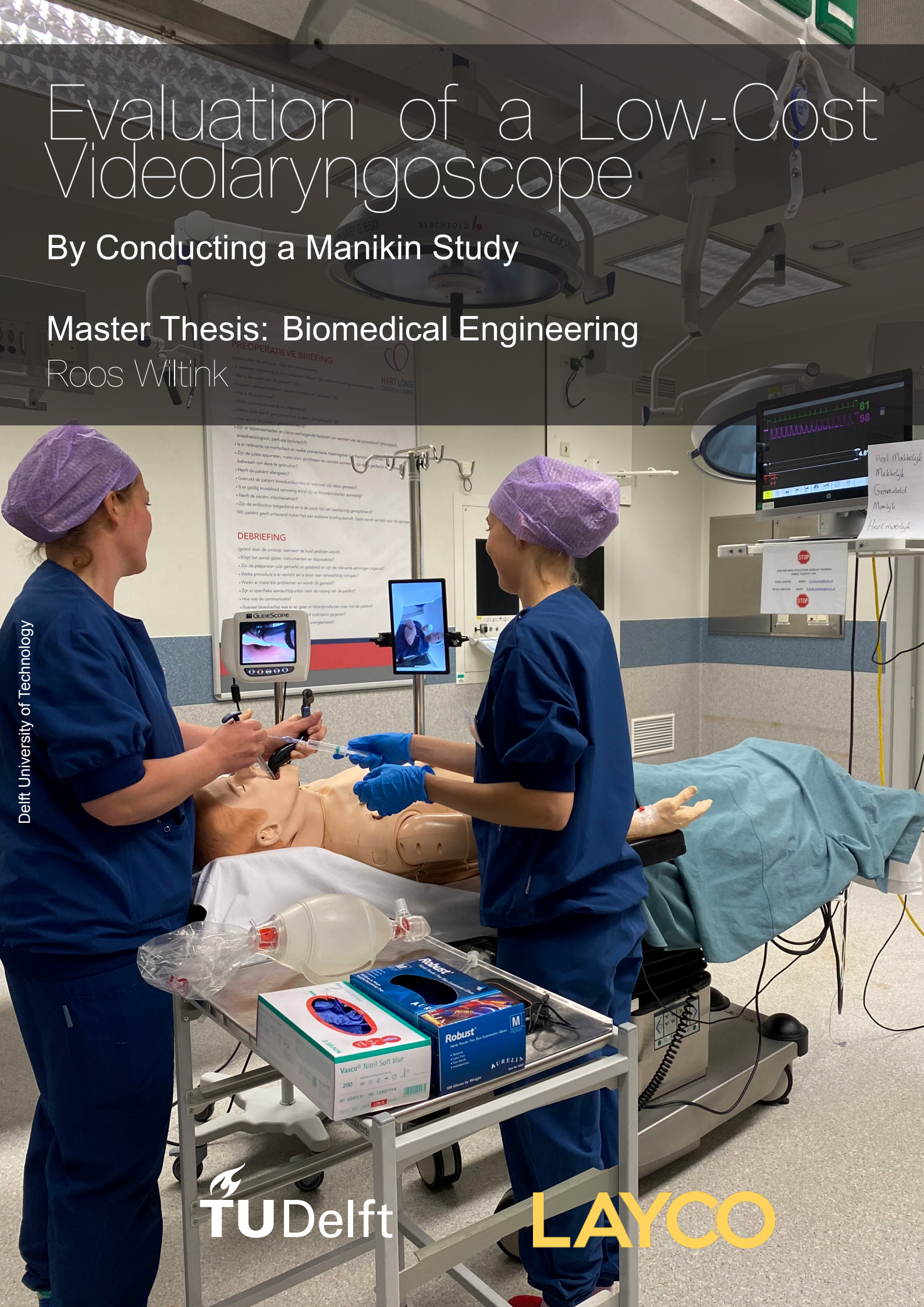
Evaluation of a Low-Cost Videolaryngoscope

By Conducting a Manikin Study

Master Thesis: Biomedical Engineering

Roos Wiltink



Delft University of Technology

TU Delft LAYCO

Evaluation of a Low-Cost Videolaryngoscope

By Conducting a Manikin Study

by

Roos Wiltink

to obtain the degree of

Master of Science
in Biomedical Engineering

at the Delft University of Technology,
to be defended publicly on Thursday September 8, 2022 at 10:00

TU Delft supervisor:	Prof. dr. J. Dankelman
Layco Medical Devices supervisor:	D. Drexhage
Leids University Medical Centre supervisor:	Dr. C. Martini
TU Delft external member:	Dr. ir. J. C. Diehl
TU Delft external member:	Prof. dr. J. Klein
Project Duration:	October, 2021 - June, 2022

TU Delft

LAYCO

Preface

Before I started my bachelor of Mechanical Engineering I had already looked into the various master's programs that were offered. One of these master's programs immediately appealed to me. It was the master Biomedical Engineering because biology, in particular the functioning of the human body, has always fascinated me. Now that I am nearly finished with my master's degree in Biomedical Engineering, I am confident that this was the best master's I could have chosen.

In the first year of my master's program I took a variety of courses, however, one lecture stands out in my memory. This lecture, of the course Medical Instruments, was about global surgery and why there are still few medical devices being developed for low- and middle-income countries. My curiosity about the subject was sparked, and I immediately decided I wanted to pursue it as a graduation subject. Therefore, I am grateful that I was able to conduct this master thesis at Layco Medical Devices, a Dutch start-up that develops high-quality medical devices for low- and middle-income countries. In addition, I would like to thank several people who made this graduation research possible and were of considerable help during this process.

First, I would like to thank my TU Delft supervisor, Jenny Dankelman, for the excellent guidance throughout the project and for providing clear feedback when needed. Second, I want to thank my daily supervisor, Dieuwertje, for your enthusiasm, your help at any hour of the day, your involvement in this project and for laughing at my jokes. Third, I want to thank my bonus supervisor, Chris Martini, for all your clinical insights and your guidance in carrying out the manikin study.

Additionally, I would like my parents, Anniek and Scip for their mental support during this master thesis. Thank you for always letting me call one of you and bore you with the ups and downs of my project. I would also like to thank the whole Layco crew for the fun nine months I got to spend with you. In special I want to thank Julia, for reading my paper over and over again. Thank you, Jackie, Martha, Sterre and AW for all the days we could work together on our thesis, which has made the past few months a lot more fun.

Lastly, I want to thank all my friends, housemates and classmates. They made my time at the TU Delft not only interesting but also fun. I'm looking back with a lot of happiness. The next phase is now at hand!

Roos Wiltink
Delft, September 2022

Contents

Nomenclature

Abbreviations

Abbreviation	Definition
LMICs	Low- and Middle-Income Countries
HICs	High-Income Countries
UMC	University Medical Centre
LUMC	Leiden University Medical Centre
UMCG	University Medical Centre Groningen
ETT	Endotracheal Tube
BURP	Backward, Upward, Rightward Pressure
IQR	Interquartile Range

1

Journal Article

Comparison of the Goodscope Versus GlideScope for Time to Successful Intubation in a Randomised Crossover Manikin Study

A multicentre study

Author: Roos Wiltink | Supervisors: Prof. dr. J. Dankelman, D. Drexhage and Dr. C. Martini

July 10, 2022

***Abstract*— *Background*: Existing videolaryngoscopes do not meet the needs, budgets, and cleaning protocols of low- and middle-income countries. To solve these problems, a new videolaryngoscope, the Goodscope, has been developed which is less expensive, reusable and easy to clean. The aim of this study was to evaluate the efficacy of the Goodscope compared with a commonly used videolaryngoscope, the GlideScope, when used by experienced anaesthetists and residents in anaesthesia in both a normal and difficult airway scenario.**

***Methods*: Participants randomly intubated the manikin four times using both the Goodscope and the GlideScope twice in a normal and a difficult airway scenario. The primary endpoint was time to successful intubation. Secondary endpoints were time to glottic view, time to ventilation, number of intubation attempts, successful intubation rate, and ease of intubation.**

***Results*: A total of 73 participants were included in this study. The primary endpoint, time to successful intubation, showed no statistically significant difference between the Goodscope and GlideScope in both the normal (median Goodscope 10.3 s, inter-quartile range (IQR) 8.5, 12.2 vs GlideScope 10.1 s, IQR 8.4, 13.6, P = 0.614), and difficult scenario (median Goodscope 18.5 s, IQR 14.3, 25.3 vs GlideScope 18.4 s, IQR 13.7, 24.2, P = 0.238). Similarly, no significant differences between the two videolaryngoscopes were identified for all secondary endpoints in both scenarios.**

***Conclusion*: The findings of this study suggest that the Goodscope is non-inferior to the GlideScope since no significant differences between the Goodscope and the GlideScope were identified for all primary and secondary endpoints. Therefore, this study contributes to proving the concept of an affordable reusable videolaryngoscope without compromising on quality.**

I. Background

Despite the considerable need for the improvement of healthcare services in low- and middle-income countries (LMICs), the development of medical devices has historically focused on high-income countries (HICs). LMICs have limited access to most standard medical devices and for some of these countries up to 80% of their medical device supply is donated [1]. Unfortunately, it has been estimated that 40% of these donated devices is out of service [2]. Similarly, the World Health Organisation has estimated that 70% of the medical devices developed in HICs do not function in LMICs due to infrastructural restrictions, a lack of skilled staff, and a shortage of spare parts or technical support [1], [3].

Limited access is also encountered for essential airway equipment, with its over-all access being considerably larger in HICs compared to LMICs [4]. Endotracheal intubation is an important airway management procedure in which the patient's airway is secured by inserting a tube into the trachea. Direct laryngoscopes are the golden standard for this procedure, that allow the insertion of a tube into the trachea under direct vision. Nonetheless, it was found that direct laryngoscopy fails in approximately 6% of adult surgical patients [5].

As an alternative to direct laryngoscopy, videolaryngoscopy was developed in which a camera is incorporated into the tip of the laryngoscope to enlarge the angle of view. Videolaryngoscopy is becoming increasingly popular and promising results in terms of laryngeal view, fewer failed intubations, and higher success rates have been found [6]–[10]. These benefits are also recognized by recent guidelines [11], [12]. Similarly, it was shown that videolaryngoscopy is the most frequently chosen and most effective rescue technique after failed intubation with direct laryngoscopy [6].

Unfortunately, only 46% of LMIC hospitals have access to videolaryngoscopy in contrast to HIC hospitals were the access rate is 93% [4]. This difference is mainly due to the fact that current videolaryngoscopes were designed for use in HICs. Therefore, they are too expensive for LMICs, costing between $2,000 and $22,000 [13]. Moreover, the blades are often not detachable or designed for single-use, requiring a new device or blade for each patient. For most LMICs, these blades are too expensive and hard to obtain. As a result, they are often reused while not designed for it which may lead to complications [14]. Even if reusable components are used in LMICs, they are designed for cleaning protocols in HICs, which are primarily based on autoclave sterilisation. So, conventional videolaryngoscopes do not meet the needs, budgets, and protocols of LMICs.

To solve this issue, Layco Medical Devices has created the Goodscope, a new, reusable, low-cost videolaryngoscope that will cost approximately a third of the videolaryngoscopes currently used in HICs. The Goodscope consists of a handheld part, which contains a battery-operated camera and light source, to which various reusable blades can be attached. Moreover, it can be wirelessly connected to a smartphone or monitor on which an interface application can be used for video view. Although the Goodscope is designed for LMICs, it's lower cost and sustainable qualities may also be advantageous to HICs. This is for two reasons. First, it

is a cheaper alternative which may be desired as healthcare expenses in HICs are expected to climb rapidly in the future years [15]. Second, the blades of the Goodscope are designed to be reused for approximately 250 times. This is expected to be a more sustainable solution since using a reusable videolaryngoscope could reduce the waste and CO2 footprint generated by a videolaryngoscope for each intubation by 69% and 92% respectively [16].

Despite its financial and sustainable benefits, it is of utmost importance that the quality of the Goodscope will not be compromised. Therefore, this manikin study was performed to evaluate the efficacy of the Goodscope compared with a commonly used videolaryngoscope, the GlideScope, both of which have a hyperangulated blade design. A manikin setup was chosen for this study since this is the first assessment of the Goodscope, as suggested by Cook [17]. We hypothesise that the efficacy of the Goodscope will be non-inferior to the GlideScope.

II. Methods

An ethical waiver was provided by the Institutional Review Board of the Leiden University Medical Centre in March 2022. Participation was voluntary. Prior to the start of the trial, written informed consent was obtained. All data were collected anonymously.

Inclusion criteria for this study were that participants had to be anaesthetists or residents in anaesthesia with a minimal clinical intubation experience of 2 years. Literature shows that the learning curve for endotracheal intubation flattens after 40 clinical intubations [18], [19]. Participant's estimated number of previous clinical intubations was so noted as $<$40 intubations, 40-80 intubations, or $>$80 intubations. All participants were recruited from the department of anaesthesiology of the Amsterdam University Medical centre (UMC), Leiden University Medical Centre (LUMC) and the University Medical Centre Groningen (UMCG).

A. Protocol

The study incorporated a randomised crossover design, with all participants intubating the manikin four times using both devices twice in a normal and a difficult airway scenario. The devices used were the GlideScope (SPECTRUM™ Single-Use Videolaryngoscope, Verathon Inc., United States) and the Goodscope (Reusable Videolaryngoscope, Layco Medical Devices, The Netherlands), both with a size S4 hyperangulated blade (Fig 1). The order of the four scenarios in which participants intubated the manikin was randomised using a block randomisation scheme to ensure equal distribution of the participants over the 24 possible sequences. To minimise bias, a closed envelope technique was used and only the device order was told. So, this study was partially blinded since the participants were aware of the device they were using and unaware of the different levels of difficulty.

Each participant was given a standardised instruction of the trial and no device-specific instructions were given. Participants were then asked to practice intubation on the manikin in the normal airway scenario with a Macintosh laryngoscope until tracheal intubation had been achieved.

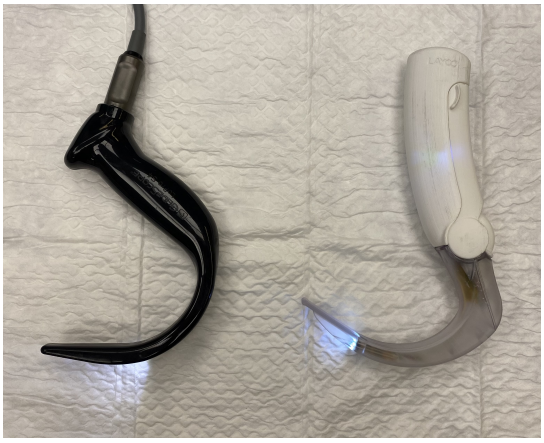


Fig. 1. Left: GlideScope, Right: Goodscope

Both the normal and the difficult scenario were simulated using the SimMan 3G manikin (SimMan 3G, Laerdal Medical, Norway) which is a high-fidelity airway model found to be acceptable realistic [20], [21]. The normal airway setting, without airway compromise, was used for the normal airway scenario. Maximal tongue swelling was used to create the difficult scenario, based on the study of Maharajj and colleagues that showed tongue oedema to cause the highest degree of intubation difficulty and the longest intubation times in the SimMan 3G [22].

Prior to each new participant the airway of the manikin was lubricated using Training Lubricant from Leardal Medical. The head of the manikin was placed on an intubation pillow in a standardized 'sniffing' position. Although the participants were not allowed to remove the intubation pillow, they were allowed to adjust the position of the manikin's head. A 7,5 mm endotracheal tube (Hi-Contour Oral/Nasal Tracheal Tube Cuffed Murphy Eye, COVIDIEN™, Ireland) in combination with a rigid stylet (GLIDERITE® rigid stylet, Verathon Inc., United States) was used during each intubation. The stylet was placed inside the endotracheal tube (ETT) before the start of the trial to shape the ETT to the predesired form. The participants were not allowed to alter the curve of the stylet or to use optimisation manoeuvres such as a gum elastic bougie and backward, upward, rightward pressure (BURP).

B. Measurements

The primary endpoint was time to successful intubation. The secondary endpoints were time to glottic view, time to ventilation, number of intubation attempts, successful intubation rate, and ease of intubation according to a 5-point Likert scale (1 = very easy, 2 = easy, 3 = moderate, 4 = difficult, 5 = very difficult).

For time to successful intubation, time to glottic view, and time to ventilation, timing commenced when the tip of the blade passed the manikin's teeth and stopped when the cuff of the ETT had visually passed the vocal cords, a view on

the vocal cords was obtained, and ventilation was confirmed by observing a consistent capnographic waveform using a self-inflating bag (Medisize, Flexicare (Group) Limited, UK) respectively. The executing researcher determined when timing stopped by following the operation through the monitor. Both the GlideScope and the Goodscope were connected to a separate monitor, by cable and by wireless connection respectively. The number of intubation attempts was defined as the total number of intubations a participant needed to achieve successful intubation. An intubation attempt was successful when a consistent capnographic waveform was observed. Intubation failed if the oesophagus was intubated, if successful intubation was not achieved in 60 seconds, or if the participant removed the videolaryngoscope from the manikin's mouth before the ETT had passed the vocal cords and reinserted it for another attempt. The rate of successful intubations was defined as the percentage of all intubations that were successful per intubation attempt. Following each successful intubation, participants were asked to assess the ease of intubation using a 5-point Likert scale, as well as provide a verbal rationale for their choice (data not shown). For time to glottic view and time to ventilation, only the data obtained from a successful intubation were included in the study.

