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Original articles

Prospective comparison of video laryngoscopes for emergency endotracheal intubation

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Abstract

Objective: Video laryngoscopes are used for management of difficult airways. This study compares the performance of the Pentax-Airway Scope™ (PAS), King Vision® (KV), McGrath® MAC (MCG) and Macintosh laryngoscope (ML) in emergency tracheal intubations (TI).

Setting: Two tertiary-level hospitals in Japan.

Participants: All consecutive video-recorded cases of emergency TI in emergency departments and intensive care units between December 2013 and June 2015.

Outcomes: The primary study endpoint was success rate of first attempts at TI. A subanalysis examined the success of first attempts by expert versus non-expert operators. A logistic regression analysis was performed to identify predictors of successful first attempts.

Results: 287 emergency TI were included. TI was successful in 78% of first attempts with PAS, 58% with KV, 78% with MCG, and 58% with ML (P=0.004). In post hoc analysis, the success rates with PAS and MCG were significantly higher than with KV and ML. The success rates by non-expert operators were significantly higher (P=0.00004) with PAS (87%) and MCG (78%), than with KV (50%) and ML (46%), though not when performed by experts (67% with PAS vs. 67% with MCG vs. 78% with KV vs. 78% with ML, P=0.556). After adjustments for TI indications, difficult airway characteristics, and expert versus non-expert

operator, PAS (odds ratio = 3.422, 95% confidence interval 1.551-7.550; P=0.002) and MCG (3.758, 1.640-8.612; P=0.002) were associated with higher odds of successful first attempt.

Conclusion: PAS and MCG were associated with significantly higher success rates of first attempts at emergency TI than KV and ML, especially by non-expert operators.

Trial registration: UMIN000027925

Keywords: Emergency intubation, tracheal intubation, laryngoscopy, video-assisted laryngoscopy, video laryngoscope

Strengths and limitations of this study

- This study is the first report directly comparing the three different types of VLs (Pentax-Airway Scope™ (PAS), the King Vision® (KV), the McGrath™ MAC (MCG)) and ML in the emergency TI.
- Significantly higher successful rates shown in PAS and MCG, especially when operated by non-experts, is another strength of this study possibly affecting clinical practice.
- Major limitation of this study is its observational design. Although we tried to adjust for almost all possible confounding factors based on previous studies, we cannot totally exclude other unnoticed confounding factors influencing the results,

Background

Tracheal intubation (TI) performed in emergency setting is more challenging than when attempted in an operating room, because of patients, operators and environmental factors [1-3]. Consequently, the success rate is lower, the time needed to undertake the TI is longer and the complication rate is higher [1, 2, 4, 5].

Video laryngoscopes (VL) are increasingly being used to increase the safety and success rate of emergency TI. The main VL used in clinical practice are the Pentax-Airway Scope™ (PAS; HOYA Corporation, Tokyo, Japan), the King Vision® (KV; King Systems, Noblesville, IN) and the McGrath™ MAC (MCG; Medtronic Inc, Minneapolis, MN). VL are classified by the guidance method of the tracheal tube. PAS and KV are L-shaped, with an attachment of the tracheal tube to the blade, while MCG has no attachment, which facilitates the flexible orientation of the tube. Compared with the Macintosh laryngoscope (ML), the superiority of VL in viewing the glottis and in successfully completing TI has been confirmed in a manikin model [6], in patients undergoing elective surgery [7-10], and in patients presenting in emergency rooms [11-13]. No study, however, has examined the relative performance of VL, especially in emergency TI.

The identification of the optimal VL is important, in view of a) the high failure rate of

emergency TI in the emergency department (ED) and the intensive care unit (ICU), and b) the increased incidence of adverse events associated with unsuccessful attempts [14, 15].

The aim of this study was to identify the optimal VL among PAS, KV, MCG and ML in the emergency performance of TI in the ED or the ICU.

Methods

Study design and setting

This prospective, observational study was conducted at a university hospital and at a general, public hospital. The study protocol was approved by the institutional review boards of both institutions. Both boards waived the need to obtain the patients' informed consents before collecting the data. We disclosed the information regarding this study by web page and offered an opportunity to opt out.

The ED and ICU of both institutions treated ambulatory and postoperative, medical and surgical, pediatric and adult patients. The physicians were responsible for primary care in the ED and for critical care in the ICU. Both were staffed by board-certified attending physicians in emergency or intensive care medicine, or by anesthesiologists, and by post-graduate residents (years 3-7) in emergency medicine, anesthesiology and internal medicine. In addition, transitional post-graduate residents (years 1 and 2) rotated for several months in the ED and ICU. Most of the transitional year residents completed ≥1 month of training in anesthesiology in the operating room, during which they performed TI, using ML in patients undergoing general anesthesia, under the supervision of attending anesthesiologists. When difficult airways or cervical instability were anticipated, the choice

of VL was left to the discretion of the supervisors.

PAS (model S100L), KV, MCG and ML were available for this study. Channeled disposable blades were used with the KV. The laryngoscopes, drugs, or operators for the TI procedures were chosen by the attending physician(s) without protocol. Using a hand-held or fixed camera, the procedures were systematically video-recorded for archival and quality control.

Study participants

We included consecutive video-recorded cases of emergency TI performed in the ED and ICU of both institutions between December 2013 and June 2015.

Data collection and measurements

We recorded the patients demographic and clinical characteristics, indications for TI (cardiopulmonary arrest, airway obstruction, respiratory failure, hemodynamic instability or altered mental status), drugs used for TI (sedatives, analgesics or muscle relaxants), pre-procedurally defined complicating airway characteristics, including obesity (body mass index ≥28), limited mouth opening (inter-incisor distance <4 cm), restricted neck

mobilization, short neck (thyro-mental distance <6 cm), facial trauma (diagnosed clinically and by imaging), edema of the glottis visualized by the operator, and presence of blood, secretions or vomitus in the airways, needing suction or interfering with the procedure. The laryngoscopes used, the length of clinical experience and the specialty of the operators were recorded. The subjective difficulty, using a visual analogue scale between 0 (easy) and 100 (difficult) was scored by the operators. The success of first attempts at TI, the number of attempts until successful TI, the changes of laryngoscopes and operators, the time between insertion of the laryngoscope into the mouth and the onset of ventilation after TI, the complications (edema or spasm of the glottis, dental injuries, regurgitation and airway hemorrhages), esophageal intubations, and the laryngoscope in use when the complication or the esophageal intubation occurred, were recorded. The data were collected from the video recording for measurements of variables, in addition to medical records and a questionnaire.

Study endpoints

The primary study endpoint was the rate of successful first attempt at TI, and the secondary endpoints were the time needed to perform the procedure, the subjective difficulty score, procedural complications and esophageal intubation.

Sample size and statistical analysis

Estimated sample size was based on a previous TI study performed by residents in patients undergoing elective surgery, where the rates of successful first attempts, using the ML and PAS were 64 and 90%, respectively. Assuming a 20% difference in rates of successful first attempts between two laryngoscopes, we calculated a sample size of 62 procedures in each group at the 5% α level and a power (1−β) of 80%. Including missing data, we set the sample sizes of each group at 70, and at a total of 280 procedures.

Categorical variables are expressed as counts and percentages, and continuous variables as means ± standard deviations. We compared the outcomes among the 4 laryngoscopes by Fisher's exact or Kruskal-Wallis tests. The procedures without an accurate measurement of time needed to perform the TI from the video recording and the procedures without descriptions of the subjective difficulty score were excluded from the each analysis. A *post hoc* analysis was performed, using Turkey's test for all paired comparisons. We also examined whether the rates of successful first attempts differed among the 4 laryngoscopes, in each pre-specified subgroups, according to the duration of clinical experience (1st and 2nd post-graduate years as non-expert operators; ≥3rd post-graduate year as experts). A logistic

regression analysis was performed to identify factors influencing the successful first attempt rate. We included possible confounding factors, which were significantly different among the 4 laryngoscopes (indication for TI and restricted neck mobility) and which were identified in previous studies (limited mouth aperture,[16] blood, secretion or vomitus in the airways,[17] experts versus non-expert operator[18]). A P value <0.05 was considered statistically significant. The analyses were performed using the SPSS® statistical package, version 23 (IBM Corporation, Armonk, NY).

Results

Characteristics of the study population

The patients characteristics are summarized in table 1. Two-hundred and eighty-seven patients underwent video-recorded emergency TI. Among the indications for TI, hemodynamic instability was significantly different among the 4 laryngoscopes, with MCG most frequently used in presence of hemodynamic instability. Complicating airway characteristics were present in 56% of cases, consisting of blood, secretions or vomitus in the airways in 123 procedures (43%). PAS was often used during procedures complicated by a restricted neck mobility. Among the 67 non-experts, 57 operators (89.1%) had received some anesthesiology training in the operating room. They performed 33±14 TI, including 6±5 procedures using VL with PAS or MCG. TI was interrupted in 3 cases (1%), of which one was managed without TI, another underwent emergency cricothyroidotomy, and a third suffered a fatal cardiopulmonary arrest. In the remaining 284 procedures, TI was attempted once in 199 (69%), twice in 49 (17%) and >twice in 36 instances (13%). The laryngoscope was replaced in 22 cases (8%). Out of 59 procedures, the KV was replaced by another laryngoscope in 9 instances (15%; P=0.043 vs. other groups). The KV was replaced by another device in 7 procedures because of separation of the laryngoscope from its disposable

blade. The operator was replaced in 21 attempts at TI (7%), of which 19 were initially made by a non-expert operator. The number of operators were similarly replaced in the 4 study groups.

