.[9 26 27 41 42] Cervical collars uniformly inhibit neck movement and reduce mouth opening, providing standardized and reproducible airway research conditions that represent important causes of difficult airways, such as, for example, in trauma. In contrast, we did not study difficult airways caused by other factors, such as obesity. It is possible that the performance of videolaryngoscopes varies depending on the type of difficult airway so that there might not be a single perfect videolaryngoscope, but instead videolaryngoscopes that are ideal for specific airway situations.

Although previous clinical experience with the videolaryngoscopes was not uniform among participating anaesthetists, none of the videolaryngoscopes was a standard intubation device at any of the study centres before and during the study. Given that no validated tool for objective assessment of competency exists and because suggested training repetitions are very vague,[43] we relied on the self-assessment of the participating airway experts who trained with all videolaryngoscopes until they felt competent. The absolute performance of the study centres varied, but there were no statistically significant interactions between the study centre and the device. Thus, although the absolute success rates differed, the same pattern, with McGrath™ and C-MAC™ D-blade performing best, closely followed by GlideScope™, Airtraq™, and KingVision™, and lastly followed by the A.P. Advance™, was seen in all centres.

All study-related measurements during induction of anaesthesia and intubation were carried out by a member of the research team who was not involved in the clinical procedure. To assure a smooth conduction of the study with adherence to the protocol and with valid measurements of parameters such as intubation time, this researcher was not blinded.

We did not include a standard Macintosh laryngoscope with direct laryngoscopy because it is known that in patients with difficult airways videolaryngoscopes are superior regarding intubation success rates, glottic view, and rates of difficult intubation.[9 12 16–18 37]

### Conclusions

This study showed marked differences between six videolaryngoscopes in patients with inhibited neck movement and limited mouth opening. The McGrath™ and C-MAC™ D-blade showed highest success rates and lowest rates of tissue trauma. KingVision™, GlideScope™, and Airtraq™ followed in performance. The A.P. Advance™ difficult airway blade performed weakest and cannot be recommended in the described setting. Half of the failures were because of problems with tube advancement despite a good view of the glottic opening. Future studies should clarify the impact of guiding channels on the performance of videolaryngoscopes and whether performance depends on the presence or absence of guiding channels or on the design of the blades.

## Authors' contributions

Study design: M.K.-B., R.G., P.S., G.L.S., S.N., L.G.T.
Conduct of the study: M.K.-B., R.G., P.S., G.L.S., L.G.T.
Data control: S.N.
Data analysis: M.K.-B., L.G.T.
Work on preliminary version of manuscript: P.S., G.L.S., S.N.
Writing of the final manuscript: M.K.-B., R.G., L.G.T.

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None declared.

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