C. Statistics

The sample size was estimated using the formula for sample size calculation for continuous outcome non-inferiority trials [23]. For this calculation, a standard deviation (σ) of 15 seconds was used, based on the time to intubation found with the GlideScope in several similar studies [24]–[31]. Following advice of three clinical experts, a non-inferiority limit (d) of 10 seconds was used. With a level of significance (α) of 0.05, it was calculated that a minimum of 39 participants were required to be 90% (1-β) sure that the lower limit of a one-sided 95% confidence interval will be above the non-inferiority limit of -10 seconds. However, because this calculation was an estimation, it was chosen to include a minimum of 48 participants such that every intubation sequence would be included at least two times.

Results were analysed using IBM SPSS Statistics version 27. Data of all endpoints was tested for normality using the Shapiro-Wilk test. If the assumption of normality was violated, Wilcoxon signed-ranks tests were used instead of paired samples t-tests for all data of the primary and secondary endpoints where continuous or ordinal repeated measures were performed. The Wilcoxon signed-ranks test was used with H_0 stating that the Goodscope is inferior to the GlideScope and with H_1 stating that the Goodscope is non-inferior to the GlideScope. One-sided p values were calculated from the two-sided p values obtained from the Wilcoxon signed-ranks test and were considered significant if $p \leq 0.05$. If $p > 0.05$, non-inferiority could be assumed. All results were summarised by median and interquartile range (IQR).

III. Results

Between April 13, 2022 and April 22, 2022, a total of 84 participants from Amsterdam UMC (n=28), LUMC (n=37) and UMCG (n=19) were recruited for this randomised crossover trial as depicted in the flowchart in figure 2. However, 11 participants were excluded from this study because the inclusion criteria (participants had to be anaesthetists or residents in anaesthesia with a minimal clinical intubation experience of 2 years) were not met as they were anaesthesia assistants. Their results are detailed in Appendix A. Eventually, 73 participants were included in this study. Among them, no dropouts occurred and they all had performed 80 previous clinical intubations or more.

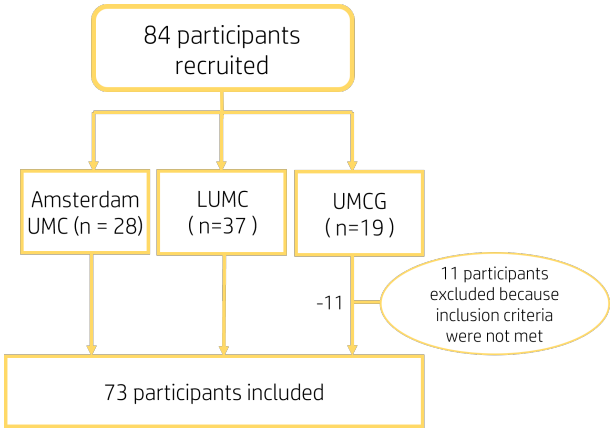


Fig. 2. Flowchart of included participants

A. Primary endpoint

For the primary endpoint, time to successful intubation, median times of 10.3 s (IQR 8.5, 12.2) and 10.1 s (IQR 8.4, 13.6) were found in the normal scenario for the Goodscope and the GlideScope respectively. In the difficult scenario, a median time of 18.5 s (IQR 14.3, 25.3) was found for the Goodscope and 18.4 s (IQR 13.7, 24.2) was found for the GlideScope. No statistically significant difference between the Goodscope and the GlideScope in both the normal [Z = 0.289, P = 0.614] and the difficult scenario [Z = -0.715, P = 0.238] was found.

B. Secondary endpoints

For time to glottic view and time to ventilation median times of 4.8 s (IQR 3.5, 6.6) and 22.8 s (IQR 20.3, 25.8) were found for the Goodscope and median times of 4.6 s (IQR 3.1, 6.4) and 24.1 s (IQR 21.0, 27.7) were found for the GlideScope in the normal scenario respectively. In the difficult scenario, median times of 11.9 s (IQR 8.7, 16.9) and 33.3 s (IQR 27.7, 40.0) were found for the Goodscope and median times of 10.8 s (IQR 7.8, 14.4) and 32.0 s (IQR 26.8, 39.0) were found for the GlideScope respectively. In the normal scenario, no significant difference was found between the Goodscope and the GlideScope for time to glottic view [Z = -0.605, P = 0.273] and time to ventilation [Z = 1.583, P = 0.944]. Similarly, no significant difference was found in

TABLE I

TIME TO SUCCESSFUL INTUBATION, TIME TO GLOTTIC VIEW AND TIME TO VENTILATION

	Normal scenario			**Difficult scenario**		
	Goodscope, median (IQR)	GlideScope, median (IQR)	Test statistics Wilcoxon signed ranks test (Z-score, **one-sided *p* value**)	Goodscope, median (IQR)	GlideScope, median (IQR)	Test statistics Wilcoxon signed ranks test (Z-score, **one-sided *p* value**)
Primary endpoint						
Time to successful intubation (s)	10.3 (8.5, 12.2)	10.1 (8.4, 13.6)	0.289, **0.614**	18.5 (14.3, 25.3)	18.4 (13.7, 24.2)	-0.715, **0.238**
Secondary endpoints						
Time to glottic view (s)	4.8 (3.5, 6.6)	4.6 (3.1, 6.4)	-0.605, **0.273**	11.9 (8.7, 16.9)	10.8 (7.8, 14.4)	-1.385, **0.083**
Time to ventilation (s)	22.8 (20.3, 25.8)	24.1 (21.0, 27.7)	1.583, **0.944**	33.3 (27.7, 40.0)	32.0 (26.8, 39.0)	-0.415, **0.339**

the difficult scenario for time to glottic view [Z = -1.385, P = 0.083] and time to ventilation [Z = -0.415, P = 0.339]. Results of the time measurements are summarised in table I. Moreover, in figure 3, a graphical representation of all time measurements versus the percentage of trials is given.

For the Goodscope and the GlideScope, similar numbers of intubation attempts were found, [median 1, IQR 1, 1] vs [median 1, IQR 1, 1], in both the normal and the difficult airway scenario. No significant differences were found for this endpoint between the GlideScope and the Goodscope in both the normal [Z = 1.000, P = 0.842] and the difficult [Z = 2.388, P = 0.992] scenario. In table II, the number of intubation attempts and the successful intubation rate per intubation attempt are given.

Lastly, for ease of intubation no significant difference was found [Z = -0.473, P = 0.318] between the Goodscope [median 2, IQR 1, 2] and the GlideScope [median 2, IQR 1, 2] in the normal scenario. Correspondingly, in the difficult scenario, no significant difference was found [Z = -0.262, P = 0.397] between the Goodscope [median 3, IQR 2, 3] and the GlideScope [median 3, IQR 2, 3]. The grades given by the participants for the ease of intubation according to the 5-point Likert scale are shown in figure 4.

Similar to the primary endpoint, no significant differences between the two videolaryngoscopes were identified for all secondary endpoints in both scenarios.

TABLE II

NUMBER OF INTUBATION ATTEMPTS NEEDED TO OBTAIN A SUCCESSFUL INTUBATION AND THE SUCCESSFUL INTUBATION RATE PER INTUBATION ATTEMPT N (%)

	Normal scenario		**Difficult scenario**	
	Goodscope	GlideScope	Goodscope	GlideScope
1	72 (98.6%)	71 (97.3%)	71 (97.3%)	63 (86.3%)
2	1 (1.4%)	2 (2.7%)	2 (2.7%)	7 (9.6%)
3	0	0	0	1 (1.4%)
$\geq$ 4	0	0	0	2 (2.7%)

IV. DISCUSSION

This study aimed to evaluate the efficacy of the Goodscope compared with the GlideScope when used by experienced anaesthetists and residents in anaesthesia in two different airway scenarios. The hypothesis for both the normal and the difficult airway scenario was that the Goodscope's intubation times, number of intubation attempts, success rate, and ease of intubation were non-inferior to those of the GlideScope. This expectation is supported by the results that show no significant differences between the two videolaryngoscopes for all primary and secondary endpoints in both scenarios.

These similar results may be explained by the fact that, due to design similarities, the technique needed to efficiently use the Goodscope is essentially identical to that of the GlideScope, with which all participants were familiar. Furthermore, prior to the experiment, no device-specific information about the Goodscope was provided to the participants. This suggests that if participants are familiar with videolaryngoscopy with a hyperangulated blade, the Goodscope is intuitive to use and its learning curve is steep.

Along with the similarities, differences are present between the designs of the Goodscope and the GlideScope. First, the handle of the Goodscope is considerably longer compared to the handle of the GlideScope. Although the length of the handle is mostly critical in patients with a thick chest, large breasts or obese patients [32]–[34], which is not true for the manikin used in this study, several participants specifically indicated that insertion problems were due to the long handle of the Goodscope. Second, the blade of the Goodscope is slightly higher, often associated with longer intubation times, compared to the blade of the GlideScope [35]. However, the participants showed no indications that the higher blade contributed to a more difficult intubation. Third, the camera type and its location vary between the two videolaryngoscopes. The camera of the GlideScope has a wider angle of view, often linked to better glottic views, compared to the camera of the Goodscope [26], [36]. Moreover, the GlideScope's camera is located at a

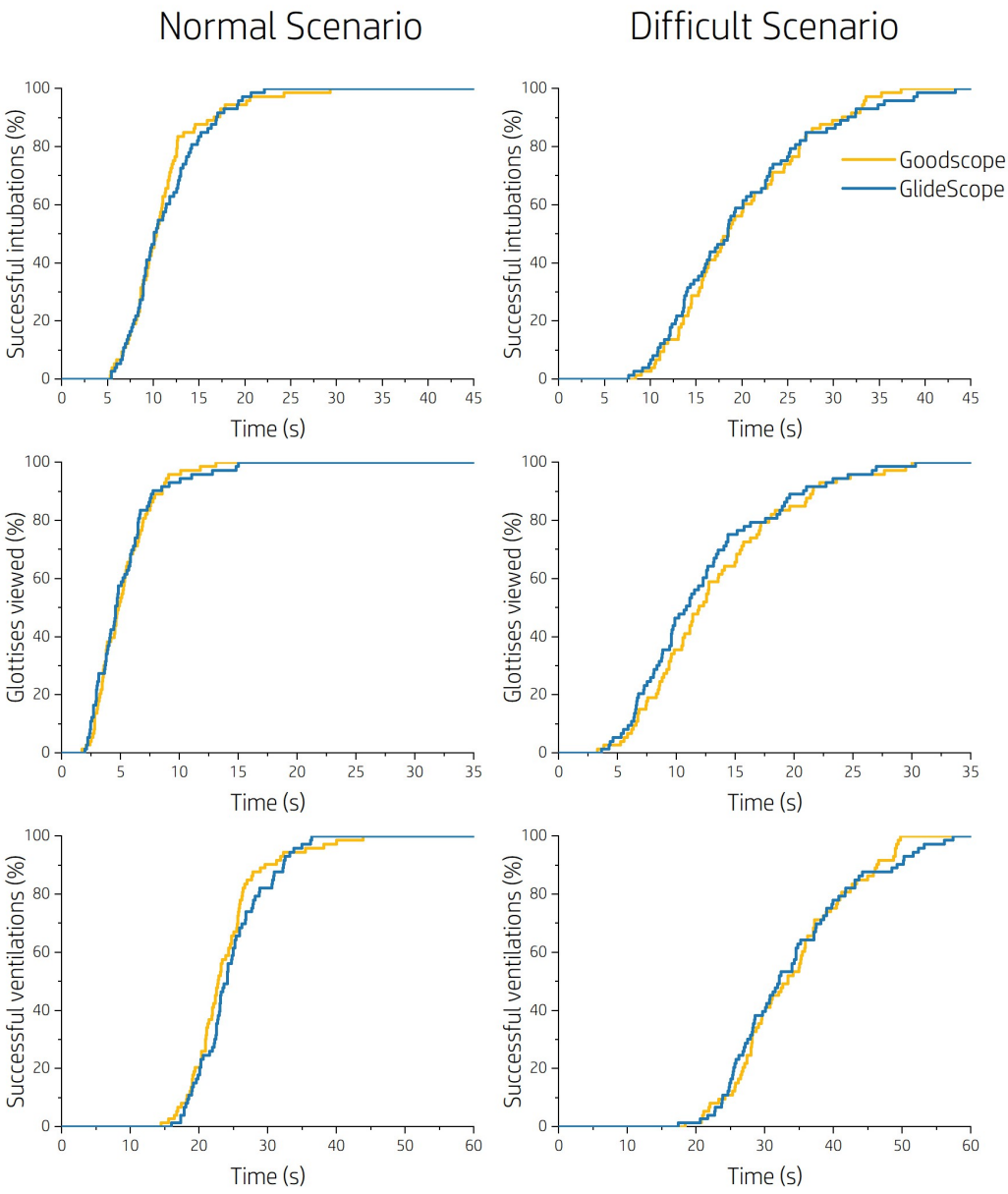


Fig. 3. Graphical representation of time vs percentages of successful intubations, glottises viewed and successful ventilations

larger distance from the tip of the blade, which has been associated to poorer glottic views, compared to the camera of the Goodscope [37]. Therefore, the longer camera-to-tip distance of the GlideScope may have contributed to the higher number of intubation attempts required in the difficult scenario, since participants frequently inserted the blade of the GlideScope too deep in this scenario, resulting in a poor glottic view. However, these differences did not lead to statistically significant different results.

In various manikin studies using the SimMan 3G, the time to intubation was measured for the GlideScope in both normal and difficult scenarios. In previous studies, in the normal scenario, intubation times of 10, 12, 14 and 25 seconds were found with the GlideScope compared to 10.1 seconds found in this study [24]–[27]. For the difficult scenario, maximal tongue swelling, intubation times of 19, 23, 28 and 29 seconds were found with the GlideScope compared to 18.4 sec found in this study [27], [38]–[40]. Differences in time to intubation with the GlideScope between this study and previous studies may be explained by the more extensive intubation experience of the participant group included in this study.

Because this was the first evaluation of the Goodscope, the results of the Goodscope cannot be compared to existing literature. However, several manikin studies were conducted, some in response to the COVID-19 pandemic, in which dif-

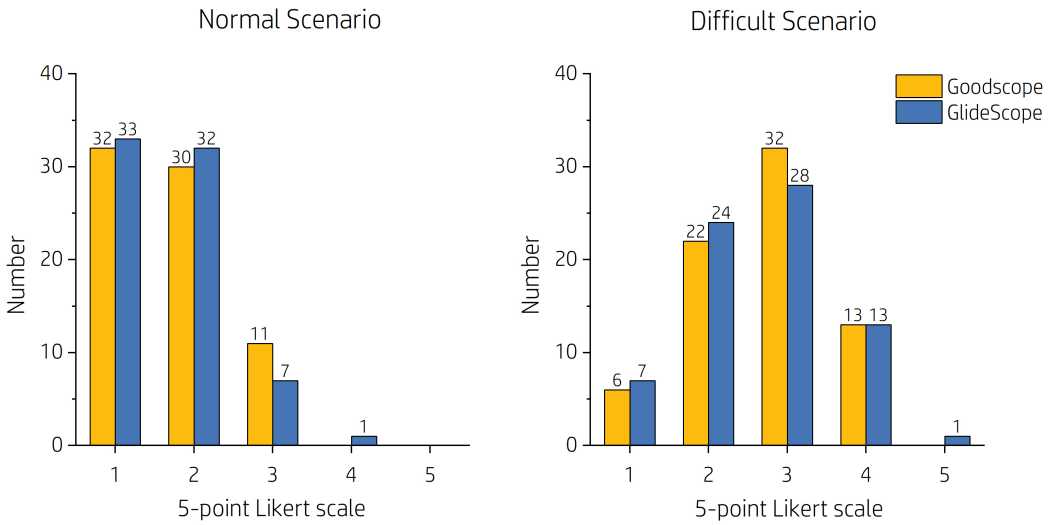


Fig. 4. Subjective scoring of ease of intubation for both devices in the normal and difficult scenario on a 5-point Likert scale with 1 = very easy, 2 = easy, 3 = moderate, 4 = difficult, 5 = very difficult

ferent low-cost videolaryngoscopes were evaluated by using similar endpoints. In these studies, in which the SimMan 3G was used in varying setups, intubation times of 27 and 18 seconds were found in a normal airway and a tongue inflation and stiff neck scenario respectively [14], [41]. It is difficult to relate these findings to the results from this study since other low-cost videolaryngoscopes, with different designs compared to the Goodscope, were evaluated.

This study has several strengths and limitations. The endpoints used in this study were securely chosen by performing an extensive literature study (see Appendix B), in which 171 studies were analysed to define a minimum set of endpoints that should be measured and reported in future manikin studies evaluating videolaryngoscopes. Such a standardised set is needed because the wide range of endpoints, small number of participants, and lack of standardised terminology utilised in studies evaluating videolaryngoscopes, makes it difficult to identify meaningful and comparable results [42]. Although the Cormack-Lehane laryngeal view grade was included in the minimum set of endpoints in the literature study, it was not included as an endpoint in this study because its use in videolaryngoscopy has been questioned since a good view does not correspond to an easy intubation in videolaryngoscopy as is the case in direct laryngoscopy [43]. Contrarily, the endpoint time to glottic view was added as an endpoint in this study based on clinical expert advice, since it was expected that it would provide extra valuable information next to the other time measurements.

The participant's equal experience with the GlideScope is another strength of this study. Extra attention was given to including an equally experienced participant group to ensure that this study solely quantified differences between the two videolaryngoscopes instead of variations in participant intubation experience. This was accomplished through the inclusion criteria on the one hand, and by selecting the medical centres in the Netherlands that utilised the GlideScope as their standard videolaryngoscope on the other hand. However, due to the inclusion criteria, the focus in this study design was on the experienced user, leading to little information about the use of the Goodscope by less experienced users and novices. The inclusion of multiple medical centres allowed a larger number of participants to be included. The corresponding limitations are that differences in clinical practice between the medical centres may have jeopardised the participant group's equal experience, and that, although using the same materials in all centres, small differences in setup may have affected the results. However, the results give no reason to assume that these limitations led to substantial differences.