Main results

The overall rate of successful first attempts was 69% and differed significantly (P=0.004) among the 4 laryngoscopes (table 2). In *post hoc* analysis, the rates of successful first attempts were higher with AWS and MCG than with KV or ML, though the difference was significant only in the subgroup of non-expert operators (table 2). The rates of successful first attempts were similar in non-experts and experts. By logistic regression analysis with adjustments for indication of TI, restricted neck mobilization, limited mouth opening, bloods/secretion/vomitus in the airway and experts/non-expert, the use of PAS and MCG was associated with significantly higher rates of successful first attempts at TI (table 3).

There was a significant difference in time needed to perform TI among the 4 laryngoscopes, though no difference was found in the *post hoc* analysis. There was a significant difference in the difficulty scores among the 4 laryngoscopes and the use of MCG was significantly easier than ML in the *post hoc* analysis (table 4).

Complications of TI occurred in 21 procedures (7%), consisting of 1 dental trauma, 7 spasms or edemas of the glottis, 5 instances of regurgitation and 10 hemorrhages, though there was no significant difference among the 4 laryngoscopes. The esophagus was intubated in 3 instances (1.2%) by non-experts using the ML.

Discussion

In this prospective, observational, two-center study, after adjustments for confounding factors, the success rates of first attempts at emergency TI were significantly higher with PAS or MCG than with KV or ML, when performed by non-expert operators. The use of MCG was associated with a lower subjective difficulty of performing TI than the use of ML.

A previous study of VL for TI by experienced anesthetists in the operating room revealed a better visualization of the glottis with PAS than with ML, while the success rates and TI procedure times were similar [8]. Moreover, studies with inexperienced residents revealed a 96% success rate at first attempt with PAS, versus 70% with ML, and 44 sec to secure the airways with PAS, versus 71 sec with ML [9]. Our results are concordant with these success rates, suggesting advantageous characteristics of PAS, specifically with novice operators. The suitable shape of the PBLADE®, which indirectly visualizes the glottis regardless of the head and neck position, the existence of a blade channel to set the tracheal tube and the guiding function of the target mark on the screen, supports the preferential use of PAS among the VL [19].

MCG is a relatively compact device without tracheal tube guide channel [20]. Like ML, it offers an indirect view of the glottis by flexible manipulations of the

laryngoscope and tracheal tube. Several factors, therefore, such as a restricted neck mobility or the operator's experience with TI might influence the success rate of PAS versus MCG. However, the rates of successful first attempt at TI were nearly the same with PAS and MCG in this study population. A randomized study comparing the performance of PAS versus MCG in emergency TI seems warranted.

This study was the first to compare PAS versus KV in clinical settings. Although they have similar shapes and tracheal tube guiding characteristics, the rate of successful first attempt was significantly lower with KV than with PAS. The orientation of the KV tracheal tube is relatively downward compared with PAS, interfering with its advancement. In addition, KV has no marking to help in the placement of the tube. Malfunction of the system, which occurred in 7 patients in this study, may also have lowered the success rate of KV.

Several factors, which varied among the 4 laryngoscopes, had repercussions on the success rate of TI. Blood or vomitus in the airways, an important complication when performing TI in emergency, may lower the image quality. Blood, secretions or vomitus were present in the airways in 43% of procedures, significantly lowering the rate of successful first attempts [17]. However, after adjustment for this factor, the multiple variable analysis confirmed the advantage of using PAS and MCG. A limited mouth aperture was also

correlated with the difficulty of TI [16]. This, however, was problematic in only 6% of cases and did not represent a major obstacle to the insertion of the devices.

Limitations of our study

This was an observational study, in which confounding factors may have influenced the success rate of TI and biased the results. We adjusted, however, for possible confounding factors based on previous studies, and found a significant relationship between VL and rate of successful first attempts. Furthermore, we classified the "non-experts" on the basis of their clinical experience. A precise index to grade the level of intubation skill might have been preferable, although it does not currently exist. Finaly, bias based on operator's familiarity with each laryngoscope cannot be excluded. However, given the scarce overall experience of TI itself prior to this study (4.6 times/person), the results of Non-expert group are likely to be less biased.

Conclusion

When performing emergency TI in the ED or the ICU, PAS and MCG were associated with significantly higher rates of successful first attempts, especially when operated by non-experts.

List of Abbreviations

ML	Macintosh laryngoscope
TI	tracheal intubation
VL	video laryngoscope
AWS	Pentax-Airway Scope™
KV	King Vision®
McG	McGrath® MAC
TT	tracheal tube
ED	emergency department
ICU	intensive care unit
IRB	institutional review board
PGY	post-graduate year
DAF	difficult airway factors
FAS	first attempt success

Declarations

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Contributions: Suzuki conceived the study, designed the trial, collected and managed the data. Kusunoki, Tanigawa and Shime supervised the conduct of the trial and data collection. Suzuki drafted the manuscript, and all authors contributed substantially to its revision. Suzuki takes responsibility for the paper as a whole.

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Competing interests: The authors declare that they have no competing interests.

Ethics approval and consent to participate: This study was reviewed and approved by the research ethics committee of Hiroshima University (No.1069) and Hiroshima prefectural hospital (No.2013-76).

Trial registration number: University Hospital Medical Information Network Clinical Trials Registry (UMIN000027925, https://upload.umin.ac.jp/cgi-open-bin/ctr_e/ctr_view.cgi?recptno=R000016182); date of registration 26.06.2017 (retrospectively registered)

Consent for publication： Not applicable.

Data sharing statement: No additional data available.

Patient and Public Involvement statement: Patients were not involved.

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Table 1. Baseline and difficult airway characteristics

	All (n=287)	Pentax-Airway (n=82)	King VISION (n=59)	McGrath (n=82)	Macintosh (n=64)	P
Men	165 (57.5)	54 (65.9)	31 (52.5)	51 (62.2)	29 (45.3)	0.057
Age	65.4±20.5	60.7±24.8	69.0±16.2	67.4±17.1	65.7±21.4	0.457
Height, cm	158.1±14.4	156.9±19.3	159.3±9.0	160.9±10.2	154.9±14.9	0.044
Weight, kg	55.9±13.9	56.3±16.9	56.2±10.2	56.7±11.9	54.0±15.2	0.400
Body mass index	22.0±3.7	22.3±3.8	22.1±3.6	21.7±3.2	22.1±4.2	0.794
Expert operators	131 (45.6)	36 (43.9)	27 (45.8)	45 (54.9)	23 (35.9)	0.149
Indications for tracheal intubation						
Cardiopulmonary arrest	114 (39.7)	34 (41.5)	26 (44.1)	25 (30.5)	29 (45.3)	0.220
Airway obstruction	14 (4.9)	4 (4.9)	1 (1.7)	7 (8.5)	2 (3.1)	0.305
Respiratory failure	45 (15.7)	12 (14.6)	11 (18.6)	14 (17.1)	8 (12.5)	0.789
Hemodynamic instability	32 (11.1)	6 (7.3)	2 (3.4)	20 (24.4)	4 (6.3)	0.000
Altered mental status	82 (28.6)	26 (31.7)	19 (32.2)	16 (19.5)	21 (32.8)	0.182
Drugs used for tracheal intubation						
None	148 (51.6)	44 (53.7)	32 (54.2)	35 (42.7)	37 (57.8)	0.274
Sedatives	116 (40.4)	33 (40.2)	24 (40.7)	35 (42.7)	24 (37.5)	0.944
Analgesics	91 (31.7)	22 (26.8)	15 (25.4)	36 (43.9)	18 (28.1)	0.053
Muscle relaxants	59 (20.6)	15 (18.3)	10 (16.9)	22 (26.8)	12 (18.8)	0.450
Drugs used for tracheal intubation in Non-CPA cases	(n=173)	(n=48)	(n=33)	(n=57)	(n=35)	
None	34 (19.7)	10 (20.8)	6 (18.2)	10 (17.5)	8 (22.9)	0.925
Sedatives	116 (67.1)	33 (68.8)	24 (72.7)	35 (61.4)	24 (68.6)	0.722
Analgesics	91 (52.6)	22 (45.8)	15 (45.5)	36 (63.2)	18 (51.4)	0.250
Muscle relaxants	59 (34.1)	15 (31.3)	10 (30.3)	22 (38.6)	12 (34.3)	0.842
Difficult airway characteristics						
Obesity	16 (5.6)	6 (7.3)	3 (5.1)	3 (3.7)	4 (6.3)	0.793
Limited mouth opening	17 (5.9)	5 (6.1)	5 (8.5)	6 (7.3)	1 (1.6)	0.319
Restricted neck mobilization	39 (13.6)	19 (23.2)	6 (10.2)	7 (8.5)	7 (10.9)	0.040
Short neck	9 (3.1)	3 (3.7)	1 (1.7)	3 (3.7)	2 (3.1)	0.937
Facial trauma	13 (4.5)	7 (8.5)	1 (1.7)	4 (4.9)	1 (1.6)	0.171
Edema of glottis	7 (2.4)	2 (2.4)	0 (0.0)	4 (4.9)	1 (1.6)	0.390
Bloods, secretion or vomitus in airway	123 (42.9)	36 (43.9)	23 (39.0)	38 (46.3)	26 (40.6)	0.821
Cases with difficult airway characteristics	161 (56.1)	47 (57.3)	31 (52.5)	48 (58.5)	35 (54.7)	0.897

Values are numbers (%) of observations or means ± standard deviations.

Table 2. Success rates of first attempts at tracheal intubations with 4 laryngoscopes

	All laryngoscopes	Pentax-Airway Scope	King VISION	McGrath	Macintosh	P
All operators, n	287	82	59	82	64	
Successful first attempt	199 (69)	64 (78)*	34 (58)	64 (78)†	37 (58)	0.004
Non-expert operators	156	46	32	37	41	
Successful first attempt	104 (67)	40 (87)‡	16 (50)	29 (78)§	19 (46)	0.00004
Expert operators	131	36	27	45	23	
Successful first attempt	95（73）	24 (67)	18 (67)	35 (78)	18 (78)	0.556

Values are numbers (%) of observations; *post hoc* analyses were performed using Tukey's test for paired comparisons of 4 laryngoscopes.
*:vs. King VISION P=0.043, *:vs. Macintosh P=0.039, †:vs. King VISION P=0.043, †:vs. Macintosh P=0.039
‡:vs. King VISION P=0.002, ‡:vs. Macintosh P<0.001, §:vs. King VISION P=0.043, §:vs. Macintosh P=0.009

Table 3. Multiple variable analysis of factors influencing the success rate of first attempts at tracheal intubations

Factors	Odd ratios	95% confidence intervals	P
Laryngoscopes			
Macintosh (reference)	1	-	-
Pentax-Airway Scope	3.422	1.551-7.550	0.002
King VISION	1.056	0.487-2.289	0.889
McGrath	3.758	1.640-8.612	0.002
Indications for tracheal intubation			
Cardiopulmonary arrest	1 (reference)		
Airway obstruction	0.226	0.063-0.812	0.023
Respiratory failure	0.720	0.284-1.822	0.488
Hemodynamic instability	0.380	0.137-1.054	0.063
Altered mental status	0.361	0.180-0.723	0.004
Difficult airway characteristics			
Mouth opening			
Unlimited	1 (reference)	-	-
Limited	0.092	0.026-0.323	0.000
Neck mobility			
Unrestricted	1 (reference)	-	-
Restricted	0.951	0.414-2.182	0.905
Blood, secretions, vomitus in the airways			
Absent	1 (reference)	-	-
Present	0.455	0.257-0.804	0.007
Operators			
Non-expert	1 (reference)	-	-
Expert	1.688	0.916-3.108	0.093

Table 4. Comparisons of times needed to perform tracheal intubations and of difficulty scores, using 4 different laryngoscopes

	Overall	Pentax-Airway	King VISION	McGrath	Macintosh	P
Time to perform intubations, sec	60±31 (n=269)	63±34 (n=78)	63±31 (n=45)	62±31 (n=79)	52±27 (n=67)	0.043
Difficulty score†	39±27 (n=258)	39±26 (n=72)	43±26 (n=45)	32±27* (n=78)	45±26 (n=63)	0.009

Values are means ± standard deviations; *P=0.027 vs. Macintosh laryngoscope.
†Difficulty was scored by visual analogue scale, from very easy (0) to very difficult (100).
post hoc analyses were performed using Tukey's test for paired comparisons of 4 laryngoscopes.

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Reported on page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1, 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2-3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	4-5
Methods			
Study design	4	Present key elements of study design early in the paper	6-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	7
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-8
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9-10
		(*b*) Describe any methods used to examine subgroups and interactions	9
		(*c*) Explain how missing data were addressed	9
		(*d*) If applicable, explain how loss to follow-up was addressed	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	25
		(b) Indicate number of participants with missing data for each	11

		variable of interest	
		(c) Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	Report numbers of outcome events or summary measures over time	12-13, 26
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	26, 27
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	12, 26
Discussion			
Key results	18	Summarise key results with reference to study objectives	14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14
Generalisability	21	Discuss the generalisability (external validity) of the study results	16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	20

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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Comparison of three video laryngoscopes and direct laryngoscopy for emergency endotracheal intubation - a retrospective cohort study

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Original articles

Comparison of three video laryngoscopes and direct laryngoscopy for emergency endotracheal intubation - a retrospective cohort study

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Abstract

Objective: Video laryngoscopes are used for the management of difficult airways. This study compared the performances of three video laryngoscopes (Pentax-Airway Scope™ [Pentax], King Vision® [King], and McGrath® MAC [McGrath]) with the Macintosh direct laryngoscope [Macintosh] as reference in emergency tracheal intubations (TIs) to identify the optimal video laryngoscopes among them.

Setting: The emergency department and the intensive care unit of two tertiary-level hospitals in Japan.

Participants: All consecutive video-recorded cases of emergency TI in emergency departments and intensive care units between December 2013 and June 2015.

Outcomes: The primary study endpoint was first-pass intubation success. A subgroup analysis examined the first-pass intubation success of expert versus non-expert operators. A logistic regression analysis was performed to identify the predictors of first-pass success.

Results: A total of 287 emergency TIs were included. The first-pass intubation success rates were 78%, 58%, 78%, and 58% for the Pentax, King, McGrath, and Macintosh instruments, respectively (P=0.004). In post hoc analysis, the success rates of the Pentax and McGrath instruments were significantly higher than those of the King and Macintosh instruments. The success rates of non-expert operators were significantly higher (P=0.00004) for the Pentax

(87%) and McGrath (78%) instruments than those with the King (50%) and Macintosh (46%) instruments but not when used by experts (67% with Pentax vs. 67% with McGrath vs. 78% with King vs. 78% with Macintosh, P=0.556). After adjusting for TI indications, difficult airway characteristics, and expert versus non-expert operator parameters, the odds for a first-pass intubation success were significantly higher with the Pentax (odds ratio = 3.422, 95% confidence interval 1.551-7.550; P=0.002) and McGrath (3.758, 1.640-8.612; P=0.002) instruments.

Conclusion: The Pentax and McGrath laryngoscopes were associated with significantly higher first-pass success rates in emergency TI than those for the King and Macintosh laryngoscopes, especially for non-expert operators.

Trial registration: UMIN000027925

Keywords: Emergency intubation, tracheal intubation, laryngoscopy, video-assisted laryngoscopy, video laryngoscope, video laryngoscopy

Strengths and limitations of this study

- To our knowledge, this study is the first to directly compare three different video laryngoscopes (Pentax-Airway Scope™, King Vision®, McGrath™ MAC) and the Macintosh laryngoscope for emergency TI.
- The strength of this study is that we precisely evaluated the intubation process among four laryngoscopes using real-world video records of TI.
- The major limitation of this study is its observational design. Although we tried to adjust for almost all possible confounding factors based on previous studies, we could not completely exclude the influence of other confounding factors on the results.

Background

Tracheal intubation (TI) performed in the emergency setting is more challenging than when attempted in an operating room due to patient, operator, and environment-associated factors [1-3]. Consequently, the success rate is lower, the time needed to undertake the TI is longer, and the complication rate is higher [1, 2, 4, 5].

Video laryngoscopes (VLs) are increasingly used to increase the safety and success rates of emergency TIs. The VLs used in clinical practice include the Pentax-Airway Scope™ (Pentax), the King Vision® (King), and the McGrath™ MAC (McGrath). VLs are classified according to the guidance method of the tracheal tube. The Pentax and King VLs are L-shaped, with an attachment of the tracheal tube to the blade, while McGrath has no attachment, which facilitates the flexible orientation of the tube. Compared to the Macintosh laryngoscope (Macintosh), the superiority of VLs in viewing the glottis and in successfully completing TIs has been confirmed in a manikin model [6] and in patients undergoing elective surgery [7-10]. However, a randomized trial in intensive care units (ICUs) showed no difference in first-pass intubation success rates between VLs and the Macintosh system [11]. A systematic review of emergency TIs in emergency departments (EDs) and ICUs showed that the use of VLs had no significant advantage with regards to first-attempt success

rates, although their use was significantly associated with a lower number of intubation attempts [12]. However, these studies included various types of VL in a single group and did not consider the characteristics of each VL. To our knowledge, no study has examined the relative performance of VLs, especially in emergency TIs.

The identification of the optimal VL is important, in view of a) the high rate of difficult emergency TIs (10% in the non-operative area including the ED and the ICU) and multiple intubation attempts (11% in the ED) [1, 13] and b) the increased incidence of adverse events associated with unsuccessful attempts, in which more than one attempt at TI was a significant predictor of one or more adverse events (adjusted odds ratio= 7.5, 95% confidence interval [CI] = 5.9 to 9.6)). [14].

The aim of this study was to identify the optimal VL among the Pentax, King, and McGrath systems when compared to the Macintosh for the emergency performance of TI in the ED or ICU.

Methods

Study design and setting

This retrospective, observational study was conducted at a university hospital and at a general, public hospital. This study was reviewed and approved by the research ethics committee of Hiroshima University and Hiroshima Prefectural Hospital (Nos. 1069 and 2013-76, respectively). Both boards waived the need to obtain patient informed consent before collecting the data. We disclosed information regarding this study on a webpage and offered an opportunity to opt out.