Due to the crossover design of this study, participants performed multiple intubations. This may have led to learning curve effects in the results. To compensate for these effects, block randomisation was used including each randomisation sequence two or three times. The randomised crossover study was only partially blinded. While participants would see the type of videolaryngoscope they were using, potentially altering participant's behavior, they were blinded for the type of scenario (normal or difficult). Moreover, despite not informing participants about the endpoints to minimise the Hawthorne effect [44], some participants may have felt they were being timed.

This study only compared one similar videolaryngoscope to the Goodscope. Other videolaryngoscopes available on the market have not been investigated in this study because the GlideScope was the standard videolaryngoscope used in the medical centres included. Moreover, direct laryngoscopy was kept out of the scope of this study design since extensive research has already been performed about the differences between video- and direct laryngoscopy. Although its overall superiority is still questioned, the GlideScope is in several studies associated with improved glottic visualisation and fewer failed intubations in the difficult airway [45], [46].

Despite the use of a realistic airway model, the findings of this study differ from those of clinical trials [47]. This may be due to the fact that man and manikin are not the same and their internal anatomies differ. Therefore, the results found in this manikin study cannot be extrapolated to patients [48].

Following this study, a number of recommendations can be made. A study with patients has to be performed to identify the efficacy of the Goodscope in clinical practice. Before performing a clinical trial, a cadaver study could be conducted to determine the safety and effectiveness of the Goodscope in a more realistic model [49]. Moreover, because the Goodscope is also designed for inexperienced users, it is advisable that an additional manikin study testing the efficacy of the Goodscope by less experienced or novice users should be performed. Since the Goodscope has only been compared to the GlideScope, further comparative research with other existing videolaryngoscopes is required to assess the relative effectiveness of these devices. Although research regarding the environmental costs of airway equipment in general has been performed [50], research regarding the environmental impact of disposable versus reusable videolaryngoscopes is necessary such that a complete trade-off between both alternatives can be made.

Two recommendations regarding the design of the Goodscope can be given as a result of this study. First, because several participants indicated that the handle of the Goodscope is too long, the handle should be made shorter. Secondly, another camera with a wider angle of view, similar to the camera of the GlideScope, is recommended to optimise the view of the glottis.

V. Conclusion

In conclusion, the findings of this study suggest that the Goodscope is non-inferior to the GlideScope since no significant differences between the Goodscope and the GlideScope were identified for all primary and secondary endpoints. Therefore, we conclude that the Goodscope has acceptable efficacy in manikins. Moreover, this study contributes to proving the concept of an affordable reusable videolaryngoscope without compromising on quality.

References

[1] P. Howitt, A. Darzi, G. Z. Yang, H. Ashrafian, R. Atun, J. Barlow, A. Blakemore, A. M. Bull, J. Car, L. Conteh, G. S. Cooke, N. Ford, S. A. Gregson, K. Kerr, D. King, M. Kulendran, R. A. Malkin, A. Majeed, S. Matlin, R. Merrifield, H. A. Penfold, S. D. Reid, P. C. Smith, M. M. Stevens, M. R. Templeton, C. Vincent, and E. Wilson, "Technologies for global health," *The Lancet*, vol. 380, pp. 507–535, 2012.

[2] L. Perry and R. Malkin, "Effectiveness of medical equipment donations to improve health systems: How much medical equipment is broken in the developing world?," *Medical and Biological Engineering and Computing*, vol. 49, pp. 719–722, 7 2011.

[3] W. WORLD HEALTH ORGANIZATION, "Guidelines for health care equipment donations," Mar 2000.

[4] L. Armstrong, F. Harding, J. Critchley, A. F. McNarry, S. N. Myatra, R. Cooper, and P. A. Baker, "An international survey of airway management education in 61 countries†," *British Journal of Anaesthesia*, vol. 125, pp. e54–e60, 7 2020.

[5] R. M. Cooper, "Preparation for and management of "failed" laryngoscopy and/or intubation," *Anesthesiology*, vol. 130, pp. 833–849, 5 2019.

[6] M. F. Aziz, A. M. Brambrink, D. W. Healy, A. W. Willett, A. Shanks, T. Tremper, L. Jameson, J. Ragheb, D. A. Biggs, W. C. Paganelli, J. Rao, J. L. Epps, D. A. Colquhoun, P. Bakke, and S. Kheterpal, "Success of intubation rescue techniques after failed direct laryngoscopy in adults," *Anesthesiology*, vol. 125, pp. 656–666, 10 2016.

[7] A. D. Jong, N. Molinari, M. Conseil, Y. Coisel, Y. Pouzeratte, F. Belafia, B. Jung, G. Chanques, and S. Jaber, "Video laryngoscopy versus direct laryngoscopy for orotracheal intubation in the intensive care unit: A systematic review and meta-analysis," *Intensive Care Medicine*, vol. 40, pp. 629–639, 2014.

[8] M. Michailidou, T. O'Keeffe, J. M. Mosier, R. S. Friese, B. Joseph, P. Rhee, and J. C. Sakles, "A comparison of video laryngoscopy to direct laryngoscopy for the emergency intubation of trauma patients," *World Journal of Surgery*, vol. 39, pp. 782–788, 2015.

[9] R. Mihai, E. Blair, H. Kay, and T. M. Cook, "A quantitative review and meta-analysis of performance of non-standard laryngoscopes and rigid fibreoptic intubation aids," *Anaesthesia*, vol. 63, pp. 745–760, 7 2008.

[10] S. R. Lewis, A. R. Butler, J. Parker, T. M. Cook, O. J. Schofield-Robinson, and A. F. Smith, "Videolaryngoscopy versus direct laryngoscopy for adult patients requiring tracheal intubation: A cochrane systematic review," *British Journal of Anaesthesia*, vol. 119, pp. 369–383, 9 2017.

[11] C. Frerk, V. S. Mitchell, A. F. McNarry, C. Mendonca, R. Bhagrath, A. Patel, E. P. O'Sullivan, N. M. Woodall, and I. Ahmad, "Difficult airway society 2015 guidelines for management of unanticipated difficult intubation in adults," *British Journal of Anaesthesia*, vol. 115, pp. 827–848, 12 2015.

[12] J. L. Apfelbaum and et al., "Practice guidelines for management of the difficult airway an updated report by the american society of anesthesiologists task force on management of the difficult airway," *Anesthesiology*, vol. 118, pp. 251–270, 2013.

[13] M. Guerra-Hernández, G. J. Vidaña-Martínez, J. S. Camacho-Juárez, H. Barragán-Villegas, J. E. Calacuayo-Rojas, B. A. Reyes, J. A. Castañón-González, O. F. Núñez-Olvera, and M. D. P. Fonseca-Leal, "Novel video-laryngoscope with wireless image transmission via wi-fi towards a smartphone," *Electronics (Switzerland)*, vol. 9, pp. 1–12, 10 2020.

[14] C. T. Lambert, S. C. John, and A. V. John, "Development and performance testing of the low-cost, 3d-printed, smartphone-compatible 'tansen videolaryngoscope' vs. pentax-aws videolaryngoscope vs. direct macintosh laryngoscope a manikin study," vol. 37, pp. 992–998, Lippincott Williams and Wilkins, 11 2020.

[15] OECD, *Fiscal Sustainability of Health Systems*. 2015.

[16] A. Ville, *Reuse of intubation devices as a catalyser for systemic change*. PhD thesis, 2022.

[17] T. M. Cook, "Novel airway devices: Spoilt for choice?," *Anaesthesia*, vol. 58, no. 2, p. 107–110, 2003.

[18] J. Toda, A. A. Toda, and J. Arakawa, "Learning curve for paramedic endotracheal intubation and complications," *International Journal of Emergency Medicine*, vol. 6, p. 38, 2013.

[19] H. E. Wang, S. R. Seitz, D. Hostler, and D. M. Yealy, "Defining the "learning curve" for paramedic student endotracheal intubation," *Prehospital Emergency Care*, vol. 9, pp. 156–162, 4 2005.

[20] R. Hesselfeldt, M. S. Kristensen, and L. S. Rasmussen, "Evaluation of the airway of the simman™ full-scale patient simulator," *Acta Anaesthesiologica Scandinavica*, vol. 49, pp. 1339–1345, 10 2005.

[21] G. M. Jordan, J. Silsby, G. Bayley, and T. M. Cook, "Evaluation of four manikins as simulators for teaching airway management procedures specified in the difficult airway society guidelines, and other advanced airway skills," *Anaesthesia*, vol. 62, pp. 708–712, 7 2007.

[22] C. H. Maharaj, B. D. Higgins, B. H. Harte, and J. G. Laffey, "Evaluation of intubation using the airtraq® or macintosh laryngoscopy - a manikin study," *Anaesthesia*, vol. 61, pp. 469–477, 5 2006.

[23] S. A. Julious, "Sample sizes for clinical trials with normal data," *Statistics in Medicine*, vol. 23, no. 12, p. 1921–1986, 2004.

[24] B. Pieters, N. Wilbers, M. Huijzer, B. Winkens, and A. V. Zundert, "Comparison of seven videolaryngoscopes with the macintosh laryngoscope in manikins by experienced and novice personnel," *Anaesthesia*, vol. 71, pp. 556–564, 2016.

[25] T. Russell, C. Lee, M. Firat, and R. Cooper, "A comparison of the forces applied to a manikin during laryngoscopy with the glidescope® and macintosh laryngoscopes," *Anaesthesia and Intensive Care*, vol. 39, pp. 1098–1102, 2011.

[26] J. Hodd, D. Doyle, S. Gupta, J. Dalton, J. Cata, E. Brewer, M. James, and D. Sessler, "A mannequin study of intubation with the ap advance and glidescope ranger videolaryngoscopes and the macintosh laryngoscope," *Anesthesia and Analgesia*, vol. 113, pp. 791–800, 2011.

[27] D. Shin, P. Choi, and S. Han, "Tracheal intubation during chest compressions using pentax-aws ¡sup¿®¡/sup¿, glidescope ¡sup¿®¡/sup¿, and macintosh laryngoscope: A randomized crossover trial using a mannequin," *Canadian Journal of Anesthesia*, vol. 58, pp. 733–739, 2011.

[28] A. Moritz, L. Holzhauser, T. Fuchte, S. Kremer, J. Schmidt, and A. Irouschek, "Comparison of glidescope core, c-mac miller and conventional miller laryngoscope for difficult airway management by anesthetists with limited and extensive experience in a simulated pierre robin sequence: A randomized crossover manikin study," *PLoS ONE*, vol. 16, 4 2021.

[29] J. Pius and R. R. Noppens, "Learning curve and performance in simulated difficult airway for the novel c-mac® video-stylet and c-mac® macintosh video laryngoscope: A prospective randomized manikin trial," *PLoS ONE*, vol. 15, 11 2020.

[30] A. Moritz, V. Leonhardt, J. Prottengeier, T. Birkholz, J. Schmidt, and A. Irouschek, "Comparison of glidescope® go™, king vision™, dahlhausen vl, i-view™ and macintosh laryngoscope use during difficult airway management simulation by experienced and inexperienced emergency medical staff: A randomized crossover manikin study," *PLoS ONE*, vol. 15, 7 2020.

[31] K. Suzuki, S. Kusunoki, T. Sadamori, Y. Tanabe, J. Itai, and N. Shime, "Comparison of video and conventional laryngoscopes for simulated difficult emergency tracheal intubations in the presence of liquids in the airway," *PLoS ONE*, vol. 14, 6 2019.

[32] J. Duke, "Airway management," *Anesthesia Secrets*, vol. 8, p. 58–67, 2011.

[33] A. Nileshwar and V. Garg, "Comparison of bullard laryngoscope and short-handled macintosh laryngoscope for orotracheal intubation in pediatric patients with simulated restriction of cervical spine movements," *Paediatric Anaesthesia*, vol. 20, pp. 1092–1097, 12 2010.

[34] N. Neeharika, "The comparative study of standard macintosh handle versus short handle for laryngoscopy and intubation in obstetric patients for lower segment cesarean section," *Journal of Evolution of Medical and Dental Sciences*, vol. 3, pp. 11080–11089, 9 2014.

[35] P. Huang, R. Zhou, Z. Lu, Y. Hang, S. Wang, and Z. Huang, "Glidescope® versus c-mac®(d) videolaryngoscope versus macintosh laryngoscope for double lumen endotracheal intubation in patients with predicted normal airways: A randomized, controlled, prospective trial," *BMC Anesthesiology*, vol. 20, 5 2020.

[36] M. Cierniak, D. Timler, A. Wieczorek, P. Sekalski, N. Borkowska, and T. Gaszynski, "The comparison of the technical parameters in endotracheal intubation devices: the cmac, the vividtrac, the mcgrath mac and the kingvision," *Journal of Clinical Monitoring and Computing*, vol. 30, pp. 379–387, 8 2016.

[37] K. Raymondos, T. Seidel, B. Sander, A. Gerdes, F. Goetz, V. Helmstädter, B. Panning, and T. Dieck, "The intubation scoop (i-scoop) - a new type of laryngoscope for difficult and normal airways," *Anaesthesia*, vol. 69, pp. 990–1001, 2014.

[38] S. Lee, W. Kim, H. Kang, J. Oh, T. H. Lim, Y. Lee, C. Kim, and J. H. Cho, "Comparisons of the pentax-aws, glidescope, and macintosh laryngoscopes for intubation performance during mechanical chest compressions in left lateral tilt: A randomized simulation study of maternal cardiopulmonary resuscitation," *BioMed Research International*, vol. 2015, 2015.

[39] H. Ecker, S. Kolvenbach, S. Stranz, H. Herff, and W. A. Wetsch, "Comparison of the novel viescope with conventional and video laryngoscope in a difficult airway scenario – a randomized, controlled simulation trial," *BMC Emergency Medicine*, vol. 21, 12 2021.

[40] R. Martin and K. Armstrong, "Comparison of the bullard and glidescope laryngoscopes in a simulated difficult airway," *Anesthesiology*, vol. 103, Oct 2005.

[41] Y. Cohen, R. M. Rubinstein, and H. Berkenstadt, "A do-it-yourself videolaryngoscope for under 25$ - a solution for lower income countries?," *Anesthesia & Analgesia*, vol. 123, pp. 680–681, 9 2016.

[42] J. Hinkelbein, R. Greif, P. Diemunsch, and P. Kranke, "Publication and innovation in airway management: Quality not quantity!," *European Journal of Anaesthesiology*, vol. 34, pp. 408–410, 7 2017.

[43] F. Landucci, A. Byrne, and D. Caldiroli, "Interpreting the cormack and lehane classification during videolaryngoscopy," *Anaesthesia*, vol. 73, no. 5, p. 652–653, 2018.

[44] J. McCambridge, K. Kypri, and D. Elbourne, "In randomization we trust? there are overlooked problems in experimenting with people in behavioral intervention trials," *Journal of Clinical Epidemiology*, vol. 67, pp. 247–253, 2014.

[45] D. E. Griesdale, D. Liu, J. McKinney, and P. T. Choi, "Glidescope ® video-laryngoscopy versus direct laryngoscopy for endotracheal intubation: A systematic review and meta-analysis," *Canadian Journal of Anesthesia*, vol. 59, pp. 41–52, 1 2012.

[46] M. A. Malik, C. O'Donoghue, J. Carney, C. H. Maharaj, B. H. Harte, and J. G. Laffey, "Comparison of the glidescope®, the pentax aws®, and the truview evo2® with the macintosh laryngoscope in experienced anaesthetists: A manikin study," *British Journal of Anaesthesia*, vol. 102, pp. 128–134, 2009.

[47] D. A. Sun, C. B. Warriner, D. G. Parsons, R. Klein, H. S. Umedaly, and M. Moult, "The glidescope® video laryngoscope: Randomized clinical trial in 200 patients," *British Journal of Anaesthesia*, vol. 94, pp. 381–384, 2005.

[48] K. Schebesta, M. Hü, B. Rö, H. Ringl, M. P. Mü, and O. Kimberger, "Degrees of reality airway anatomy of high-fidelity human patient simulators and airway trainers," 2012.

[49] M. W. V. Emden, J. J. Geurts, P. Schober, and L. A. Schwarte, "Comparison of a novel cadaver model (fix for life) with the formalin-fixed cadaver and manikin model for suitability and realism in airway management training," *Anesthesia and Analgesia*, vol. 127, pp. 914–919, 2018.

[50] F. McGain, D. Story, T. Lim, and S. McAlister, "Financial and environmental costs of reusable and single-use anaesthetic equipment," *British Journal of Anaesthesia*, vol. 118, pp. 862–869, 6 2017.

A

Results of Anesthesia Assistants

A.1. Methods

The data of 11 participants was excluded from this study since the inclusion criteria (participants had to be anaesthetists or residents in anaesthesia with a minimal clinical intubation experience of 2 years) were not met as they were anaesthesia assistants. As this group has on average less extensive experience with videolaryngoscopy, their results may offer information about the use of the Goodscope and the GlideScope by less experienced users. Despite the small sample size, the data of all endpoints was analysed in SPSS using the Wilcoxon signed-ranks test. One-sided P-values were calculated from the two-sided P-values obtained from the Wilcoxon signed-ranks test and are considered significant if $P<0.05$. All results are summarized by median and interquartile range (IQR).