The ICUs of both institutions treat ambulatory and postoperative, medical and surgical, and pediatric and adult patients. The physicians were responsible for primary care in the ED and for critical care in the ICU. Both were staffed by board-certified attending physicians in emergency or intensive care medicine, or by anesthesiologists, and by post-graduate residents (years 3-7) in emergency medicine, anesthesiology, and internal medicine. In addition, transitional post-graduate residents (years 1 and 2) rotated for several months in the EDs and ICUs. Most of the transitional year residents completed ≥1 month of training in anesthesiology in the operating room, during which they performed TI, using Macintosh in patients undergoing general anesthesia, under the supervision of attending

anesthesiologists. When difficult airways or cervical instability were anticipated, the choice of VL was left to the discretion of the supervisors.

Three VLs, including the Pentax (Pentax-Airway Scope™; AWS-S100, HOYA Corporation, Tokyo, Japan), King, (King Vision®, King Systems, Noblesville, IN) and McGrath (McGrath™ MAC; 300-000-000, Medtronic Inc, Minneapolis, MN) systems, as well as a Macintosh laryngoscope (Macintosh blade, KARL STORZ SE & Co, Tuttingen, Germany) as a reference standard, were available in this study. These VL had been commonly used prior to this study for several years in both institutions and there was no specific off-the-job training for these VLs. Channeled disposable blades were used with the King system. The laryngoscopes, drugs, or operators for the TI procedures were chosen by the attending physician(s) without protocol. Using a hand-held or fixed camera, the procedures were systematically video-recorded for archival and quality control.

Study participants

We included consecutive video-recorded cases of emergency TI performed in the ED and ICU of both institutions between December 2013 and June 2015.

Data collection and measurements

We recorded the patient demographic and clinical characteristics; location of the TI (ED or ICU); indications for TI (cardiopulmonary arrest, airway obstruction, respiratory failure, hemodynamic instability, or altered mental status); drugs used for TI (sedatives, analgesics, and muscle relaxants); pre-procedurally defined complicating airway characteristics including obesity (body mass index ≥28 kg/m^2), limited mouth opening (inter-incisor distance <4 cm), restricted neck mobilization, short neck (thyromental distance <6 cm), facial trauma (diagnosed clinically and by imaging), edema of the glottis visualized by the operator, and the presence of blood, secretions, or vomitus in the airways requiring suction or interfering with the procedure. The laryngoscopes used, the length of clinical experience, and the specialty of the operators were recorded. The subjective difficulty, using a visual analogue scale between 0 (easy) and 100 (difficult) was scored by the operators. The first-pass intubation success rate, the number of attempts until successful TI, changes of laryngoscopes and operators, time between laryngoscope insertion into the mouth and the onset of ventilation after TI, complications (edema or spasm of the glottis, dental injuries, regurgitation, and airway hemorrhages), esophageal intubations, and the laryngoscope in use when the complication or the esophageal intubation occurred, were recorded. The data were

collected from the video recording for measurements of variables, in addition to medical records and a questionnaire. Data collection and analysis were performed by a single author (KS).

Study endpoints

The primary study endpoint was the first-pass intubation success rate, while the secondary endpoints were the time needed to perform the procedure, the subjective difficulty score, procedural complications, and esophageal intubation.

Sample size and statistical analysis

The estimated sample size was based on our own unpublished TI study performed by residents in patients undergoing elective surgery, in which the first-pass intubation success rates using the Macintosh and Pentax instruments were 64% and 90%, respectively. Assuming a 20% difference in first-pass intubation success rates between the two laryngoscopes, we calculated a sample size of 62 procedures in each group at the 5% α level and a power (1−β) of 80%. Including missing data, we set the sample sizes of each group at 70 and a total of 280 procedures.

Categorical variables are expressed as counts and percentages and continuous variables as means ± standard deviations. We compared the outcomes among the four laryngoscopes by Fisher's exact or Kruskal-Wallis tests. Procedures without an accurate measurement of the time needed to perform the TI from the video recording as well as those without subjective difficulty scores were excluded from the analysis. A *post hoc* analysis was performed by comparing all laryngoscopes pairwise to each other using Tukey's test. We also examined whether the first-pass intubation success rates differed among the four laryngoscopes, in each prespecified subgroup, according to the duration of clinical experience (1st and 2nd post-graduate years as non-expert operators and ≥3rd post-graduate year as experts). A logistic regression analysis was performed to identify factors influencing the first-pass intubation success rate. We included possible confounding factors that differed significantly among the four laryngoscopes (indication for TI and restricted neck mobility) and which were identified in previous studies (limited mouth aperture,[15] blood, secretion or vomitus in the airways,[16] experts versus non-expert operator[17]). P-values <0.05 were considered statistically significant. The analyses were performed using IBM SPSS Statistics for Mac, version 23.0 (IBM Corporation, Armonk, NY).

Results

Characteristics of the study population

The patient characteristics are summarized in Table 1. A total of 287 patients underwent video-recorded emergency TI. Among the indications for TI, hemodynamic instability differed significantly among the four laryngoscopes, with the McGrath most frequently used in the presence of hemodynamic instability. Complicating airway characteristics were present in 56% of cases, including blood, secretions, or vomitus in the airways in 123 procedures (43%). The Pentax was often used during procedures complicated by restricted neck mobility. Among the 67 non-experts, 57 operators (89.1%) had received some anesthesiology training in the operating room. They performed 33±14 TIs, including 6±5 procedures using Pentax or McGrath VLs. TI was interrupted in three cases (1%), of which one was managed without TI; another underwent emergency cricothyroidotomy and a third suffered fatal cardiopulmonary arrest. In the remaining 284 procedures, TI was attempted once in 199 (69%), twice in 49 (17%), and >twice in 36 instances (13%). The number of attempts until successful TI were 1.3±0.9 with Pentax, 1.4±0.7 with King, 1.3±0.6 with McGrath, and 1.5±0.7 with Macintosh (P=0.007). The laryngoscope was replaced in 22 cases (8%). Out of 59 procedures, the King was replaced by another laryngoscope in nine instances (15%; P=0.043 vs. other groups).

The King was replaced by another device in seven procedures because of separation of the laryngoscope from its disposable blade. The operator was replaced in 21 attempts at TI (7%), of which 19 were initially made by a non-expert operator. The number of operators were similarly replaced in the four study groups.

Main results

The overall first-pass intubation success rate was 69% and differed significantly (P=0.004) among the four laryngoscopes (table 2). In *post hoc* analysis, the first-pass intubation success rates were higher for the Pentax and McGrath than those with the King or Macintosh laryngoscopes, respectively, although the difference was significant only in the subgroup of non-expert operators (Table 2). The first-pass intubation success rates were similar in non-experts and experts. Logistic regression analysis with adjustments for the indication for TI, restricted neck mobilization, limited mouth opening, blood/secretion/vomitus in the airway, and experts/non-expert revealed that the odds ratios for first-pass intubation success were significantly higher for the Pentax and McGrath laryngoscopes (Table 3).

There were significant differences in the times needed to perform TI among the four laryngoscopes, although no differences were observed in pairwise comparisons of the

laryngoscopes in the *post hoc* analysis. There was a significant difference in the difficulty scores among the four laryngoscopes, with the McGrath significantly easier to use than the Macintosh in *post hoc* analysis (Table 4).

TI complications occurred in 21 procedures (7%), consisting of one dental trauma, seven spasms or edemas of the glottis, five instances of regurgitation, and 10 hemorrhages, although there were no significant differences among the four laryngoscopes. The esophagus was intubated in three instances (1.2%) by non-experts using the Macintosh.

Discussion

In this retrospective, observational, two-center study, the first-pass success rates for emergency TI were significantly higher for Pentax or McGrath laryngoscopes than for King or Macintosh laryngoscopes when performed by non-expert operators. After adjusting for confounding factors, the odds ratios for first-pass intubation success were significantly higher for the Pentax and McGrath laryngoscopes. The use of the McGrath was associated with a lower subjective difficulty of performing TI than that for the use of the Macintosh.

A previous study of VLs for TI by experienced anesthetists in the operating room revealed a better visualization of the glottis with the Pentax than that with the Macintosh, while the success rates and TI procedure times were similar [8]. Moreover, studies with inexperienced residents reported a 96% first-pass success rate with the Pentax versus 70% with the Macintosh and 44 and 71 sec, respectively, to secure the airways [9]. Our results are concordant with these success rates, suggesting the advantageous characteristics of the Pentax, particularly for novice operators. The suitable shape of the PBLADE®, which indirectly visualizes the glottis regardless of the head and neck position, the existence of a blade channel to set the tracheal tube, and the guiding function of the target mark on the screen support the preferential use of the Pentax among the VLs [18].

The McGrath is a relatively compact device without a tracheal tube guide channel [19]. Like the Macintosh, it offers an indirect view of the glottis by flexible manipulations of the laryngoscope and tracheal tube. Several factors, therefore, such as a restricted neck mobility or the operator's experience with TI, might influence the success rate of the Pentax versus the McGrath. However, the first-pass intubation success rates were nearly the same between these VLs in this study population. A randomized study comparing the performance of Pentax versus McGrath in emergency TI is, therefore, warranted.

To our knowledge, the present study was the first to compare the Pentax and King in clinical settings. Although they have similar shapes and tracheal tube guiding characteristics, the first-pass intubation success rate was significantly lower for the King than that for the Pentax. The orientation of the King tracheal tube is relatively downward compared to that of the Pentax, which may interfere with its advancement. In addition, the King has no marking to help in the placement of the tube. System malfunction, which occurred in seven patients in this study, may also have lowered the success rate of the King.

Several factors, which varied among the four laryngoscopes, had repercussions on the success rate of TI. Blood or vomitus in the airways, an important complication when performing emergency TI, may lower the image quality. Blood, secretions, or vomitus were

present in the airways in 43% of procedures, significantly lowering the first-pass intubation success rate [16]. However, after adjusting for this factor, multiple variable analysis confirmed the advantage of the Pentax and McGrath. A limited mouth aperture was also correlated with the difficulty of TI [15]. This, however, was problematic in only 6% of cases and did not represent a major obstacle to the insertion of the devices.

The results of the present study suggest the usefulness of the Pentax or McGrath VLs for emergency TI performed by novice physicians. However, the generalizability of the results for intubation in other settings (in the operating theater or prehospital settings, or by non-physicians) remains uncertain.

Study limitations

This was an observational study, in which confounding factors may have influenced the success rate of TI and biased the results. However, after adjusting for possible confounding factors based on those reported in previous studies, we observed a significant relationship between VLs and first-pass intubation success rates. We included video-recorded cases of TI during the study period. Unfortunately, only 22% of cases were recorded due to the limited availability of physicians who were able to operate the video cameras. Thus, there might be a

selection bias. The data collection and analysis were performed by a single author (KS), leaving the potential for observer bias. Furthermore, we classified the "non-experts" based on their clinical experience. A precise index to grade the level of intubation skill might have been preferable, although it does not currently exist. Finally, bias based on operator familiarity with each laryngoscope cannot be excluded. However, given the scarce overall experience of TI itself prior to this study (4.6 times/person), the results of the non-expert group are likely to be less biased.

Conclusion

When performing emergency TI in the ED or the ICU, the use of the Pentax and McGrath laryngoscopes was associated with significantly higher first-pass intubation success rates, especially when operated by non-experts.

2

List of Abbreviations

TI	tracheal intubation
VL	video laryngoscope
Pentax	Pentax-Airway Scope™
King	King Vision®
McGrath	McGrath® MAC
Macintosh	Macintosh laryngoscope
ICU	intensive care unit
ED	emergency department

Declarations

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Contributions: Suzuki conceived the study, designed the trial, and collected and managed the data. Kusunoki, Tanigawa, and Shime supervised the conduct of the trial and data collection. Suzuki drafted the manuscript, and all authors contributed substantially to its revision. Suzuki takes responsibility for the paper as a whole.

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Competing interests: The authors declare that they have no competing interests.

Ethics approval and consent to participate: This study was reviewed and approved by the research ethics committees of Hiroshima University (No.1069) and Hiroshima Prefectural Hospital (No.2013-76).

Trial registration number: University Hospital Medical Information Network Clinical Trials Registry (UMIN000027925, https://upload.umin.ac.jp/cgi-open-bin/ctr_e/ctr_view.cgi?recptno=R000016182); date of registration 26.06.2017 (retrospectively registered)

Consent for publication: Not applicable.

Data sharing statement: No additional data available.

Patient and Public Involvement statement: Patients were not involved.

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Table 1. Baseline and difficult airway characteristics

	All (n=287)	Pentax-Airway Scope (n=82)	King VISION (n=59)	McGrath Mac (n=82)	Macintosh (n=64)	P
Men	165 (57.5)	54 (65.9)	31 (52.5)	51 (62.2)	29 (45.3)	0.057
Age, years	65.4±20.5	60.7±24.8	69.0±16.2	67.4±17.1	65.7±21.4	0.457
Height, cm	158.1±14.4	156.9±19.3	159.3±9.0	160.9±10.2	154.9±14.9	0.044
Weight, kg	55.9±13.9	56.3±16.9	56.2±10.2	56.7±11.9	54.0±15.2	0.400
Body mass index	22.0±3.7	22.3±3.8	22.1±3.6	21.7±3.2	22.1±4.2	0.794
Expert operators	131 (45.6)	36 (43.9)	27 (45.8)	45 (54.9)	23 (35.9)	0.149
Location of tracheal intubation (ED/ICU)	162 (56.4)/125 (43.6)	49 (59.8)/33 (40.2)	37 (62.7)/22 (37.3)	37 (45.1)/45 (54.9)	39 (60.9)/25 (39.1)	0.111
Indications for tracheal intubation						
Cardiopulmonary arrest	114 (39.7)	34 (41.5)	26 (44.1)	25 (30.5)	29 (45.3)	0.220
Airway obstruction	14 (4.9)	4 (4.9)	1 (1.7)	7 (8.5)	2 (3.1)	0.305
Respiratory failure	45 (15.7)	12 (14.6)	11 (18.6)	14 (17.1)	8 (12.5)	0.789
Hemodynamic instability	32 (11.1)	6 (7.3)	2 (3.4)	20 (24.4)	4 (6.3)	0.000
Altered mental status	82 (28.6)	26 (31.7)	19 (32.2)	16 (19.5)	21 (32.8)	0.182
Drugs used for tracheal intubation						
None	148 (51.6)	44 (53.7)	32 (54.2)	35 (42.7)	37 (57.8)	0.274
Sedatives	116 (40.4)	33 (40.2)	24 (40.7)	35 (42.7)	24 (37.5)	0.944
Analgesics	91 (31.7)	22 (26.8)	15 (25.4)	36 (43.9)	18 (28.1)	0.053
Muscle relaxants	59 (20.6)	15 (18.3)	10 (16.9)	22 (26.8)	12 (18.8)	0.450
Drugs used for tracheal intubation in Non-CPA cases	(n=173)	(n=48)	(n=33)	(n=57)	(n=35)	
None	34 (19.7)	10 (20.8)	6 (18.2)	10 (17.5)	8 (22.9)	0.925
Sedatives	116 (67.1)	33 (68.8)	24 (72.7)	35 (61.4)	24 (68.6)	0.722
Analgesics	91 (52.6)	22 (45.8)	15 (45.5)	36 (63.2)	18 (51.4)	0.250
Muscle relaxants	59 (34.1)	15 (31.3)	10 (30.3)	22 (38.6)	12 (34.3)	0.842
Difficult airway characteristics						
Obesity	16 (5.6)	6 (7.3)	3 (5.1)	3 (3.7)	4 (6.3)	0.793
Limited mouth opening	17 (5.9)	5 (6.1)	5 (8.5)	6 (7.3)	1 (1.6)	0.319
Restricted neck mobilization	39 (13.6)	19 (23.2)	6 (10.2)	7 (8.5)	7 (10.9)	0.040
Short neck	9 (3.1)	3 (3.7)	1 (1.7)	3 (3.7)	2 (3.1)	0.937
Facial trauma	13 (4.5)	7 (8.5)	1 (1.7)	4 (4.9)	1 (1.6)	0.171
Edema of glottis	7 (2.4)	2 (2.4)	0 (0.0)	4 (4.9)	1 (1.6)	0.390
Bloods, secretion, or vomitus in airway	123 (42.9)	36 (43.9)	23 (39.0)	38 (46.3)	26 (40.6)	0.821
Cases with difficult airway characteristics	161 (56.1)	47 (57.3)	31 (52.5)	48 (58.5)	35 (54.7)	0.897

2

Values are numbers (%) of observations or means ± standard deviations. ED, emergency department; ICU, intensive care unit; CPA, cardiopulmonary arrest.

Table 2. First-pass intubation success rates of four laryngoscopes

	All laryngoscopes	Pentax-Airway Scope	King VISION	McGrath Mac	Macintosh	P
All operators, n	287	82	59	82	64	
First-pass intubation success	199 (69)	64 (78)*	34 (58)	64 (78)†	37 (58)	0.004
Non-expert operators	156	46	32	37	41	
First-pass intubation success	104 (67)	40 (87)‡	16 (50)	29 (78)§	19 (46)	0.00004
Expert operators	131	36	27	45	23	
First-pass intubation success	95 (73)	24 (67)	18 (67)	35 (78)	18 (78)	0.556

Values are numbers (%) of observations; *post hoc* analyses were performed using Tukey's test for paired comparisons of four laryngoscopes .
*:vs. King VISION P=0.043, *:vs. Macintosh P=0.039, †:vs. King VISION P=0.043, †:vs. Macintosh P=0.039
‡:vs. King VISION P=0.002, ‡:vs. Macintosh P<0.001, §:vs. King VISION P=0.043, §:vs. Macintosh P=0.009

Table 3. Multiple variable analysis of factors influencing the first-pass intubation success rates

Factors	Odd ratios	95% confidence intervals	P
Laryngoscopes			
Macintosh (reference)	1	-	-
Pentax-Airway Scope	3.422	1.551-7.550	0.002
King VISION	1.056	0.487-2.289	0.889
McGrath Mac	3.758	1.640-8.612	0.002
Indications for tracheal intubation			
Cardiopulmonary arrest	1 (reference)		
Airway obstruction	0.226	0.063-0.812	0.023
Respiratory failure	0.720	0.284-1.822	0.488
Hemodynamic instability	0.380	0.137-1.054	0.063
Altered mental status	0.361	0.180-0.723	0.004
Difficult airway characteristics			
Mouth opening			
Unlimited	1 (reference)	-	-
Limited	0.092	0.026-0.323	0.000
Neck mobility			
Unrestricted	1 (reference)	-	-
Restricted	0.951	0.414-2.182	0.905
Blood, secretions, vomitus in the airways			
Absent	1 (reference)	-	-
Present	0.455	0.257-0.804	0.007
Operators			
Non-expert	1 (reference)	-	-
Expert	1.688	0.916-3.108	0.093

Table 4. Comparisons of times needed to perform tracheal intubations and of difficulty scores for four different laryngoscopes

	Overall	Pentax-Airway Scope	King VISION	McGrath Mac	Macintosh	P
Time to perform intubations, sec	60±31 (n=269)	63±34 (n=78)	63±31 (n=45)	62±31 (n=79)	52±27 (n=67)	0.043
Difficulty score†	39±27 (n=258)	39±26 (n=72)	43±26 (n=45)	32±27* (n=78)	45±26 (n=63)	0.009

Values are means ± standard deviations; *P=0.027 vs. Macintosh.
†Difficulty was scored by visual analogue scale, from very easy (0) to very difficult (100).
post hoc analyses were performed using Tukey's test for paired comparisons of 4 laryngoscopes.