A.2. Results

For the primary endpoint, time to successful intubation, median times of 12.4 s (IQR 9.3, 19.4) and 11.4 s (IQR 9.1, 21.0) were found in the normal scenario for the Goodscope and the GlideScope respectively. In the difficult scenario, a median time of 19.3 s (IQR 13.5, 24.9) was found for the Goodscope and 17.1 s (IQR 15.9, 23.0) was found for the GlideScope. No statistically significant difference between the Goodscope and the GlideScope in both the normal [Z = -0.178, P = 0.430] and the difficult scenario [Z = -0.178, P = 0.430] was found. The results for all time measurements including time to glottic view and time to ventilation are detailed in table A.1.

	Normal scenario			**Difficult scenario**		
	Goodscope, median (IQR)	GlideScope, median (IQR)	Test statistics Wilcoxon signed ranks test (Z-score, **one- sided p-value**)	Goodscope, median (IQR)	GlideScope, median (IQR)	Test statistics Wilcoxon signed ranks test (Z-score, **one- sided p-value**)
Primary endpoint						
Time to successful intubation (s)	12.4 (9.3, 19.4)	11.4 (9.1, 21.0)	-0.178, **0.430**	19.3 (13.5, 24.9)	17.1 (15.9, 23.0)	-0.178, **0.430**
Secondary endpoints						
Time to glottic view (s)	6.0 (5.4, 7.8)	5.9 (4.1, 13.1)	0.711, **0.762**	10.7 (7.5, 16.3)	12.0 (9.8, 15.4)	0.533, **0.703**
Time to ventilation (s)	28.3 (23.9, 37.9)	27.6 (24.3, 38.3)	0.089, **0.536**	35.9 (31.2, 44.3)	36.9 (33.5, 43.0)	0.800, **0.788**

Table A.1: Time to successful intubation, time to glottic view, and time to ventilation in seconds

For the Goodscope and the GlideScope, similar medians of the number of intubation attempts were found in the normal [median 1, IQR 1, 1] and the difficult [median 1, IQR 1, 2] airway scenario. No

significant differences were found for this endpoint between the GlideScope and the Goodscope in both the normal [Z = -1.000, P = 0.500] and the difficult [Z = 1.000, P = 0.842] scenario. In table A.2, the number of intubation attempts and the successful intubation rate per intubation attempt are given.

	Normal scenario		**Difficult scenario**	
	Goodscope	GlideScope	Goodscope	GlideScope
1	11 (100%)	11 (100%)	8 (72.7%)	6 (54.5%)
2	0	0	3 (27.3%)	4 (36.4%)
3	0	0	0	1 (9.1%)
$\geq$ **4**	0	0	0	0

Table A.2: Number of intubation attempts needed to obtain a successful intubation and the successful intubation rate per intubation attempt n (%).

Lastly, for ease of intubation no significant difference was found [Z = 0.000, P = 0.500] between the Goodscope [median 2, IQR 2, 2] and the GlideScope [median 2, IQR 2, 2] in the normal scenario. Correspondingly, in the difficult scenario, no significant difference was found [Z = 0.730, P = 0.768] between the Goodscope [median 2, IQR 2, 4] and the GlideScope [median 2, IQR 3, 4]. The grades given by the participants for the ease of intubation are shown in figure A.1.

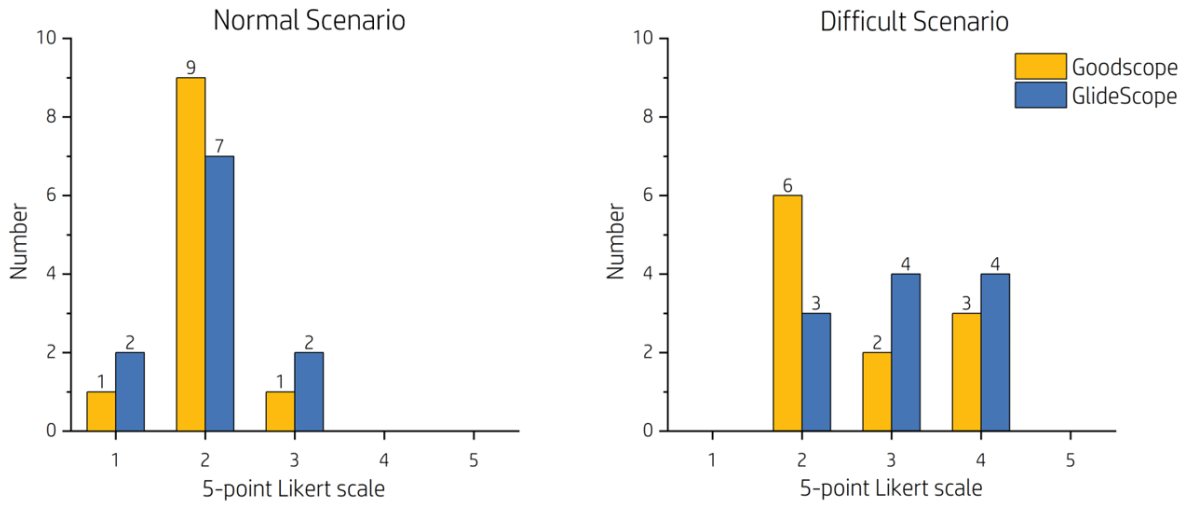


Figure A.1: Subjective scoring of ease of intubation for both devices in the normal and difficult scenario on a 5-point Likert scale with 1 = very easy, 2 = easy, 3 = moderate, 4 = difficult, 5 = very difficult.

A.3. Discussion and Conclusion

No significant differences were found between medians of the Goodscope and the GlideScope for all endpoints in both airway scenarios. This implies that the Goodscope is also non-inferior to the GlideScope for anesthesia assistants for all endpoints. However, given the small sample size and hence low power, it is unknown if the results or the low power are to cause for the non-significance. Moreover, the difference between the medians was analyzed which tends to be more biased and less accurate than the mean for small sample sizes ($n < 25$). So, although it can be concluded from these results that significant differences were not found between the Goodscope and the GlideScope, it can not be concluded if the Goodscope is non-inferior to the GlideScope for this participant group.

B

Literature Study

Relevant End-Points for the Validation of Videolaryngoscopes in Manikin Studies

A Scoping Review

Author: Roos Wiltink (4482190) | Supervisors: Prof. dr. J. Dankelman and D. Drexhage

January 25, 2022

***Abstract*— *Background*: Airway management is one of the fields of anesthesia in which the most complications occur and it is, therefore, no surprise that this is a topic of major research interest. However, the quality of research performed in this field is questionable because of the low amount of participants, large variety in end-points, and the lack of standardised definitions. Similarly, this applies to manikin studies carried out in the field of videolaryngoscopy. Therefore, this literature review aimed to gather, analyse and select the most relevant end-points used to validate videolaryngoscopes in manikin studies published over the last ten years.**

***Methods*: Studies were gathered by using the MEDLINE and SCOPUS bibliographic databases. Studies were included for analysis if both the search terms 'manikin' and 'videolaryngoscope' (or one of their synonyms) were included in the title/abstract and if clear end-points were stated. Additionally, the DAEN and TPLC adverse event databases were used to identify the most harmful device problems of (video)laryngoscopes. Subsequently, the end-points found in the literature were linked to those harmful device problems that could be assessed with a manikin study.**

***Results*: In the 171 studies analysed, 47 different end-points were identified. The five most frequently reported end-points were found to be: *Successful intubation rate 75,4% (n=129), Time to intubation 50,9% (n=87), Time to ventilation 50,3% (n=86), Laryngeal view grade (CL) 47,4% (n=81)* and *Number of intubation attempts 37,4% (n=64)*. The device problems that could be assessed with a manikin study were found to be: *Difficult to Advance, Poor Glottic View, Intubation Difficulty, Optical Obstruction, Inadequacy of Device Shape and/or Size* and *High Resistance*.**

***Conclusion*: Standardised definitions of end-points and consistent use can contribute to increasing the value of manikin studies that are carried out in the field of videolaryngoscopy. Therefore, six end-points, which were selected due to their high incidence as well as relevance to the patient, are recommended for use in future manikin studies: *Time to intubation, Time to ventilation, Successful intubation rate, Number of intubation attempts, Laryngeal view grade (CL)* and *Ease of intubation*.**

I. Introduction

A. Risks of anesthesia

Worldwide, 230 million anesthetic procedures are performed annually [1]. Although the anesthesia-related mortality rates have decreased in high-, middle- and low-income countries over the past few decades, the anesthetic risk remains relevant because of its high incidence [1] [2] [3] [4]. However, the mortality rates in low- and middle-income countries (LMIC) are found to decrease at a slower pace [3] [5]. This global downward trend is driven by several safety improvements, including the development of improved airway techniques and devices [3] [6]. Despite the decline in mortality rates, the need for improvement in anesthetic safety remains significant, especially in low resource settings [7] [8] [9]. The gap between LMIC and high-income countries is large when it comes to safe anesthetics. To close this gap, not only funding and training but also robust and functional equipment are needed in LMIC [7] [10]. To improve the safety of anesthesia, the focus should be on those anesthetic fields in which the most adverse events occur.

B. The field of airway management

Airway management is one of those fields in which most anesthetic-related complications occur. It is estimated that failure to manage a difficult airway accounts for 30% of the anesthetic deaths [11]. Airway management is a crucial aspect of anesthesia that covers the entire range of airway manipulations that may be required in the fields of emergency medicine, intensive care medicine, and during general anesthesia [4] [12] [13]. Therefore, it is not surprising that of the 230 million anesthetic procedures performed worldwide, 50 million involve intubation [14]. Although complications that arise from airway management are rare, the results can be life-threatening [15]. Therefore, improvements in airway management can further increase the global safety of anesthesia. The airway management technique which is the gold standard procedure in general anesthetics is endotracheal intubation (ETI) [16]. This technique is used to secure the airway of patients in several clinical fields: resuscitation, prehospital airway management, emergency medicine, intensive care, and anesthesiology [17].

C. Validation of videolaryngoscopy

It is no surprise that airway management is a topic of major interest in research because airway management is of great importance and a key competence for anaesthesiologists [18]. To improve patient care, thorough research is of utmost importance. Unfortunately, only a small number of high-quality research is published [19]. In the field of airway management, comparative studies between several devices are often performed to evaluate the efficacy of these devices. However, due to the low amount of participants, the large

variety in end-points, and the lack of standardised definitions, relevant and comparable results are hard to find [18]. Moreover, standardised definitions of end-points and consistent use can contribute to increasing the value of research [20]. Therefore, Hinkelbein et al. developed a core outcome set (COS), consisting of 12 different end-points, that should be used in future videolaryngoscopy studies [21]. These end-points were partly selected from clinical trials. Because clinical trials need approval, are time-consuming, and have a risk of adverse events, manikin studies are a popular alternative [22]. Moreover, before a videolaryngoscope is introduced to the market, clinical trials are often not required because they are considered low-risk devices. So, in these cases, evaluating the device on a manikin would meet the standards [22]. For this reason, many manikin studies are performed in the field of VL. Unfortunately, these manikin studies have the same problem as clinical trials: the results of the studies are generally not comparable because of the already indicated low number of participants and different end-points used. However, the COS developed by Hinkelbein et al. does not necessarily apply to manikin studies because it was based on clinical trials. Moreover, end-points used in clinical trials are often not as relevant to measure in a manikin because man and manikin are simply not the same [23]. For example, complications are generally measured in clinical trials while these are hard to simulate in a manikin. On the contrary, force measurements on the body are difficult to perform in clinical trials but can be accurately measured in manikin studies because sensors can be located inside the manikin.

II. Objective

The aim of this literature review was to gather, analyse and select the most relevant end-points used to validate videolaryngoscopes in manikin studies published over the last ten years. The relevance of the end-points was determined in two different ways. On the one hand, by examining which end-points were most frequently used in manikin studies. These studies were found by performing a literature search in bibliographic databases. On the other hand, the relevance was determined by searching the most harmful device problems of (video)laryngoscopes which led to complications and linking these to the end-points found. The device problems were found by searching adverse event databases. Together, this will answer the research question which was defined as *What are the most relevant end-points for the validation of a videolaryngoscope in a manikin study?* As a result, a list was established which consisted of relevant end-points to be used in future manikin studies. A scoping review approach was chosen for this literature research because the research question aims to map the evidence rather than providing a critically appraised answer [24] [25].

III. Background of laryngoscopy

A. The procedure of endotracheal intubation

Endotracheal intubation is the procedure that consists of inserting a tube (the endotracheal tube) into the trachea. This can be accomplished in two ways, through the nose (nasotracheal intubation) or the mouth (orotracheal intubation). The oral route is most often used, in 98% - 94.6% of all endotracheal intubations [26]. This is mainly because orotracheal intubation is faster, easier to perform and less painful for the patient [26]. Orotracheal intubation consists of the following steps:

- Positioning and preparation: Before starting the procedure it must be ensured that the right materials and back-up parts are available. The patient must be brought into the right position prior to intubation depending on the weight of the patient, the injury type and the laryngoscope used [27] [28] [29].
- Preoxygenation: As patients are often under general anesthesia when they are intubated, there is a time limit to the procedure. Since the drugs have a paralyzing effect on the patient's muscles, the patient cannot breathe on its own because the diaphragm is paralysed as well. In order to increase the time (safe apnea time) before hypoxemia occurs, preoxygenation is performed [30]. Through a close-fitting face mask, inspired oxygen is administered to the patient for a number of minutes in order to build up a reserve in which intubation can be performed [31]. If intubation takes longer than the safe apnea time, complications such as arterial desaturation and hypoxic injury may arise [29].
- Laryngoscopy: Subsequently, a laryngoscope is used to visualise the vocal cords through which the endotracheal tube will eventually be inserted. An overview of the relevant anatomy is depicted in figure 1. Two types of

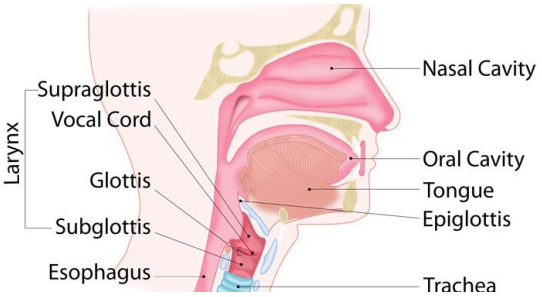


Fig. 1. Basic anatomy of the larynx. Source: [32]

laryngoscopes exist: direct and indirect. Direct laryngoscopy (DL) is the most commonly used technique which uses the laryngoscope to obtain direct visualization of the glottis [33]. Indirect laryngoscopy refers to techniques that can visualise the glottis without a direct line-of-sight view. Videolaryngoscopy (VL) is the most common indirect laryngoscopy technique [27]. By making use of a camera or another visualization technique, an indirect sight of the glottis is obtained. While DL is preferred for normal intubations, VL is mostly used for difficult intubations because the camera increases the anaesthesiologist's field of view. In both techniques, the laryngoscope is inserted through the right side of the mouth while pushing the tongue out of the way to the

left side, see figure 2 [29] [27]. The laryngoscope is

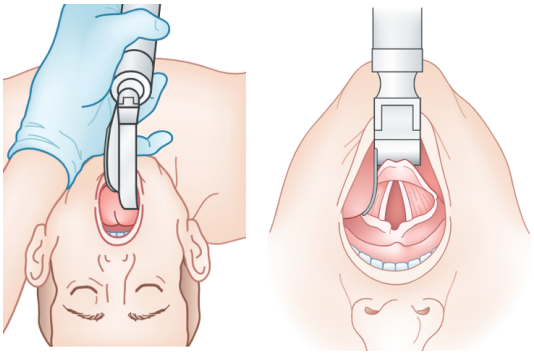


Fig. 2. Left: laryngoscope is inserted through the right side of the mouth, Right: the tongue is pushed to the left side. Source: [29]

advanced towards the base of the tongue and lifted to visualise the epiglottis. Depending on the blade type of the laryngoscope, a different technique is required to visualise the glottis. In the case of a straight blade (Miller), the tip of the laryngoscope is placed posterior to the epiglottis. Thereby, the epiglottis is flattened and a view on the vocal cords is obtained, see figure 3. In

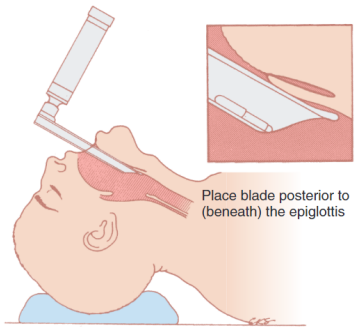


Fig. 3. Laryngoscopy with a Miller laryngoscope blade. Source: [29]

the case of a curved blade (Macintosh), the tip of the laryngoscope is placed in the space formed between the base of the tongue and the epiglottis (vallecula), see figure 4 [34]. Subsequently, the laryngoscope is moved

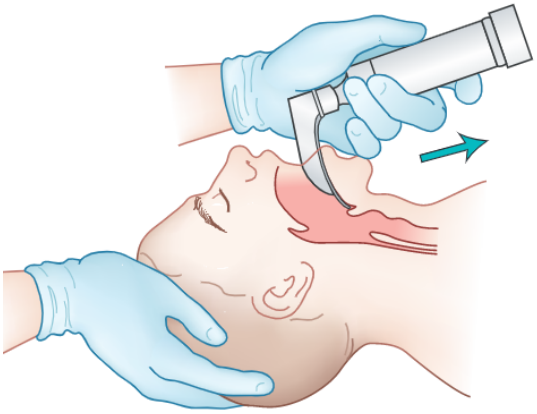


Fig. 4. Laryngoscopy with a Macintosh laryngoscope blade. Source: [29]

up and forward several times allowing the glottis to come into view.