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Reported on page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1, 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2-3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	4-5
Methods			
Study design	4	Present key elements of study design early in the paper	6-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	7
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-8
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9-10
		(*b*) Describe any methods used to examine subgroups and interactions	9
		(*c*) Explain how missing data were addressed	9
		(*d*) If applicable, explain how loss to follow-up was addressed	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	25
		(b) Indicate number of participants with missing data for each	11

		variable of interest	
		(c) Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	Report numbers of outcome events or summary measures over time	12-13, 26
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	26, 27
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	12, 26
Discussion			
Key results	18	Summarise key results with reference to study objectives	14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14
Generalisability	21	Discuss the generalisability (external validity) of the study results	16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	20

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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Comparison of three video laryngoscopes and direct laryngoscopy for emergency endotracheal intubation - a retrospective cohort study

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Original articles

Comparison of three video laryngoscopes and direct laryngoscopy for emergency endotracheal intubation - a retrospective cohort study

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Abstract

Objective: Video laryngoscopes are used for managing difficult airways. This study compared three video laryngoscopes' (Pentax-Airway Scope™ [Pentax], King Vision® [King], and McGrath® MAC [McGrath]) performances with the Macintosh direct laryngoscope [Macintosh] as emergency tracheal intubations (TIs) reference.

Design: Retrospective cohort study.

Setting: The emergency department and the intensive care unit of two Japanese tertiary-level hospitals.

Participants: All consecutive video-recorded emergency TI cases in emergency departments and intensive care units between December 2013 and June 2015.

Primary outcome measures: The primary study endpoint was first-pass intubation success. A subgroup analysis examined the first-pass intubation success of expert versus non-expert operators. A logistic regression analysis was performed to identify the predictors of first-pass intubation success.

Results: A total of 287 emergency TIs were included. The first-pass intubation success rates were 78%, 58%, 78%, and 58% for the Pentax, King, McGrath, and Macintosh instruments, respectively (P=0.004, Fisher's exact test). The non-expert operators' success rates were significantly higher (P=0.00004, Fisher's exact test) for the Pentax (87%) and McGrath

(78%) instruments than that for the King (50%) and Macintosh (46%) instruments, unlike that of the experts (67%, 67%, 78%, and 78% for Pentax, McGrath, King and Macintosh, respectively; P=0.556, Fisher's exact test). After TI indication, difficult airway characteristics, and expert versus non-expert operator parameters adjustments, the Pentax (odds ratio = 3.422, 95% confidence interval 1.551-7.550; P=0.002) and McGrath (3.758, 1.640-8.612; P=0.002) instruments showed significantly higher first-pass intubation success odds when compared to the Macintosh laryngoscope (reference, odds ratio = 1). The King instrument, however, (odds ratio = 1.056; 95% confidence interval 0.487-2.289, p = 0.889) failed to show any significant superiority.

Conclusion: The Pentax and McGrath laryngoscopes showed significantly higher emergency TI first-pass intubation success rates than the King laryngoscope when compared to the Macintosh laryngoscope, especially for non-expert operators.

Trial registration: UMIN000027925

Keywords: Emergency intubation, tracheal intubation, laryngoscopy, video-assisted laryngoscopy, video laryngoscope, video laryngoscopy

Strengths and limitations of this study

- To our knowledge, this study is the first to directly compare three different video laryngoscopes (Pentax-Airway Scope™, King Vision®, McGrath™ MAC) and the Macintosh laryngoscope for emergency TI.
- The strength of this study is that we precisely evaluated the intubation process among four laryngoscopes using real-world video records of TI.
- The major limitation of this study is its observational design. Although we tried to adjust for almost all possible confounding factors based on previous studies, we could not completely exclude the influence of other confounding factors on the results.

Background

Tracheal intubation (TI) performed in the emergency setting is more challenging than when attempted in an operating room due to patient, operator, and environment-associated factors [1-3]. Consequently, the success rate is lower, the time needed to undertake the TI is longer, and the complication rate is higher [1, 2, 4, 5].

Video laryngoscopes (VLs) are increasingly used to increase the safety and success rates of emergency TIs. Amongst others, the VLs used in clinical practice include the Pentax-Airway Scope™ (Pentax), the King Vision® (King), and the McGrath™ MAC (McGrath). VLs are classified according to the guidance method of the tracheal tube. The Pentax and King VLs are L-shaped, with an attachment of the tracheal tube to the blade, while McGrath has no attachment, which facilitates the flexible orientation of the tube. Compared to the Macintosh laryngoscope (Macintosh), the superiority of VLs in viewing the glottis and in successfully completing TIs has been confirmed in a manikin model [6] and in patients undergoing elective surgery [7-10]. However, a randomized trial in intensive care units (ICUs) showed no difference in first-pass intubation success rates between VLs and the Macintosh system [11]. A systematic review of emergency TIs in emergency departments (EDs) and ICUs showed that the use of VLs had no significant advantage with regards to

first-attempt success rates, although their use was significantly associated with a lower number of intubation attempts [12]. However, these studies included various types of VL in a single group and did not consider the characteristics of each VL. To our knowledge, no study has examined the relative performance of VLs, especially in emergency TIs.

The identification of the optimal VL is important, in view of a) the high rate of difficult emergency TIs (10% in the non-operative area including the ED and the ICU) and multiple intubation attempts (11% in the ED) [1, 13] and b) the increased incidence of adverse events associated with unsuccessful attempts, in which more than one attempt at TI was a significant predictor of one or more adverse events (adjusted odds ratio= 7.5, 95% confidence interval [CI] = 5.9 to 9.6)). [14].

The aim of this study was to compare the emergency TI performances of the Pentax, King, and McGrath systems with that of the Macintosh in the ED or ICU.

Methods

Study design and setting

This retrospective, observational study was conducted at a university hospital and at a general, public hospital. This study was reviewed and approved by the research ethics committee of Hiroshima University and Hiroshima Prefectural Hospital (Nos. 1069 and 2013-76, respectively). Both boards waived the need to obtain patient informed consent before collecting the data. We disclosed information regarding this study on a webpage and offered an opportunity to opt out.

The ICUs of both institutions treat ambulatory and postoperative, medical, and surgical, and pediatric and adult patients. The physicians were responsible for primary care in the ED and for critical care in the ICU. Both were staffed by board-certified attending physicians in emergency or intensive care medicine, or by anesthesiologists, and by post-graduate residents (years 3-7) in emergency medicine, anesthesiology, and internal medicine. In addition, transitional post-graduate residents (years 1 and 2) rotated for several months in the EDs and ICUs. Most of the transitional year residents completed ≥1 month of training in anesthesiology in the operating room, during which they performed TI, using Macintosh in patients undergoing general anesthesia, under the supervision of attending anesthesiologists.

When difficult airways or cervical instability were anticipated, the choice of VL was left to the discretion of the supervisors.

Three VLs, including the Pentax (Pentax-Airway Scope™; AWS-S100, HOYA Corporation, Tokyo, Japan), King, (King Vision®, King Systems, Noblesville, IN) and McGrath (McGrath™ MAC; 300-000-000, Medtronic Inc, Minneapolis, MN) systems, as well as a Macintosh laryngoscope (Macintosh blade, KARL STORZ SE & Co, Tuttingen, Germany) as a reference standard, were available in this study. These VL had been commonly used prior to this study for several years in both institutions and there was no specific off-the-job training for these VLs. Channeled disposable blades were used with the King system. The laryngoscopes, drugs, or operators for the TI procedures were chosen by the attending physician(s) without protocol. Using a hand-held or fixed camera, the procedures were systematically video-recorded for archival and quality control.

Study participants

We included consecutive video-recorded cases of emergency TI performed in the ED and ICU of both institutions between December 2013 and June 2015.

Data collection and measurements

We recorded the patient demographic and clinical characteristics; location of the TI (ED or ICU); indications for TI (cardiopulmonary arrest, airway obstruction, respiratory failure, hemodynamic instability, or altered mental status); drugs used for TI (sedatives, analgesics, and muscle relaxants); pre-procedurally defined complicating airway characteristics including obesity (body mass index ≥28 kg/m^2), limited mouth opening (inter-incisor distance <4 cm), restricted neck mobilization, short neck (thyromental distance <6 cm), facial trauma (diagnosed clinically and by imaging), edema of the glottis visualized by the operator, and the presence of blood, secretions, or vomitus in the airways requiring suction or interfering with the procedure. The laryngoscopes used, the length of clinical experience, and the specialty of the operators were recorded. The subjective difficulty, using a visual analogue scale between 0 (easy) and 100 (difficult) was scored by the operators. The first-pass intubation success rate, the number of attempts until successful TI, changes of laryngoscopes and operators, time between laryngoscope insertion into the mouth and the onset of ventilation after TI, complications (edema or spasm of the glottis, dental injuries, regurgitation, and airway hemorrhages), esophageal intubations, and the laryngoscope in use when the complication or the esophageal intubation occurred, were recorded. The data were

collected from the video recording for measurements of variables, in addition to medical records and a questionnaire. Data collection and analysis were performed by a single author (KS).

Study endpoints

The primary study endpoint was the first-pass intubation success rate, while the secondary endpoints were the time needed to perform the procedure, the subjective difficulty score, procedural complications, and esophageal intubation.

Sample size and statistical analysis

The estimated sample size was based on our own unpublished TI study performed by residents in patients undergoing elective surgery, in which the first-pass intubation success rates using the Macintosh and Pentax instruments were 64% and 90%, respectively. Assuming a 20% difference in first-pass intubation success rates between the two laryngoscopes, we calculated a sample size of 62 procedures in each group at the 5% α level and a power (1−β) of 80%. Including missing data, we set the sample sizes of each group at 70 and a total of 280 procedures.

Categorical variables are expressed as counts and percentages and continuous variables as means ± standard deviations. We compared the outcomes among the four laryngoscopes by Fisher's exact or Kruskal-Wallis tests. Procedures without an accurate measurement of the time needed to perform the TI from the video recording as well as those without subjective difficulty scores were excluded from the analysis. A *post hoc* analysis was performed by comparing all laryngoscopes pairwise to each other using Tukey's test. We also examined whether the first-pass intubation success rates differed among the four laryngoscopes, in each prespecified subgroup, according to the duration of clinical experience (1st and 2nd post-graduate years as non-expert operators and ≥3rd post-graduate year as experts). A logistic regression analysis was performed to identify factors influencing the first-pass intubation success rate. We included possible confounding factors that differed significantly among the four laryngoscopes (indication for TI and restricted neck mobility) and which were identified in previous studies (limited mouth aperture,[15] blood, secretion or vomitus in the airways,[16] experts versus non-expert operator[17]). P-values <0.05 were considered statistically significant. The analyses were performed using IBM SPSS Statistics for Mac, version 23.0 (IBM Corporation, Armonk, NY).

Patient and Public Involvement statement: Patients were not involved.

Results

Characteristics of the study population

The patient characteristics are summarized in Table 1. A total of 287 patients underwent video-recorded emergency TI. Among the indications for TI, hemodynamic instability differed significantly among the four laryngoscopes, with the McGrath most frequently used in the presence of hemodynamic instability. Complicating airway characteristics were present in 56% of cases, including blood, secretions, or vomitus in the airways in 123 procedures (43%). The Pentax was often used during procedures complicated by restricted neck mobility. Among the 67 non-experts, 57 operators (89.1%) had received some anesthesiology training in the operating room. They performed 33±14 TIs, including 6±5 procedures using Pentax or McGrath VLs. TI was interrupted in three cases (1%), of which one was managed without TI; another underwent emergency cricothyroidotomy and a third suffered fatal cardiopulmonary arrest. In the remaining 284 procedures, TI was attempted once in 199 (69%), twice in 49 (17%), and >twice in 36 instances (13%). The number of attempts until successful TI were 1.3±0.9 with Pentax, 1.4±0.7 with King, 1.3±0.6 with McGrath, and 1.5±0.7 with Macintosh (P=0.007). The laryngoscope was replaced in 22 cases (8%). Out of 59 procedures, the King was replaced by another laryngoscope in nine instances (15%;

P=0.043 vs. other groups). The King was replaced by another device in seven procedures because of separation of the laryngoscope from its disposable blade. The operator was replaced in 21 attempts at TI (7%), of which 19 were initially made by a non-expert operator. The number of operators were similarly replaced in the four study groups.

Main results

The overall first-pass intubation success rate was 69% and differed significantly (P=0.004) among the four laryngoscopes (table 2). In *post hoc* analysis, the first-pass intubation success rates were higher for the Pentax and McGrath than those with the King or Macintosh laryngoscopes, respectively, although there were no significant differences in the expert operators' subgroup (Table 2). Overall, non-experts and experts showed similar first-pass intubation success rates of 67% and 73%, respectively. Logistic regression analysis with adjustments for the indication for TI, restricted neck mobilization, limited mouth opening, blood/secretion/vomitus in the airway, and experts/non-expert revealed that the odds ratios for first-pass intubation success were significantly higher for the Pentax and McGrath laryngoscopes than that for the King laryngoscope when compared to the Macintosh laryngoscope (Table 3).

There were significant differences in the times needed to perform TI among the four laryngoscopes, although no differences were observed in pairwise comparisons of the laryngoscopes in the *post hoc* analysis (Table 4). There was a significant difference in the difficulty scores among the four laryngoscopes, with the McGrath significantly easier to use than the Macintosh in *post hoc* analysis (Table 4).

TI complications occurred in 21 procedures (7%), consisting of one dental trauma, seven spasms or edemas of the glottis, five instances of regurgitation, and 10 hemorrhages, although there were no significant differences among the four laryngoscopes. The esophagus was intubated in three instances (1.2%) by non-experts using the Macintosh.

Discussion

In this retrospective, observational, two-center study, the first-pass intubation success rates for emergency TI were significantly higher for Pentax or McGrath laryngoscopes than for King or Macintosh laryngoscopes when performed by non-expert operators. After adjusting for confounding factors, the odds ratios for first-pass intubation success were significantly higher for the Pentax and McGrath laryngoscopes than that for the King laryngoscope, when compared to the Macintosh laryngoscope. The use of the McGrath was associated with a lower subjective difficulty of performing TI than that for the use of the Macintosh.

A previous study of VLs for TI by experienced anesthetists in the operating room revealed a better visualization of the glottis with the Pentax than that with the Macintosh, while the success rates and TI procedure times were similar [8]. Moreover, studies with inexperienced residents reported a 96% first-pass intubation success rate with the Pentax versus 70% with the Macintosh and 44 and 71 sec, respectively, to secure the airways [9]. Our results are concordant with these success rates, suggesting the advantageous characteristics of the Pentax, particularly for novice operators. The suitable shape of the PBLADE®, which indirectly visualizes the glottis regardless of the head and neck position, the existence of a blade channel to set the tracheal tube, and the guiding function of the target

mark on the screen support the preferential use of the Pentax among the VLs [18].

The McGrath is a relatively compact device without a tracheal tube guide channel [19]. Like the Macintosh, it offers an indirect view of the glottis by flexible manipulations of the laryngoscope and tracheal tube. Several factors, therefore, such as a restricted neck mobility or the operator's experience with TI, might influence the success rate of the Pentax versus the McGrath. However, the first-pass intubation success rates were nearly the same between these VLs in this study population. A randomized study comparing the performance of Pentax versus McGrath in emergency TI is, therefore, warranted.

The use of a stylet facilitates the manipulation of the tracheal tube adjacent to the glottis. However, a randomized clinical trial in the ICU population, which showed no improvement in a McGrath-used first-pass intubation, did not use a stylet, which was used in all McGrath cases here [20]. This may be the reason for the nonconformance between the studies' results.

To our knowledge, the present study was the first to compare the Pentax and King in clinical settings. Although they have similar shapes and tracheal tube guiding characteristics, the first-pass intubation success rate was significantly lower for the King than that for the Pentax. The orientation of the King tracheal tube is relatively downward

compared to that of the Pentax, which may interfere with its advancement. In addition, the King has no marking to help in the placement of the tube. System malfunction, which occurred in seven patients in this study, may also have lowered the success rate of the King.

Several factors, which varied among the four laryngoscopes, had repercussions on the success rate of TI. Blood or vomitus in the airways, an important complication when performing emergency TI, may lower the image quality. Blood, secretions, or vomitus were present in the airways in 43% of procedures, significantly lowering the first-pass intubation success rate [16]. However, after adjusting for this factor, multiple variable analysis confirmed the advantage of the Pentax and McGrath. A limited mouth aperture was also correlated with the difficulty of TI [15]. This, however, was problematic in only 6% of cases and did not represent a major obstacle to the insertion of the devices.

The results of the present study suggest the usefulness of the Pentax or McGrath VLs for emergency TI performed by novice physicians. However, the generalizability of the results for intubation in other settings (in the operating theater or prehospital settings, or by non-physicians) remains uncertain.

Systematic review and meta-analysis of randomized controlled trials revealed that video laryngoscopy does not improve first-attempt intubation success rates compared to that

of direct laryngoscopy in emergency, critical and surgical patients [21, 22]. However, multiple models of VLs with various characteristics were combined as a “VL group” in the analysis. Here, we intended to compare the individual performances of VLs.

Study limitations

This was an observational study, in which confounding factors may have influenced the success rate of TI and biased the results. However, after adjusting for possible confounding factors based on those reported in previous studies, we observed a significant relationship between VLs and first-pass intubation success rates. We included video-recorded cases of TI during the study period. Unfortunately, only 22% of cases were recorded due to the limited availability of physicians who were able to operate the video cameras. Thus, there might be a selection bias. The data collection and analysis were performed by a single author (KS), leaving the potential for observer bias. Furthermore, we classified the "non-experts" based on their clinical experience. A precise index to grade the level of intubation skill might have been preferable, although it does not currently exist. Finally, bias based on operator familiarity with each laryngoscope cannot be excluded. However, given the scarce overall

experience of TI itself prior to this study (4.6 times/person), the results of the non-expert group are likely to be less biased.