- Endotracheal tube insertion: When the vocal cords are properly visible, the endotracheal tube (ETT) is inserted through the right-most side of the patient's mouth. By taking this approach the line of sight is not blocked by the ETT. The tube is advanced downwards and is stopped approximately 2 cm beyond the glottis [29]. If the first intubation attempt fails or if a difficult airway is expected, several adjuncts can be used to ease intubation, such as a bougie or stylet [35]. If successful intubation is assumed, the laryngoscope can be removed. Lastly, the cuff of the ETT is inflated to secure the tube in the trachea.
- Verification: The last and most important step in the intubation process is to verify if the ETT is properly placed in the trachea. Several physical examination methods for the verification exist. However, these methods alone are not sensitive enough [36]. Next to visual tube placement confirmation of the ETT between the vocal cords, the measurement of end-tidal CO2 (capnography) is seen as the gold standard for the verification of tube placement [37]. However, also this method has its limitations. Therefore, the *Difficult Airway Society 2015 guidelines* advise using a combination of several verification methods to determine correct intubation [38]. These include: visual confirmation of ETT through the vocal cords, chest expansion on both sides, detection of breathing sounds and capnography [29].

B. History and development of videolaryngoscopy

Although the first indications of airway management date all the way back to Ancient Egypt (3600 BC) [39], the first endotracheal intubation did not take place until the late 1900s. It was William Macewen who performed the first elective endotracheal intubation for anesthesia in 1879 [40]. Macewen packed the hypopharynx (the lower part of the throat, behind the larynx) to prevent blood from leaking into the trachea [41]. He achieved this without using a laryngoscope, which had already been invented at the time. There is some debate as to who was the first to invent the precursor to the laryngoscope, Benjamin Babington in 1829 or Manuel García in 1855 [42] [33]. Babington's laryngoscope was intended to depress the tongue and at the same time visualise the larynx with mirrors by using the sun as a light-source [42]. In contrast to Babington's medical background, García was a Spanish singer [40]. Because of his interest in his vocal cords, he was the first to see the glottis functioning as a whole by building a construction of mirrors on curved instruments. Due to Babington's vague documentation, García thought he was the first to design such a device and this is how the confusion arose [42]. Several medical practitioners continued with the techniques developed by Babington and García, where the main problem proved to be the lack of a good light source. Alfred Kirstein was the first to solve this problem by introducing an external electrical light to the system. As a result of this development, in 1895, Kirstein was the

first person who was able to obtain a direct view of the vocal cords. Therefore, the first direct laryngoscope, which he called the autoscope, is attributed to him [43]. Again, many adaptions were made to the system developed by Kirstein. However, it was Chevalier Jackson who eventually combined direct laryngoscopy and endotracheal intubation in 1903 [42]. Jackson developed several laryngoscopes over the next two decades. But it was not until the First World War that endotracheal anesthesia became predominant [43]. As a result, the laryngoscope developed by Jackson was improved by several people in the following years. In 1941 and 1943, Robert Miller and Robert Macintosh designed the straight and curved blades that we use to this day [33]. In the last 70 years, no other blades have been designed that became as successful as those of Miller and Macintosh [42] [33]. However, in contrast to the blade design, other aspects of the laryngoscope have changed. In the last few decades, various types of videolaryngoscopes have been designed with the use of different imaging techniques such as a video camera and a fiberoptic bundle. This adaption was made in order to improve the view of the glottis [27] [44]. In other words, laryngoscopy goes back to where it started: indirect laryngeal view.

C. Direct laryngoscopy versus videolaryngoscopy

Although direct laryngoscopy (DL) remains the standard for routine intubations, videolaryngoscopy (VL) is becoming increasingly popular. For many years, DL was the default method for normal orotracheal intubation. However, it is shown that DL fails in approximately 6% of adult surgical patients [45]. This failure rate is defined as the inability to see the larynx. When using VL it is easier to look around anatomical obstacles because the camera is located at the tip of the device, as depicted in figure 5.

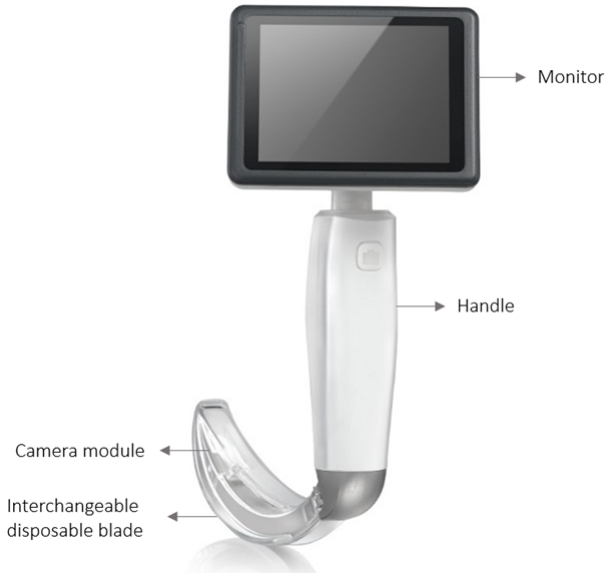


Fig. 5. A videolaryngoscope [46]

Therefore, VL is often used in anticipated difficult airway scenarios where there is a limited line-of-sight to the larynx. In addition, when failed direct laryngoscopic intubation occurs, VL is also used [27] [47]. The *Difficult Airway Society 2015 guidelines* even state that some anesthetists consider VL to be the first-line product for orotracheal intubation [38]. Moreover, in the *2022 American Society of Anesthesiologists Practice Guidelines for Management of the Difficult Airway*, the trend towards VL is acknowledged as well by the numerous advantages reported, such as "improved laryngeal views, a higher frequency of successful intubations, a higher frequency of first attempt intubations, and fewer intubation maneuvers with video-assisted laryngoscopy" [48]. Pieters et al. describe, next to the advantages, the disadvantages of VL such as better laryngeal view does not lead to easier intubation, fogging of the lens, weak hand-eye coordination and higher costs [42]. Next to the advantages reported by the American Society of Anesthesiologists, Pieters et al. add an important advantage to this list: the videolaryngoscopes that use a Macintosh blade are multi-functional because they can be used for DL as well. Although there are clear advantages of VL, some recent comparative studies do not demonstrate the superiority of VL over DL. Although the laryngoscopic view is found to be better when using VL in these studies, other parameters such as time to intubation, failure rate and ease of use do not indicate a significant difference between VL and DL [49] [50] [51] [52]. Nowadays, a videolaryngoscope is one of the standard devices in the operating rooms of high-income countries and is the superior device in difficult airway scenarios, especially for the experienced practitioner [53]. However, its advantages for the inexperienced practitioner and for routine airway management have not been shown on a large scale yet [53].

IV. Methods

The method of this review is twofold. On the one hand, a literature search was performed to obtain a list of the most used end-points in manikin studies performed over the last ten years. On the other hand, an adverse event data search was performed to obtain the most harmful (video)laryngoscopy-related device problems that led to complications that have been reported over the last ten years. These complications consisted, on the one hand, of patient problems in which the patient was harmed (such as death, lacerations or hypoxia) and, on the other hand, of the problem of not being able to intubate. In the events falling under the problem of not being able to intubate, there was never a patient problem because in all cases a back-up device was used which ensured successful intubation. The events wherein a back-up device was used but the intubation was not successful leading to patient harm, therefore belong to the patient problems. An overview of the method is depicted in figure 6.

A scoping review was deemed most appropriate for this literature study. Therefore, the reporting guidelines of the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) extension for Scoping Reviews were followed [25]. First, the method of searching and analyzing the most used end-points will be highlighted, followed by that

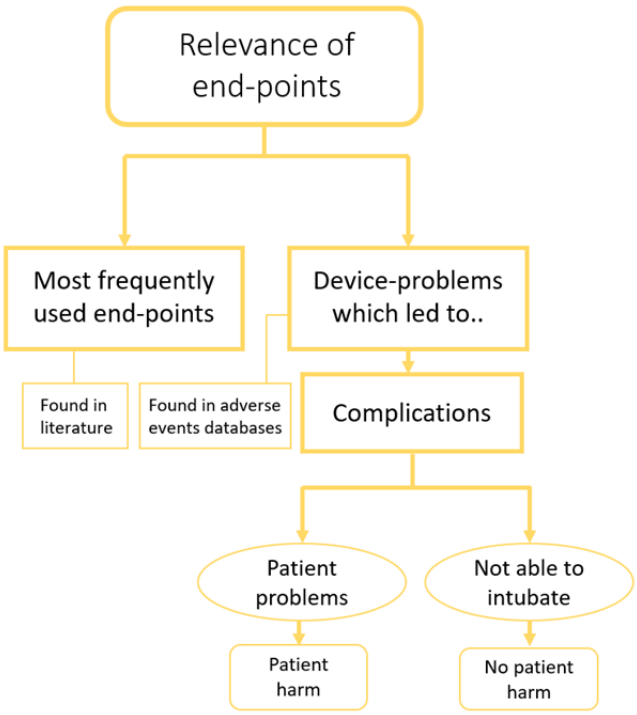


Fig. 6. Overview of the method used

of the adverse events data search to obtain device problems that led to complications. Lastly, the method of linking the device problems to the end-points will be elaborated.

A. End-points

1) Data sources and search strategy: The search strategy used to find studies in which end-points were used for the validation of videolaryngoscopes in a manikin study was twofold. On the one hand, terms describing videolaryngoscopes were used and on the other hand, terms describing manikin studies were used. Only those studies describing both themes were eventually included for analysis. The bibliographic databases that were searched to identify the potentially relevant studies were MEDLINE and SCOPUS, with a publication range of the last ten years. Search terms were identified through an iterative process of scanning reviews with a similar topic for synonyms for videolaryngoscopes and manikin studies and evaluating them with both supervisors. The final search strings that were inserted in MEDLINE and SCOPUS consisted of different keywords describing all synonyms and can be found in table II in Appendix A. The search string inserted in MEDLINE contained an additional Medical Subject Headings (Mesh) term. The search results were exported to Mendeley Reference Manager and duplicates were removed. Subsequently, the titles, abstracts and full-texts of the studies were sequentially screened for potential exclusion.

2) Eligibility criteria: To be included in the review, studies needed to fulfill certain requirements. The goal of the study had to be the validation of a videolaryngoscope and it had to be performed on a pediatric or adult manikin. Therefore, studies were only included if the terms videolaryngoscope and manikin were included in the title or abstract. Studies containing synonyms of these words were also included as can be seen in Appendix A. Moreover, the date of publication had to be in the last ten years, the full-text had to be available and written in English. No selection was made based on the income level of the country where the study was conducted. Therefore, all studies conducted in high-, middle- and low-income countries were included. Furthermore, both studies performed in and out-of-hospital settings were included. Lastly, in the SCOPUS database, studies were only included if they fell within the subject areas of medicine, nursing and/or health professions. Studies were excluded if the goal of the study was different from the validation of videolaryngoscopes, the validation was not performed by using a manikin, if a neonatal manikin was used and if no clear end-points were stated in the study.

3) Data extraction: The data that was extracted from the included studies was charted in a Microsoft 365 Excel sheet. The data was sorted by the title, author, practitioner experience and the end-points used. The end-points were extracted from the full-text of the included studies.

4) Data analysis and synthesis: The extracted end-points were interpreted and sorted within eight subject groups including *Time, View, Intubation Success, Number of Attempts, Device Use, Monitoring, Force* and *Operator Variables*. The incidence of the end-points in every subject group was counted and a graph of the results was presented. In addition, the incidence of each end-point in the included studies was counted and the results were presented in a graph.

B. Complications

As mentioned above, the search for the most harmful device problems which led to complications was twofold because complications exist of two different problems. The first being the patient problems that led to patient harm and the second being the problem of not being able to intubate that did not lead to patient harm. The device problems were obtained by extracting events in which patient problems or the problem of not being able to intubate occurred. This enabled the identification of both the device problems that caused a patient problem and the problem of not being able to intubate.

1) Data sources and search strategy: Two different databases were used to search for the patient problems and the problem of not being able to intubate which had occurred while using a (video)laryngoscope. These included the Total Product Life Cycle (TPLC) database of the U.S. Food and Drug Administration (FDA) and the Database of Adverse Event Notifications (DAEN) - medical devices of the Australian Therapeutic Goods Administration (TGA). For both databases, a rigid laryngoscope was used as the medical device search term and a date range of the last ten years was applied.

2) Eligibility criteria: For the selection of patient problems, data was only included if a patient problem was stated. Therefore, events from the TPLC database with a

patient problem which was described as *No Consequences Or Impact To Patient, No Known Impact Or Consequence To Patient, No Patient Involvement, No Clinical Signs, Symptoms Or Conditions, Insufficient Information, No Information* or *Missing Value Reason* were excluded. Events from the DAEN with a patient problem that was described as *No Injury* were also excluded.

For the selection of the problem *Not able to Intubate*, data from the TPLC database was included if the patient problem was described as *No Consequences Or Impact To Patient, No Known Impact Or Consequence To Patient, No Clinical Signs, Symptoms or Conditions, Insufficient Information* or *No Information*. Data from the DAEN was included if the patient problem was described as *No Injury*. If the inability to intubate had caused patient harm, the data would be included in the first data set.

3) Data extraction: Both data sets extracted from the databases were charted in a Microsoft 365 Excel sheet. All events were automatically sorted by report number, event date, event type, manufacturer, date received, brand name, device problem, patient problem and event text (describing how the patient problem arose).

For the data set in which events were included wherein patient problems were stated, the event text was read and interpreted for correlation between the device and patient problem(s). If it was concluded that the patient problem was caused by the device problem(s), the event was selected for analysis. Furthermore, if multiple patient problems were reported in the same event, they were included separately. Additionally, if multiple device problems were reported in the same event, the event text was read and the most applicable device problem was chosen. So, the data was interpreted in such a way that every single patient problem reported in an event was linked to one specific device problem, such that the data could be handled and summarised.

For the data set in which events were included wherein no patient problem was reported, the events in which intubation was not possible and therefore a back-up device had to be used were selected for analysis. The excel 'find and replace' dialogue box was used to identify these events by searching for the following words in sequence: backup, back up, back-up, delay, a different, another, 2nd, second, new device, direct, add'l, tracheotomy, spare and replacing. So, event texts containing one or more of these search terms were read to verify if the problem of *Not able to Intubate* had occurred. If so, the event was selected for analysis and duplicates were removed.

4) Data analysis and synthesis: From the point when the extracted data was analysed, the two data sets as described in the previous step were merged and the problem *Not able to Intubate* was handled equally to the separate patient problems, from here together referred to as complications. The incidence of all complications in the extracted data was counted and the results were plotted in a graph. In addition, for each complication was counted which device problems and how often these device problems caused that particular complication. The results were presented in a graph for each complication separately. To identify the most harmful device problems, not only the most common ones were investigated, but the severity of the complications caused by the device problems was also examined. To determine the severity, each complication was graded by the Clavien-Dindo Classification of Surgical Complications [54]. The grades were defined as follows:

- Grade I: Any deviation from the normal postoperative course without the need for pharmacological treatment orsurgical, endoscopic, and radiological interventions.
- Grade II: Requiring pharmacological treatment with drugs other than such allowed for grade I complications.
- Grade III: Requiring surgical, endoscopic or radiological intervention.
- Grade IV: Life-threatening complication requiring IC/ICU management.
- Grade V: Death of a patient.

The grades of each complication, together with their incidence, were shown in a graph. Subsequently, the device problems leading to these complications were given a score to define their harmfulness. This 'score of harmfulness' of each device problem was calculated as follows:

Score of harmfulness =SUM (Incidence of device problem X Clavien-Dindo grade of complication)

So, the incidence of a device problem leading to a complication was multiplied by the Clavien-Dindo grade of that complication. Thereafter, all multiplied scores of that device problem that led to different complications were summed up. The 'score of harmfulness' of each device problem was illustrated in a graph.

C. Linking the end-points to the device problems

Because the goal of this study was to gather, analyse and select the most relevant end-points used to validate videolaryngoscopes in manikin studies, the device problems were linked to the end-points found in the literature. To link these two, the device problems were first divided into three categories according to whether the risk of this device problem is assessed in the design process or has to be assessed by a manikin study. The three categories were defined as follows:

- *Risk of device problem assessed in ISO standards*: Included all device problems for which the risk is reduced because of the ISO standards each newly developed videolaryngoscope has to comply with. These standards set out requirements that the videolaryngoscope must fulfil before it can be put on the market. Because of these requirements, tests must be carried out to prove that the device complies and is technically safe. All the device problems within this category are assessed by ISO 60601 and ISO 7376.
- *Risk of device problem assessed with manikin study*: Included all device problems which are not assessed by

an ISO standard and therefore must be assessed with a manikin study.
- *Insufficient information*: Included the device problems for which insufficient information was available to classify them into one of the above categories.

Only those device problems whose risk has to be assessed by a manikin study were linked to the end-points. To make this translation step, it was considered for each device problem which combination of three end-points, from the list of end-points found in literature, would best identify this device problem in a manikin study. Subsequently, each chosen end-point was given the 'score of harmfulness' of the device problem it could identify. The selected end-points and their composite scores of all the device problems they identify were stated in a table.

V. Results

A. End-points

1) Selection of sources of evidence: A total of 482 articles were identified through searching the MEDLINE and SCOPUS databases. After duplicates were removed, 312 articles were screened by title and abstract. As a result, 126 articles were excluded and the remaining 186 full-text articles were assessed for eligibility. Another 15 articles were excluded after reading the full-text. The remaining 171 articles were included for analysis. Thereafter, no more articles were excluded. The PRISMA flow diagram illustrates the steps described above and can be found in Appendix B.

2) Analysis: In total, 47 different end-points were used in the 171 investigated studies and all were divided over the subject groups: *Time, View, Intubation Success, Number of Attempts, Device Use, Monitoring, Force* and *Operator Variables*. The incidence of the end-points within these subject groups is shown in figure 7.

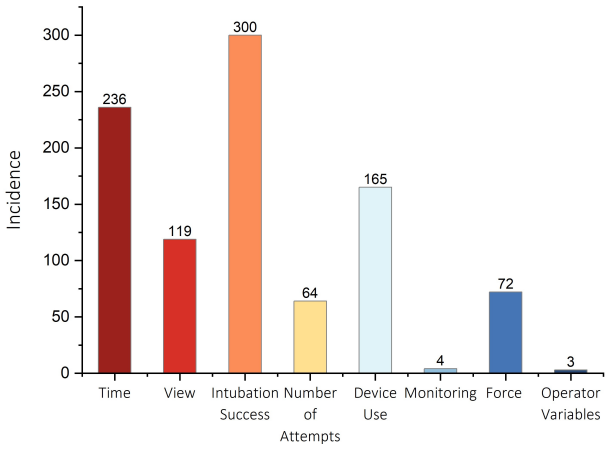


Fig. 7. Incidence of end-points within subject groups

The incidence of the 47 different end-points is presented in the graph illustrated in figure 8. The graph depicted shows the ratio between the incidence of each end-point and the total number of studies analysed. The five most frequently reported end-points were found to be: *Successfull intubation rate 75,4% (n=129), Time to intubation 50,9% (n=87), Time to ventilation 50,3% (n=86), Laryngeal view grade (CL) 47,4% (n=81)* and *Number of intubation attempts 37,4% (n=64)*. An explanation of all end-points and their corresponding frequency rates and numbers can be found in table III in Appendix C.

B. Complications

1) Selection of sources of evidence: For the selection of device problems that resulted in patient problems, a total of 263 events were identified through searching the TPLC (n=237) and DAEN (n=26) databases. After screening the event texts for correlation between the device and patient problem, 211 events were included for analysis. For the selection of device problems that resulted in the problem of not being able to intubate a total of 1608 events were identified through searching the TPLC (n=1589) and DAEN (n=19) databases. After searching the events in which a back-up device was used and reading the event texts to confirm that the problem *Not able to Intubate* had occurred, 223 events were included for analysis.

2) Analysis: The complications, directly resulting from a laryngoscopy-related device problem, and their rates of occurrence are summarised in figure 9. The five most frequently reported complications were found to be: *Not able to Intubate (n=223), Death (n=25), Foreign Body in Patient (n=24), Laceration(s) (n=24)* and *Low Oxygen Saturation (n=24)*. All the device problems that led to the complications were plotted and shown in Appendix D. In figure 10, the Clavien-Dindo classification grade and the incidence of each complication is depicted. In this graph, green represents low impact and low incidence while red represents high impact and high incidence.

Subsequently, all device problems leading to these patient problems were given a score to define their harmfulness. This 'score of harmfulness' was calculated by multiplying the incidence of a device problem leading to a complication by the Clavien-Dindo score of that complication and adding up these multiplied scores of a device problem. The scores of all device problems are illustrated in figure 11. A higher score indicates a more harmful device problem.

C. Linking the end-points to the device problems

As depicted in figure 11, all device problems were divided into three categories to determine which device problems were relevant to measure in a manikin study. The device problems *Difficult to Advance, Poor Glottic View, Intubation Difficulty, Optical Obstruction, Inadequacy of Device Shape and/or Size* and *High Resistance* were included in the category *Risk of device problem assessed with manikin study*. These six end-points were each linked to three end-points that would best identify the device problem in a manikin study. Every end-point to which a device problem was linked was given the 'score of harmfulness' of that device problem. An overview of the selected end-points and their composite score of all the 'scores of harmfulness' of the device problems they identify is shown in table I.

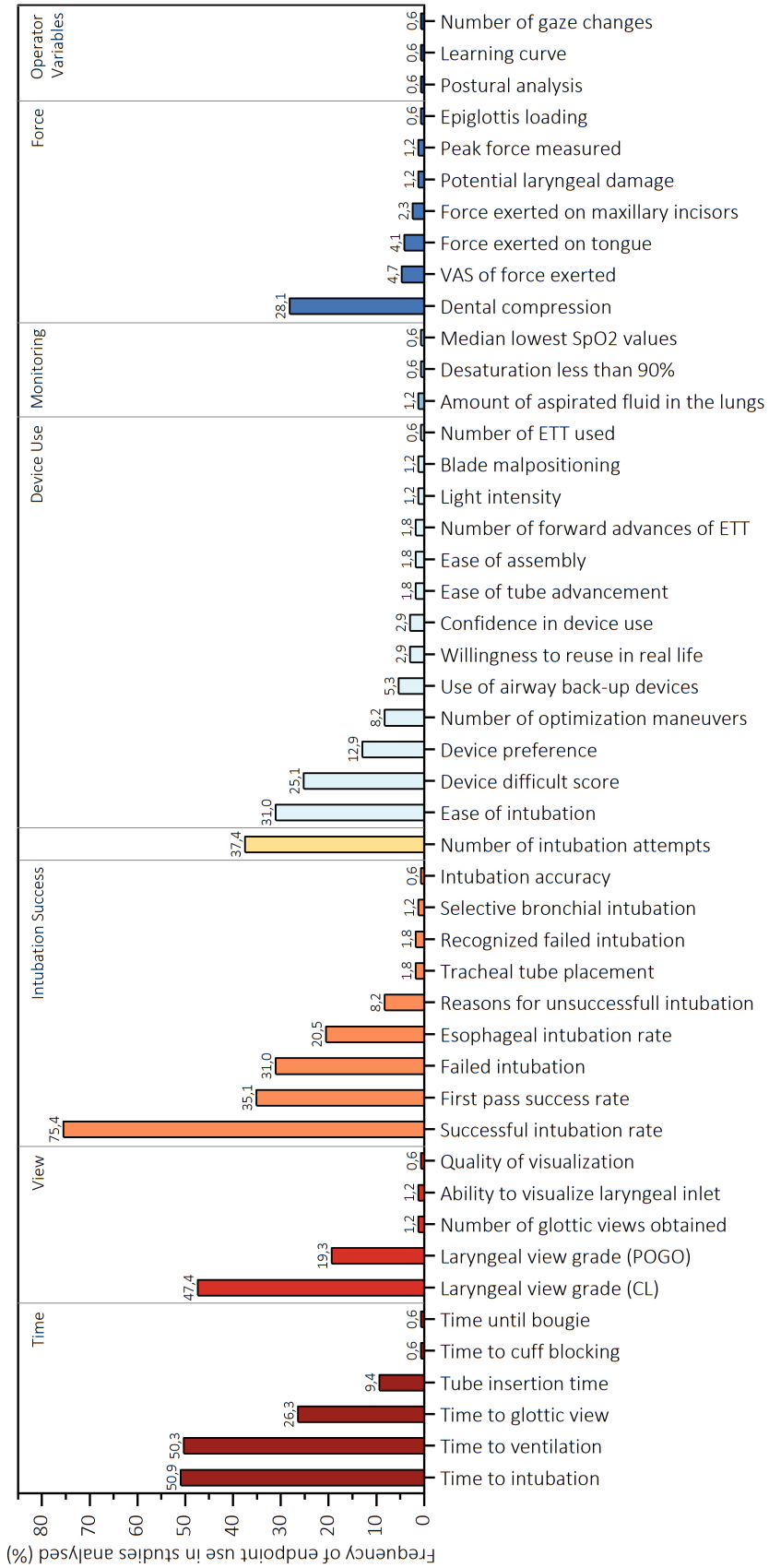


Fig. 8. Incidence of end-points in studies analysed

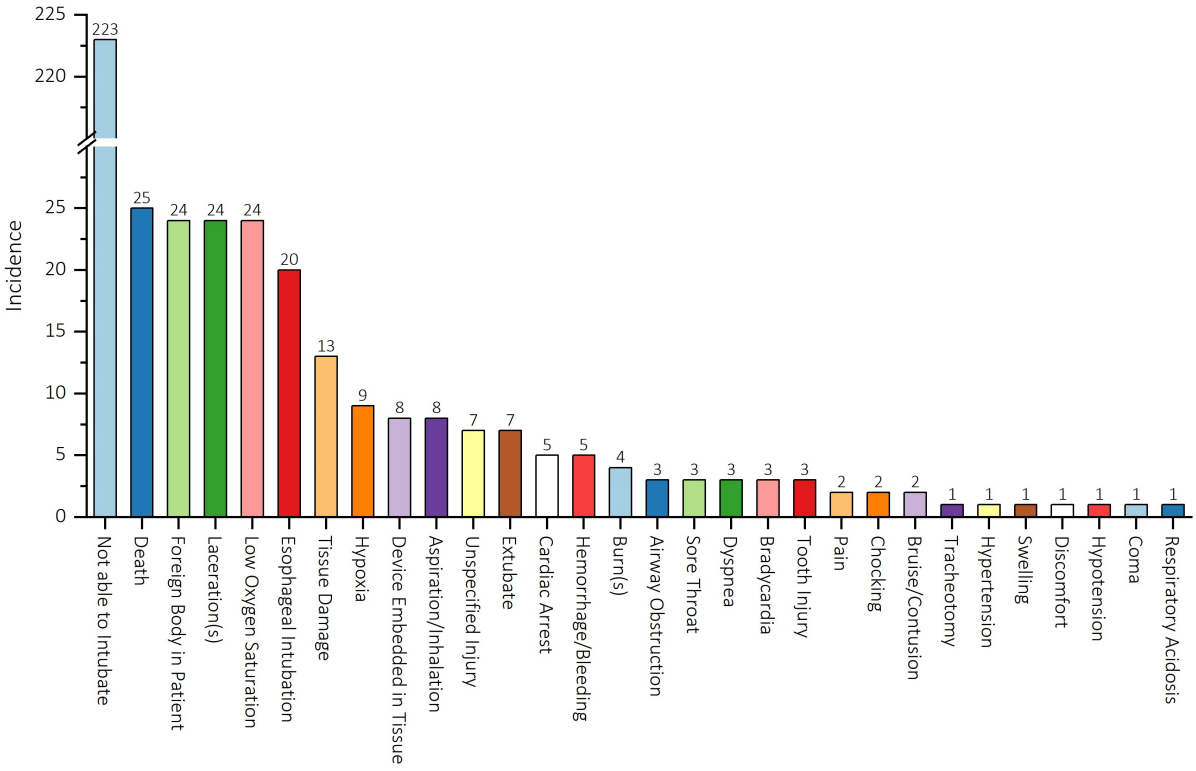


Fig. 9. Incidence of complications

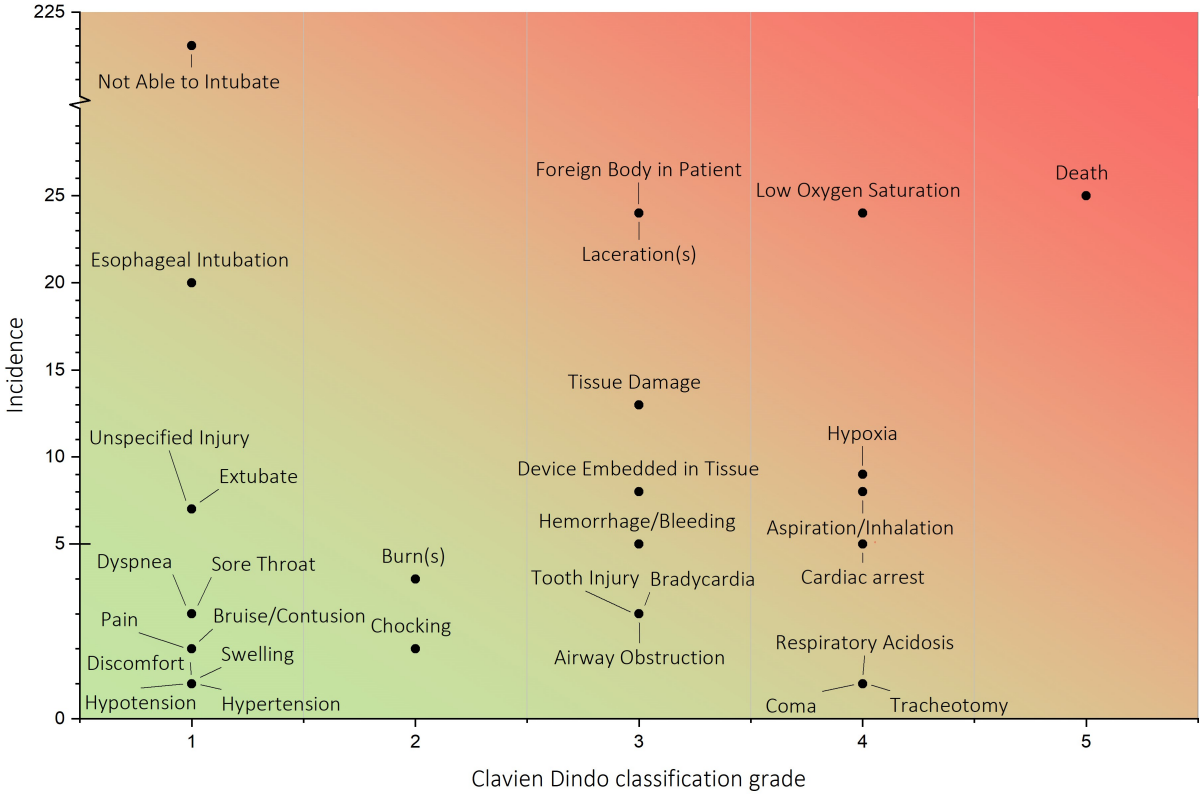


Fig. 10. Clavien-Dindo classification grade vs. Incidence

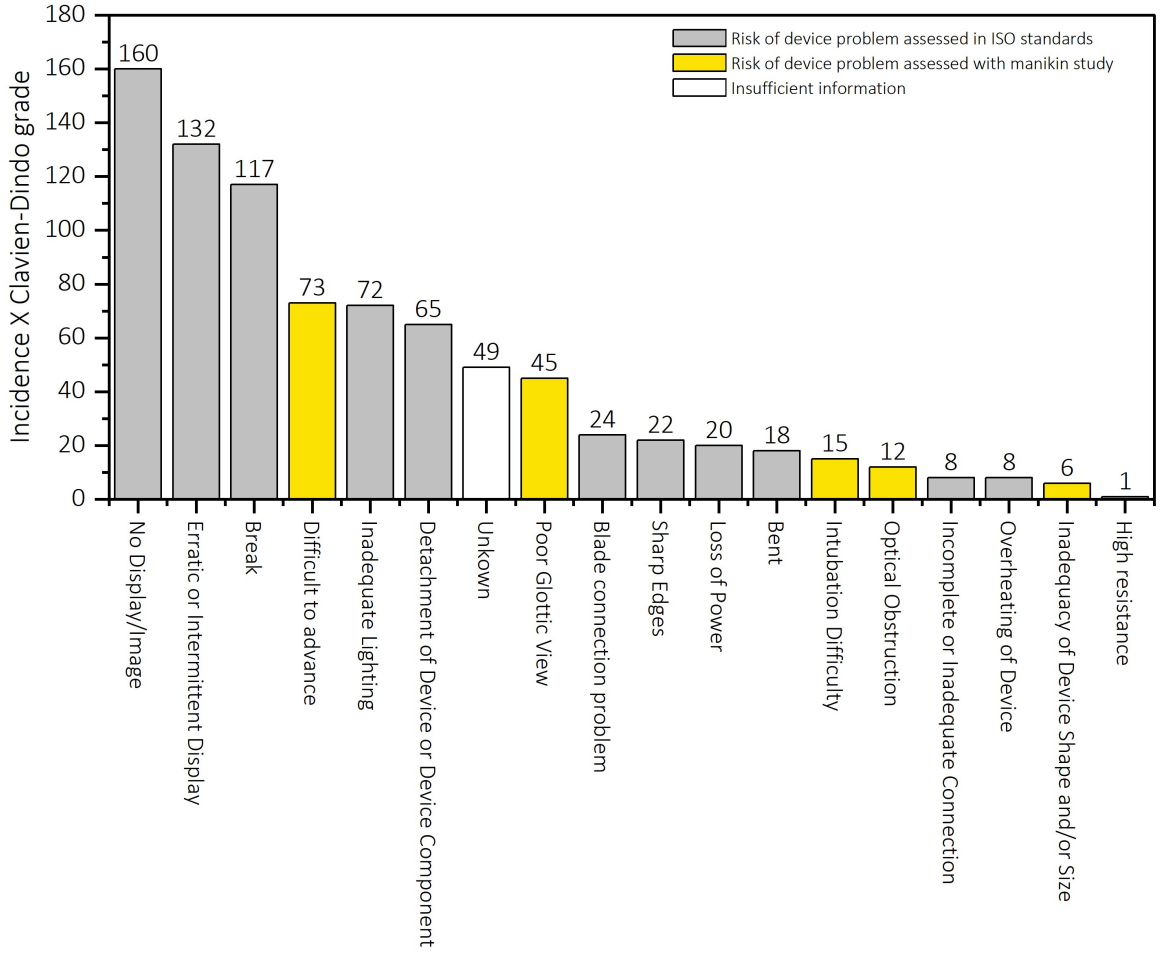


Fig. 11. 'Score of harmfulness' of device problems

TABLE I

END-POINTS WHICH BEST IDENTIFY THE DEVICE PROBLEMS

	Difficult to advance	Poor Glottic View	Intubation Difficulty	Optical Obstruction	Inadequacy of Device Shape and/or Size	High resistance	TOTAL
Time to intubation / ventilation	73		15	12			100
Number of intubation attempts	73		15			1	89
Ease of intubation	73		15			1	89
Successful intubation rate		45		12	6		63
Laryngeal view grade (CL) / (POGO)		45		12	6		63
Time to glottic view		45					45
Device difficult score					6		6
Potential laryngeal damage						1	1