Conclusion

When performing emergency TI in the ED or the ICU, the use of the Pentax and McGrath laryngoscopes were associated with significantly higher first-pass intubation success rates than that of the King laryngoscope when compared to the Macintosh laryngoscope, especially when operated by non-experts.

List of Abbreviations

TI	tracheal intubation
VL	video laryngoscope
Pentax	Pentax-Airway Scope™
King	King Vision®
McGrath	McGrath® MAC
Macintosh	Macintosh laryngoscope
ICU	intensive care unit
ED	emergency department

Declarations

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Contributions: Suzuki conceived the study, designed the trial, and collected and managed the data. Kusunoki, Tanigawa, and Shime supervised the conduct of the trial and data collection. Suzuki drafted the manuscript, and all authors contributed substantially to its revision. Suzuki takes responsibility for the paper as a whole.

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Competing interests: The authors declare that they have no competing interests.

Ethics approval and consent to participate: This study was reviewed and approved by the research ethics committees of Hiroshima University (No.1069) and Hiroshima Prefectural Hospital (No.2013-76).

Trial registration number: University Hospital Medical Information Network Clinical Trials Registry (UMIN000027925, https://upload.umin.ac.jp/cgi-open-bin/ctr_e/ctr_view.cgi?recptno=R000016182); date of registration 26.06.2017 (retrospectively registered)

Consent for publication: Not applicable.

Data sharing statement: The data included deidentified participant data. The data are available from author (KS, e-mail: suzukik@hiroshima-u.ac.jp).

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Table 1. Baseline and difficult airway characteristics

	All (n=287)	Pentax-Airway Scope (n=82)	King VISION (n=59)	McGrath Mac (n=82)	Macintosh (n=64)	P
Men	165 (57.5)	54 (65.9)	31 (52.5)	51 (62.2)	29 (45.3)	0.057
Age, years	65.4±20.5	60.7±24.8	69.0±16.2	67.4±17.1	65.7±21.4	0.457
Height, cm	158.1±14.4	156.9±19.3	159.3±9.0	160.9±10.2	154.9±14.9	0.044
Weight, kg	55.9±13.9	56.3±16.9	56.2±10.2	56.7±11.9	54.0±15.2	0.400
Body mass index	22.0±3.7	22.3±3.8	22.1±3.6	21.7±3.2	22.1±4.2	0.794
Expert operators	131 (45.6)	36 (43.9)	27 (45.8)	45 (54.9)	23 (35.9)	0.149
Location of tracheal intubation (ED/ICU)	162 (56.4)/125 (43.6)	49 (59.8)/33 (40.2)	37 (62.7)/22 (37.3)	37 (45.1)/45 (54.9)	39 (60.9)/25 (39.1)	0.111
Indications for tracheal intubation						
Cardiopulmonary arrest	114 (39.7)	34 (41.5)	26 (44.1)	25 (30.5)	29 (45.3)	0.220
Airway obstruction	14 (4.9)	4 (4.9)	1 (1.7)	7 (8.5)	2 (3.1)	0.305
Respiratory failure	45 (15.7)	12 (14.6)	11 (18.6)	14 (17.1)	8 (12.5)	0.789
Hemodynamic instability	32 (11.1)	6 (7.3)	2 (3.4)	20 (24.4)	4 (6.3)	0.000
Altered mental status	82 (28.6)	26 (31.7)	19 (32.2)	16 (19.5)	21 (32.8)	0.182
Drugs used for tracheal intubation						
None	148 (51.6)	44 (53.7)	32 (54.2)	35 (42.7)	37 (57.8)	0.274
Sedatives	116 (40.4)	33 (40.2)	24 (40.7)	35 (42.7)	24 (37.5)	0.944
Analgesics	91 (31.7)	22 (26.8)	15 (25.4)	36 (43.9)	18 (28.1)	0.053
Muscle relaxants	59 (20.6)	15 (18.3)	10 (16.9)	22 (26.8)	12 (18.8)	0.450
Drugs used for tracheal intubation in Non-CPA cases	(n=173)	(n=48)	(n=33)	(n=57)	(n=35)	
None	34 (19.7)	10 (20.8)	6 (18.2)	10 (17.5)	8 (22.9)	0.925
Sedatives	116 (67.1)	33 (68.8)	24 (72.7)	35 (61.4)	24 (68.6)	0.722
Analgesics	91 (52.6)	22 (45.8)	15 (45.5)	36 (63.2)	18 (51.4)	0.250
Muscle relaxants	59 (34.1)	15 (31.3)	10 (30.3)	22 (38.6)	12 (34.3)	0.842
Difficult airway characteristics						
Obesity	16 (5.6)	6 (7.3)	3 (5.1)	3 (3.7)	4 (6.3)	0.793
Limited mouth opening	17 (5.9)	5 (6.1)	5 (8.5)	6 (7.3)	1 (1.6)	0.319
Restricted neck mobilization	39 (13.6)	19 (23.2)	6 (10.2)	7 (8.5)	7 (10.9)	0.040
Short neck	9 (3.1)	3 (3.7)	1 (1.7)	3 (3.7)	2 (3.1)	0.937
Facial trauma	13 (4.5)	7 (8.5)	1 (1.7)	4 (4.9)	1 (1.6)	0.171
Edema of glottis	7 (2.4)	2 (2.4)	0 (0.0)	4 (4.9)	1 (1.6)	0.390
Bloods, secretion, or vomitus in airway	123 (42.9)	36 (43.9)	23 (39.0)	38 (46.3)	26 (40.6)	0.821
Cases with difficult airway characteristics	161 (56.1)	47 (57.3)	31 (52.5)	48 (58.5)	35 (54.7)	0.897

Values are numbers (%) of observations or means ± standard deviations. ED, emergency department; ICU, intensive care unit; CPA, cardiopulmonary arrest.

Table 2. First-pass intubation success rates of four laryngoscopes

	All laryngoscopes	Pentax-Airway Scope	King VISION	McGrath Mac	Macintosh	P
All operators, n	287	82	59	82	64	
First-pass intubation success	199 (69)	64 (78)*	34 (58)	64 (78)†	37 (58)	0.004
Non-expert operators	156	46	32	37	41	
First-pass intubation success	104 (67)	40 (87)‡	16 (50)	29 (78)§	19 (46)	0.00004
Expert operators	131	36	27	45	23	
First-pass intubation success	95 (73)	24 (67)	18 (67)	35 (78)	18 (78)	0.556

Values are numbers (%) of observations; *post hoc* analyses were performed using Tukey's test for paired comparisons of four laryngoscopes .
*:vs. King VISION P=0.043, *:vs. Macintosh P=0.039, †:vs. King VISION P=0.043, †:vs. Macintosh P=0.039
‡:vs. King VISION P=0.002, ‡:vs. Macintosh P<0.001, §:vs. King VISION P=0.043, §:vs. Macintosh P=0.009

Table 3. Multiple variable analysis of factors influencing the first-pass intubation success rates

Factors	Odd ratios	95% confidence intervals	P
Laryngoscopes			
Macintosh (reference)	1	-	-
Pentax-Airway Scope	3.422	1.551-7.550	0.002
King VISION	1.056	0.487-2.289	0.889
McGrath Mac	3.758	1.640-8.612	0.002
Indications for tracheal intubation			
Cardiopulmonary arrest	1 (reference)		
Airway obstruction	0.226	0.063-0.812	0.023
Respiratory failure	0.720	0.284-1.822	0.488
Hemodynamic instability	0.380	0.137-1.054	0.063
Altered mental status	0.361	0.180-0.723	0.004
Difficult airway characteristics			
Mouth opening			
Unlimited	1 (reference)	-	-
Limited	0.092	0.026-0.323	0.000
Neck mobility			
Unrestricted	1 (reference)	-	-
Restricted	0.951	0.414-2.182	0.905
Blood, secretions, vomitus in the airways			
Absent	1 (reference)	-	-
Present	0.455	0.257-0.804	0.007
Operators			
Non-expert	1 (reference)	-	-
Expert	1.688	0.916-3.108	0.093

Table 4. Comparisons of times needed to perform tracheal intubations and of difficulty scores for four different laryngoscopes

	Overall	Pentax-Airway Scope	King VISION	McGrath Mac	Macintosh	P
Time to perform intubations, sec	60±31 (n=269)	63±34 (n=78)	63±31 (n=45)	62±31 (n=79)	52±27 (n=67)	0.043
Difficulty score†	39±27 (n=258)	39±26 (n=72)	43±26 (n=45)	32±27* (n=78)	45±26 (n=63)	0.009

Values are means ± standard deviations; *P=0.027 vs. Macintosh.
†Difficulty was scored by visual analogue scale, from very easy (0) to very difficult (100).
post hoc analyses were performed using Tukey's test for paired comparisons of 4 laryngoscopes.

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Reported on page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1, 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2-3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	4-5
Methods			
Study design	4	Present key elements of study design early in the paper	6-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	7
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-8
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9-10
		(*b*) Describe any methods used to examine subgroups and interactions	9
		(*c*) Explain how missing data were addressed	9
		(*d*) If applicable, explain how loss to follow-up was addressed	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	25
		(b) Indicate number of participants with missing data for each	11

		variable of interest	
		(c) Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	Report numbers of outcome events or summary measures over time	12-13, 26
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	26, 27
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	12, 26
Discussion			
Key results	18	Summarise key results with reference to study objectives	14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14
Generalisability	21	Discuss the generalisability (external validity) of the study results	16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	20

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.