VI. Discussion

A. Summary of evidence

The aim of this study was to gather, analyse and select the most relevant end-points used to validate videolaryngoscopes in manikin studies published over the last ten years. As explained, the relevance of the end-points was determined by two factors: the incidence of the end-points in the studies analysed and the number of device problems the end-points could identify. Incidence was chosen as a factor because standardised definitions of end-points and consistent use can contribute to increasing the value of research [20]. Thus, the more often an end-point is used in similar studies, the more relevant the end-point is. However, it has been shown that the most used end-points have not always been the most relevant for patients [55]. Therefore, the number of device problems the end-points could identify was used as a second factor. By identifying the device-related problems for the most common complications and translating these into the end-points, the relevance to the patient was included. To combine these two factors, the six device problems which were included in the category *Risk of device problem assessed with manikin study* were linked to the end-points found in literature, as shown in table I. Ten of the 47 end-points found in the analysed studies were linked to the six device problems. Of the ten end-points, both *Time to intubation* and *Time to ventilation* as well as *Laryngeal view grade (CL)* and *Laryngeal view grade (POGO)* were linked to the device problems as a pair because of their similarity. Depending on the number of device problems that could be identified with an end-point and the total score and incidence of the end-point, it was decided which end-points are most relevant and will be recommended for use in future manikin studies wherein videolaryngoscopes are validated:

- **Time to intubation/ventilation**: *Time to intubation* and *Time to ventilation* were used in 50,9% and 50,3% of the analysed studies, respectively. Both end-points could identify three device problems with a total score of 100. So, the relevance of both end-points is plausible. Additionally, although both parameters are very similar, they provide different insights. Because of this and the similar incidence of both end-points, it was decided to recommend both end-points for use in future manikin studies.
- **Number of intubation attempts** and **Ease of intubation**: *Number of intubation attempts* and *Ease of intubation* were used in 37,4% and 31% of the analysed studies, respectively. Both end-points could identify three device problems with a total score of 89. Because of their relatively high incidence and their high score and amount of device problems they could identify, both *Number of intubation attempts* and *Ease of intubation* will be recommended for use in future manikin studies.
- **Successful intubation rate**: This end-point was used in 75,4% of the analysed studies and it was considered that it could identify three device problems with a total score of 63. Therefore, *Successful intubation rate* will be recommended for future manikin studies.
- **Laryngeal view grade (CL)/(POGO)**: *Laryngeal view grade (CL)* and *Laryngeal view grade (POGO)* were used in 47,4% and 19,3% of the analysed studies, respectively. Although it was considered that with both end-points three device problems could be identified with a total score of 63, *Laryngeal view grade (CL)* was used more often and was therefore recommended for use in future manikin studies. Moreover, unlike *Time to intubate* and *Time to ventilate*, *Laryngeal view grade (CL)* and *Laryngeal view grade (POGO)* do not have added value to be measured separately as they hardly provide any different insights because they measure the same thing.
- **Time to glottic view**: Although *Time to glottic view* was used in 26,3% of the analysed studies it was decided not to recommend this end-point for use in future manikin studies because it could only identify one device problem with a total score of 45. Moreover, the effect of a deviation in *Time to glottic view* could be measured in the end-points *Time to intubation/ventilation* which are both recommended to be used in future studies.
- **Device difficult score**: This end-point was used in 25,1% of the analysed studies and it was considered that it could only identify one device problem with a total score of 6. As *Ease of intubation* quantifies the difficulty of intubation, the *Device difficult score* will be partly included in this end-point because a malfunctioning laryngoscope will make intubation more difficult. Because this end-point is measured in a smaller number of studies and it is expected that the *Device difficult score* will partly be reflected in *Ease of intubation*, it was decided not to recommend this end-point for use in future manikin studies.
- **Potential laryngeal damage**: This end-point was only used in 1,2% of the analysed studies. Moreover, it could only identify one end-point with a total score of 1. Because of the relatively low incidence, total score, and amount of device problems this end-point could identify, it was decided not to recommend this end-point for use in future manikin studies.

B. Previous research

As previously indicated, Hinkelbein et al. established a core outcome set (COS) that should be reported in future videolaryngoscopy studies, which was partly based on clinical trials [21]. According to the Core Outcome Measures in Effectiveness Trials (COMET) Initiative, a COS is defined as "an agreed standardised set of outcomes that should be measured and reported, as a minimum, in all clinical trials in specific areas of health or health care" [56]. Because the current literature review also aims to define a minimum set of outcomes that should be measured and reported, it will be compared to the study of Hinkelbein et al. While the current literature review identified 47 different end-points from the

171 studies analysed, Hinkelbein et al. identified 49 different end-points from the 372 studies analysed.

According to Hinkelbein et al., the five end-points with the highest incidence in studies analysed were *Time to intubation (65.86%), Laryngeal view grade (44.89%), Successful intubation rate (36.56%), Number of intubation attempts (23.39%)* and *Complications (21.24%)*. This is partly consistent with the five most-used end-points identified in the current literature review. Remarkably, *Time to intubation* had a 15% higher incidence compared to this review. This can be explained by the fact that Hinkelbein et al. made no distinction between different time-frames which were used to measure *Time to intubation*. This review did make a distinction: *Time to intubation*, in which the time is measured until the ETT passes the vocal cords, and *Time to ventilation*, in which the time is measured until ventilation is confirmed. Moreover, Hinkelbein et al. made no distinction between *Laryngeal view grade (POGO)* and *(CL)*. However, the incidence of *Laryngeal view grade CL and/or POGO*, reported by Hinkelbein et al., was very similar to that of *Laryngeal view grade (CL)*, around 45%. For both *Successful intubation rate* and *Number of intubation attempts*, incidence rates were reported in the current review. However, the subject group and end-point *Complications* reported by Hinkelbein et al. was not used in the studies analysed in the current review. Furthermore, seven different strength-related end-points were reported in the studies analysed in the current review but only two of these were reported in the studies analysed by Hinkelbein et al. These differences can be explained by the different types of studies analysed in both reviews. In the current review, only manikin studies were analysed and therefore the end-points were more focused on the functioning of the device. Contrarily, in the review by Hinkelbein et al. patients were involved in the analysed studies resulting in more patient-related end-points.

Next to the reported incidence of the end-points identified by Hinkelbein et al., a different approach was used by them to obtain the most relevant end-points. Instead of searching the most harmful device problems, Hinkelbein et al. used the Delphi system to reach consensus on which six end-points were most important to the patient, according to experts, and therefore should be used in future studies. Remarkably, none of the five end-points Hinkelbein et al. identified as having the highest incidence were recognised by the Delphi-system as having the highest relevance to the patient. Of the six end-points which were selected through the Delphi-system, *Time to glottis view* and *Ease of intubation* could identify several device problems in the current study.

Lastly, Hinkelbein et al. suggested that 12 end-points should be used in future videolaryngoscopy studies. These existed of six end-points with the highest incidence and six end-points with the highest relevance to the patient. In the current review only six end-points are suggested to be used in future manikin studies. This difference can be explained by the fact that it seems that Hinkelbein et al. only considered end-points in the Delphi-system that had not yet been included in the six end-points with the highest incidence. In other words, these 12 proposed end-points either had a high incidence or were considered to be of utmost importance to the patient, but none of them was chosen because they possessed both factors. In the current review, only those end-points that had both a high incidence and could identify multiple device problems were recommended for future manikin studies. Despite the differences described above, five of the six recommended end-points in this study are also included in the 12 end-points recommended by Hinkelbein et al.

C. Limitations

An overview of the most relevant end-points used in previous manikin studies is provided in this review. However, the limitations of this review should be mentioned.

1) End-points: Of the 482 studies identified through searching the MEDLINE and SCOPUS databases, only 171 were analysed due to the eligibility criteria applied. Furthermore, the end-points extracted from the analysed studies often had varying or unclear definitions. As a result, the definition of the end-points in question had to be interpreted to include them. This may have led to misinterpretations and end-points being wrongly counted. Another limitation is that only those studies in which a videolaryngoscope was validated were analysed. Therefore, end-points that were used to validate direct laryngoscopes may not have been included but could have been valuable. However, some studies comparing videolaryngoscopes with direct laryngoscopes were included.

2) Complications: All complications were extracted from two databases (TPLC and DEAN) which only covered adverse events that had occurred in the U.S.A. and Australia. As the end-points were taken from studies conducted all over the world, the complications may not reflect the relevance of these end-points because they only occurred in two countries. Moreover, complications related to both direct and videolaryngoscopes were included because the databases made no distinction between them. However, the majority of complications were caused by device problems from videolaryngoscopes as can be seen by the type of device problems that were common: *No Display/Image* and *Erratic or Intermittent Display*. This can be explained by the fact that problems occurring with a direct laryngoscope are less often reported as device problems because the cause is less obvious. For example, if a poor glottic view is obtained with a direct laryngoscope, the cause is not a device problem but rather the suitability of the device for the specific patient or procedure. However, since there is no device problem, it will not be reported. This may cause the amount and types of reported patient problems to be distorted.

Another limitation is the misinterpretation of the event texts of the patient problems, which may have caused wrong decisions regarding the correlation between the device and patient problems, and choosing the most appropriate device problem if several were reported. In addition, if multiple patient problems were reported in the same event, they were included separately. However, this implies that a device problem that led to multiple patient problems was included

several times, namely once for each patient problem. This may have led to distorted results. Moreover, one of the patient problems may have been the cause of another patient problem instead of the device problem, which may also have distorted the results. Surprisingly, looking at the results, severe complications seem to occur more often than lighter complications. For example, *Death* is the most common patient problem while *Sore Throat* or *Tooth Injury* are the least common ones. These results are in contrast with the literature wherein the most common patient problems resulting from VL are found to be: injury to the soft palate, teeth, larynx, tongue and retromolar trigone [57]. This contradiction can be explained by the fact that severe patient problems may be often reported by doctors, while for less severe patient problems the effort to report is not always made. This too could have led to biased results.

Furthermore, a maximum of 500 adverse events per complication could be extracted from the TPLC database. Therefore, not all events of the complications *No Consequences Or Impact To Patient, No Known Impact Or Consequence To Patient* and *No Clinical Signs, Symptoms or Conditions* were included for analysis. Using the 'find and replace' dialogue box in excel to identify the events in which the problem *Not able to Intubate* had occurred is another limitation. By using the dialogue box to make a selection of the events for which the event texts were read rather than reading every event text, it is possible that some of these events were incorrectly excluded. Besides, by reading the event texts and using these texts to decide whether the problem *Not able to Intubate* had occurred, misinterpretations may have been made resulting in events being wrongly selected or excluded before analysis. Moreover, the problem *Not able to Intubate* was classified in the first grade of the Clavian-Dindo classification because no patient problem had occurred. However, if a back-up device could not have been used, or not quickly enough, this problem could have led to serious complications. Nevertheless, because the problem *Not able to Intubate* has a high incidence, the device problems that led to this problem have been given a relatively high 'score of harmfulness'.

3) Linking the end-points to the device problems: Three device problems in the category *Risk of device problem assessed in ISO standards* were also the three device problems with the highest 'score of harmfulness'. However, due to the category they were divided in, they were not linked with the end-points found. Because the risk of these end-points will not be assessed within a manikin study, it is strongly recommended that any newly developed videolaryngoscope should at least meet the ISO 60601 and 7376 standards.

The device problems in the category *Risk of device problem assessed with manikin study* were all linked to the three end-points that together could most comprehensively map this device problem. However, this step is subjective and could therefore have led to biased results. Moreover, less specific end-points (such as *Time to intubation* or *Ease of intubation*) were chosen more frequently because specific end-points (such as *Light intensity* or *Selective bronchial intubation*) were less likely to be able to identify part of a problem. Therefore, of the 47 end-points, only ten different end-points were linked to the device problems. As a result, six end-points were recommended for future manikin studies. This small number simplifies the measurement of all six end-points in future manikin studies.

VII. Conclusion

Even though a great number of manikin studies have been conducted in the field of VL, the quality of these studies is questionable. The low amount of participants, large variety in end-points and the lack of standardised definitions used in these studies makes it hard to find relevant and comparable results [18]. Therefore, this review aimed to gather, analyse and select the most relevant end-points used to validate videolaryngoscopes in manikin studies published over the last ten years. The end-points which are considered most relevant and therefore will be recommended for use in future manikin studies are: *Time to intubation, Time to ventilation, Successful intubation rate, Number of intubation attempts, Laryngeal view grade (CL)* and *Ease of intubation*. These end-points were selected based on their high incidence as well as relevance to the patient. Because standardised definitions of end-points and consistent use can contribute to increasing the value of research, the use of these end-points is strongly recommended for those performing a manikin study in the field of VL [20].

REFERENCES

[1] J. H. Schiff and S. Wagner, "Anesthesia related mortality? a national and international overview," *Trends in Anaesthesia and Critical Care*, vol. 9, pp. 43–48, 9 2016.

[2] W. Pignaton, J. R. C. Braz, P. S. Kusano, M. P. Módolo, L. R. D. Carvalho, M. G. Braz, and L. G. Braz, "Perioperative and anesthesia-related mortality: An 8-year observational survey from a tertiary teaching hospital," *Medicine (United States)*, vol. 95, 1 2016.

[3] . D. J. Bainbridge, M. Pharmd, M. Arango, D. Bainbridge, J. Martin, M. Arango, and D. Cheng, "Perioperative and anaesthetic-related mortality in developed and developing countries: a systematic review and meta-analysis," 2012.

[4] A. Gottschalk, H. V. Aken, M. Zenz, and T. Standl, "Ist anästhesie gefährlich?," *Deutsches Arzteblatt*, vol. 108, pp. 469–474, 7 2011.

[5] F. N. B. Pascal, A. Malisawa, A. Barratt-Due, F. Namboya, and G. Pollach, "General anaesthesia related mortality in a limited resource settings region: a retrospective study in two teaching hospitals of butembo," *BMC Anesthesiology*, vol. 21, 12 2021.

[6] T. M. Cook, "Strategies for the prevention of airway complications – a narrative review," *Anaesthesia*, vol. 73, pp. 93–111, 1 2018.

[7] F. A. Khan and A. F. Merry, "Improving anesthesia safety in low-resource settings," *Anesthesia and Analgesia*, vol. 126, pp. 1312–1320, 4 2018.

[8] T. M. Cook, N. Woodall, and C. Frerk, "Major complications of airway management in the uk: Results of the fourth national audit project of the royal college of anaesthetists and the difficult airway society. part 1: Anaesthesia," *British Journal of Anaesthesia*, vol. 106, pp. 617–631, 2011.

[9] C. J. Peden, M. Campbell, and G. Aggarwal, "Quality, safety, and outcomes in anaesthesia: What's to be done? an international perspective," *British Journal of Anaesthesia*, vol. 119, pp. i5–i14, 12 2017.

[10] I. A. Walker, T. Bashford, J. E. Fitzgerald, and I. H. Wilson, "Improving anesthesia safety in low-income regions of the world," *Current Anesthesiology Reports*, vol. 4, pp. 90–99, 6 2014.

[11] S. K. R. P. A. K. Jr, *Definition and Incidence of the Difficult Airway*, pp. 201–208. Elsevier Health, third ed., 2013.

[12] A. F. McNarry and A. Patel, "The evolution of airway management-new concepts and conflicts with traditional practice," *British Journal of Anaesthesia*, vol. 119, pp. i154–i166, 12 2017.

[13] T. E. J. Healy and P. R. Knight, *A practice of anesthesia*, ch. 28. Taylor&Francis Group, 2003.

[14] E. D. Schmitz, "airod-case-series-a-new-bougie-for-endotracheal-intubation," *iMedPubJournals*, vol. 5, 5 2020.

[15] M. Lauren C Berkow, "Airway management for induction of general anesthesia," 10 2021.

[16] J. V. Divatia and K. Bhowmick, "Officer-in-charge," *INDIAN JOURNAL OF ANAESTHESIA*, vol. 49, pp. 308–318, 2005.

[17] P. A. Baker and A. Timmermann, "Indications for endotracheal intubation," in *Benumof and Hagberg's Airway Management*, pp. 340–345, Elsevier Inc, thrid ed., 2013.

[18] J. Hinkelbein, R. Greif, P. Diemunsch, and P. Kranke, "Publication and innovation in airway management: Quality not quantity!," *European Journal of Anaesthesiology*, vol. 34, pp. 408–410, 7 2017.

[19] J. P. Ioannidis, "How to make more published research true," *PLoS Medicine*, vol. 11, 2014.

[20] P. S. Myles, M. P. Grocott, O. Boney, S. R. Moonesinghe, B. Biccard, M. Chan, L. Fleisher, C. Kalkman, A. Kurz, and D. Wijeysundera, "Standardizing end points in perioperative trials: Towards a core and extended outcome set," *British Journal of Anaesthesia*, vol. 116, pp. 586–589, 5 2016.

[21] J. Hinkelbein, I. Iovino, E. D. Robertis, and P. Kranke, "Outcomes in video laryngoscopy studies from 2007 to 2017: Systematic review and analysis of primary and secondary endpoints for a core set of outcomes in video laryngoscopy research," *BMC Anesthesiology*, vol. 19, 4 2019.

[22] M. R. Rai and M. T. Popat, "Evaluation of airway equipment: Man or manikin?," *Anaesthesia*, vol. 66, pp. 1–3, 1 2011.

[23] A. D. Luca, F. S. Sall, R. Sailley, G. Capellier, and A. Khoury, "Reliability of manikin-based studies: An evaluation of manikin characteristics and their impact on measurements of ventilatory variables," *Anaesthesia*, vol. 70, pp. 915–921, 8 2015.

[24] Z. Munn, M. D. Peters, C. Stern, C. Tufanaru, A. McArthur, and E. Aromataris, "Systematic review or scoping review? guidance for authors when choosing between a systematic or scoping review approach," *BMC Medical Research Methodology*, vol. 18, 11 2018.

[25] A. C. Tricco, E. Lillie, W. Zarin, K. K. O'Brien, H. Colquhoun, D. Levac, D. Moher, M. D. Peters, T. Horsley, L. Weeks, S. Hempel, E. A. Akl, C. Chang, J. McGowan, L. Stewart, L. Hartling, A. Aldcroft, M. G. Wilson, C. Garritty, S. Lewin, C. M. Godfrey, M. T. MacDonald, E. V. Langlois, K. Soares-Weiser, J. Moriarty, T. Clifford, Özge Tunçalp, and S. E. Straus, "Prisma extension for scoping reviews (prisma-scr): Checklist and explanation," *Annals of Internal Medicine*, vol. 169, pp. 467–473, 10 2018.

[26] V. Kumar, S. K. Angurana, A. K. Baranwal, and K. Nallasamy, "Nasotracheal vs. orotracheal intubation and post-extubation airway obstruction in critically ill children: An open-label randomized controlled trial," *Frontiers in Pediatrics*, vol. 9, 9 2021.

[27] S. R. Collins, "Direct and indirect laryngoscopy: Equipment and techniques," *Respiratory Care*, vol. 59, pp. 850–864, 2014.

[28] A. C. Alvarado, "Endotracheal tube intubation techniques," 7 2021.

[29] J. Berry and S. Harvey, *Laryngoscopic Orotracheal and Nasotracheal Intubation*, pp. 346–358.e1. Elsevier Inc., Sept. 2012.

[30] A. Patel and M. Gilhooly, "Preoxygenation and apneic oxygenation for airway management for anesthesia," 10 2021.

[31] C. Groombridge, C. W. Chin, B. Hanrahan, A. Holdgate, and R. Reardon, "Assessment of common preoxygenation strategies outside of the operating room environment," *Academic Emergency Medicine*, vol. 23, pp. 342–346, 3 2016.

[32] "Laryngeal function and pronunciation," 10 2021.

[33] R. M. Levitan and C. A. Hagberg, *Upper Airway Retraction: New and Old Laryngoscope Blades*. Elsevier Inc., 3 ed., 2013.

[34] S. S. Faiss KR, Naji A, "Direct laryngoscopy."

[35] B. Batuwitage, A. McDonald, K. Nishikawa, D. Lythgoe, S. Mercer, and P. Charters, "Comparison between bougies and stylets for simulated tracheal intubation with the c-mac d-blade videolaryngoscope," *European Journal of Anaesthesiology*, vol. 32, pp. 400–405, 1 2015.

[36] P. Rudraraju and L. A. Eisen, "Confirmation of endotracheal tube position: A narrative review," *Journal of Intensive Care Medicine*, vol. 24, pp. 283–292, 9 2009.

[37] S. Silvestri, J. G. Ladde, J. F. Brown, J. V. Roa, C. Hunter, G. A. Ralls, and L. Papa, "Endotracheal tube placement confirmation: 100% sensitivity and specificity with sustained four-phase capnographic waveforms in a cadaveric experimental model," *Resuscitation*, vol. 115, pp. 192–198, 6 2017.

[38] C. Frerk, V. S. Mitchell, A. F. McNarry, C. Mendonca, R. Bhagrath, A. Patel, E. P. O'Sullivan, N. M. Woodall, and I. Ahmad, "Difficult airway society 2015 guidelines for management of unanticipated difficult intubation in adults," *British Journal of Anaesthesia*, vol. 115, pp. 827–848, 12 2015.

[39] A. L. Pahor, "Ear, nose and throat in ancient egypt," *The Journal of Laryngology & Otology*, vol. 106, pp. 677–687, 1992.

[40] S. Goksu and E. Sen, "History of intubation," *Journal of Academic Emergency Medicine*, vol. 14, pp. 35–36, 2 2015.

[41] F. Scamman, "S21. keeping track of audio-video history," *Journal of Anesthesia History*, vol. 1, p. 96, 7 2015.

[42] B. M. Pieters, G. B. Eindhoven, C. Acott, and A. A. van Zundert, "Pioneers of laryngoscopy: indirect, direct and video laryngoscopy," *Anaesthesia and intensive care*, vol. 43, pp. 4–11, 7 2015.

[43] C. M. Burkle, F. A. Zepeda, D. R. Bacon, and S. H. Rose, "A historical perspective on use of the laryngoscope as a tool in anesthesiology," 2004.

[44] M. B. Kaplan, C. A. Hagberg, D. S. Ward, A. Brambrink, A. K. Chhibber, T. Heidegger, L. Lozada, A. Ovassapian, D. Parsons, J. Ramsay, W. Wilhelm, B. Zwissler, H. J. Gerig, C. Hofstetter, S. Karan, N. Kreisler, R. M. Pousman, A. Thierbach, M. Wrobel, and G. Berci, "Comparison of direct and video-assisted views of the larynx during routine intubation," *Journal of Clinical Anesthesia*, vol. 18, pp. 357–362, 8 2006.

[45] R. M. Cooper, "Preparation for and management of "failed" laryngoscopy and/or intubation," *Anesthesiology*, vol. 130, pp. 833–849, 5 2019.

[46] "disposable/ reusable video laryngoscope/disposable video laryngoscope blades," 01 2022.

[47] E. Cavus and V. Dörges, "Video laryngoscopes," in *Benumof and Hagberg's Airway Management* (C. A. Hagberg, ed.), Elsevier Inc., 3 ed., 2013.

[48] J. L. Apfelbaum, C. A. Hagberg, R. T. Connis, B. B. Abdelmalak, M. Agarkar, R. P. Dutton, J. E. Fiadjoe, R. Greif, P. A. Klock, D. Mercier, S. N. Myatra, E. P. O'Sullivan, W. H. Rosenblatt, M. Sorbello, and A. Tung, "2022 american society of anesthesiol-

ogists practice guidelines for management of the difficult airway.," *Anesthesiology*, 11 2021.

[49] O. Balaban, M. Hakim, H. Walia, D. Tumin, M. Lind, and J. D. Tobias, "A comparison of direct laryngoscopy and videolaryngoscopy for endotracheal intubation by inexperienced users a pediatric manikin study," *Pediatric Emergency Care*, 2017.

[50] F. J. Raimann, P. E. Dietze, C. E. Cuca, D. Meininger, P. Kessler, C. Byhahn, D. Gill-Schuster, K. Zacharowski, and H. Mutlak, "Prospective trial to compare direct and indirect laryngoscopy using c-mac pm® with macintosh blade and d-blade® in a simulated difficult airway," *Emergency Medicine International*, vol. 2019, pp. 1–8, 4 2019.

[51] S. Bakshi, V. Vanjari, and J. Divatia, "A prospective, randomised, clinical study to compare the use of mcgrath, truview and macintosh laryngoscopes for endotracheal intubation by novice and experienced anaesthesiologists," *Indian J. Anaesth.*, vol. 59, no. 7, p. 421, 2015.

[52] I. S. Abdelgadir, R. S. Phillips, D. Singh, M. P. Moncreiff, and J. L. Lumsden, "Videolaryngoscopy versus direct laryngoscopy for tracheal intubation in children (excluding neonates)," *Cochrane Database of Systematic Reviews*, vol. 2017, 5 2017.

[53] J. R. Hupp and E. M. Ferneini, eds., *Head, Neck, and Orofacial Infections*. Elsevier, first ed., 2016.

[54] D. Dindo, N. Demartines, and P. A. Clavien, "Classification of surgical complications: A new proposal with evaluation in a cohort of 6336 patients and results of a survey," *Annals of Surgery*, vol. 240, pp. 205–213, 8 2004.

[55] I. Chalmers, P. Glasziou, J. L. Library, J. Lind, and S. I. Chalmers, "Avoidable waste in the production and reporting of research evidence choosing the wrong questions for research figure: Stages of waste in the production and reporting of research evidence relevant to clinicians and patients," *www.thelancet.com*, vol. 374, pp. 86–89, 2009.

[56] "Core outcome measures in effectiveness trials," 01 2022.

[57] P. C. Pacheco-Lopez, L. C. Berkow, A. T. Hillel, and L. M. Akst, "Complications of airway management," *Respiratory Care*, vol. 59, pp. 1006–1021, 2014.

APPENDIX

A.

TABLE II
SEARCH STRINGS USED IN BIBLIOGRAPHIC DATABASES

Search Engine	Search Terms	Results (nr of studies)
MEDLINE **Date of access: 10-12-2021**	(”Video laryngoscop*”[TIAB] OR Videolaryngoscop*[TIAB] OR Video-laryngoscop*[TIAB] OR VL*[TIAB]) AND (”Manikins”[Mesh] OR Manikin*[TIAB] OR Mannequin*[TIAB] OR mannikin*[TIAB] OR ”Patient Simulator”[TIAB] OR ”Training Model”[TIAB] OR ”Airway Trainer”[TIAB] AND (y_10[Filter]) AND (fft[Filter]) AND (english[Filter])	201
SCOPUS **Date of access: 10-12-2021**	(TITLE-ABS-KEY (”Video laryngoscop*” OR videolaryngoscop* OR video-laryngoscop* OR VL) AND PUBYEAR >2010) AND (TITLE-ABS-KEY (Manikin* OR Mannequin* OR ””Patient Simulator” OR ”Training Model” OR ”Airway Trainer” OR Mannikin*) AND PUBYEAR >2010) AND (LIMIT-TO (PUBSTAGE, ”final”)) AND (LIMIT-TO(SUBJAREA, ”MEDI”) OR LIMIT-TO(SUBJAREA,”NURS”) OR LIMIT-TO(SUBJAREA, ”HEAL”)) AND (LIMIT-TO(LANGUAGE, ”English”))	281

B.

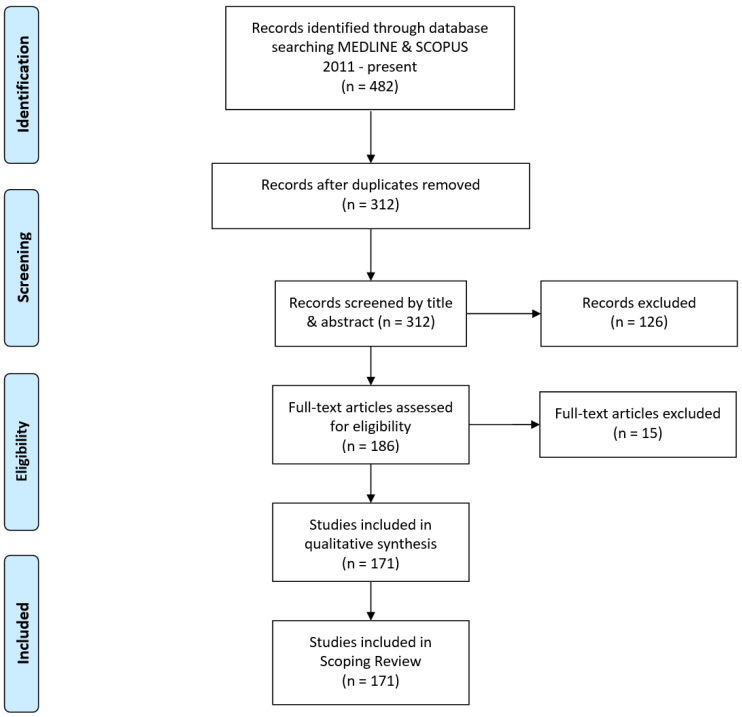


Fig. 12. PRISMA flow diagram

C.

TABLE III: Definition of End-points

Subject group	End-point	Definition	Incidence	Frequency of end-point use in studies analysed (%)
Time	Time to intubation	Time until the ETT passes the vocal cords	87	50.9%
	Time to ventilation	Time until ventilation is confirmed	86	50.3%
	Time to glottic view	Time until best glottic view is obtained	45	26.3%
	Tube insertion time	Time from best glottic view until the ETT passes the vocal cords	16	9.4%
	Time to cuff blocking	Time until succeeded blocking of the tube's cuff	1	0.6%
	Time until bougie	Time until bougie is correctly placed	1	0.6%
View	Laryngeal view grade (CL)	The Cormack-Lehane (CL) system divides the view of the larynx obtained by (video)laryngoscopy into 5 grades	81	47.4%
	Laryngeal view grade (POGO)	The Percentage Of Glottic Opening (POGO) represents the portion of the glottis visualised	33	19.3%
	Number of glottic views obtained	Amount of clear glottic views	2	1.2%
	Ability to visualize laryngeal inlet	Whether or not the laryngeal inlet could be identified	2	1.2%
	Quality of visualization	Subjective scoring of the quality of glottic view on a Likert-type scale (from 1 to 5)	1	0.6%
Intubation Success	Successful intubation rate	The percentage of successful intubations out of all intubations performed	129	75.4%
	First pass success rate	The percentage of intubations that are successful on the first intubation attempt	60	35.1%
	Failed intubation	The total number of failed intubations	53	31.0%
	Esophageal intubation rate	The percentage of esophageal intubations performed out of all intubations executed.	35	20.5%
	Reasons for unsuccessful intubation	Reasons stated for failure of intubation	14	8.2%
	Tracheal tube placement	The number of tracheal tubes placed	3	1.8%
	Recognized failed intubation	The number of intubation failures recognised by the operator	3	1.8%
	Selective bronchial intubation	The number of intubations in which the ETT is placed in one of the bronchi	2	1.2%
	Intubation accuracy	The accuracy of the placement of the ETT in the trachea measured by the location of the inflated cuff	1	0.6%
Number of attempts	Number of intubation attempts	Number of intubation attempts to first successful intubation	64	37.4%
Device Use	Ease of intubation	Subjective ease of the whole intubation procedure	53	31.0%
	Device difficult score	Subjective difficulty of the device use	43	25.1%
	Device preference	The preference for one of the (video)laryngoscopes according to the operator	22	12.9%
	Number of optimization maneuvers	Amount of optimization maneuvers to aid tracheal intubation	14	8.2%
	Use of airway back-up devices	Whether airway back-up devices are used by the operator if available	9	5.3%
	Willingness to reuse in real life	To what extent the operator would reuse the (video)laryngoscope in real life	5	2.9%

	Confidence in device use	How confident the user is during intubation with the particular (video)laryngoscope	5	2.9%
	Ease of tube advancement	Subjective ease of insertion of the ETT	3	1.8%
	Ease of assembly	Subjective ease of assembly of the (video)laryngoscope so that it is ready to use	3	1.8%
	Number of forward advances of ETT	Number of times the ETT is moved forward to insert the tube	3	1.8%
	Light intensity	The brightness of the light generated by the lamp of the (video)laryngoscope	2	1.2%
	Blade malpositioning	Incorrect placement of the blade of the (video)laryngoscope in the trachea	2	1.2%
	Number of ETTs used	The number of ETTs used for successful intubation	1	0.6%
Monitoring	Amount of aspirated fluid in the lungs	Amount of fluid in the lungs after intubation	2	1.2%
	Desaturation less than 90%	Number of times the oxygen in the blood is lower than 90%	1	0.6%
	Median lowest SpO2 values	The lowest median value of oxygen measured in the blood	1	0.6%
Force	Dental compression	Pressure exerted on the teeth during the intubation procedure	48	28.1%
	VAS of force exerted	Visual Analogue Scale (VAS) of force exerted with (video)laryngoscope on manikin	8	4.7%
	Force exerted on tongue	Measured force exerted on tongue of manikin during intubation procedure (N)	7	4.1%
	Force exerted on maxillary incisors	The force exerted on the manikin's front teeth during the intubation procedure (N)	4	2.3%
	Potential laryngeal damage	Potential estimated damage to the larynx during the intubation procedure	2	1.2%
	Peak force measured	The maximum force exerted on the manikin during the intubation procedure (N)	2	1.2%
	Epiglottis loading	The force exerted on the manikin's epiglottis during the intubation procedure (N)	1	0.6%
Operator Variables	Postural analysis	Analysis of the operator's body position during the intubation procedure	1	0.6%
	Learning curve	The progress of the operator's intubating skills	1	0.6%
	Number of gaze changes	Number of times the operator's direction of view changes during the intubation procedure	1	0.6%

D.

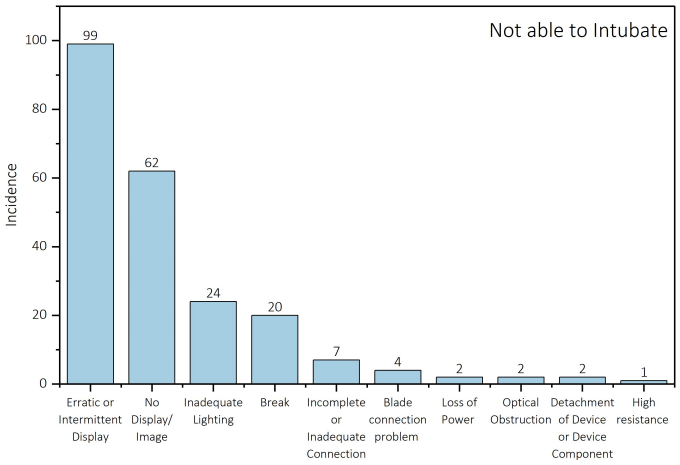


Fig. 13. Device problems that led to *Not able to Intubate*

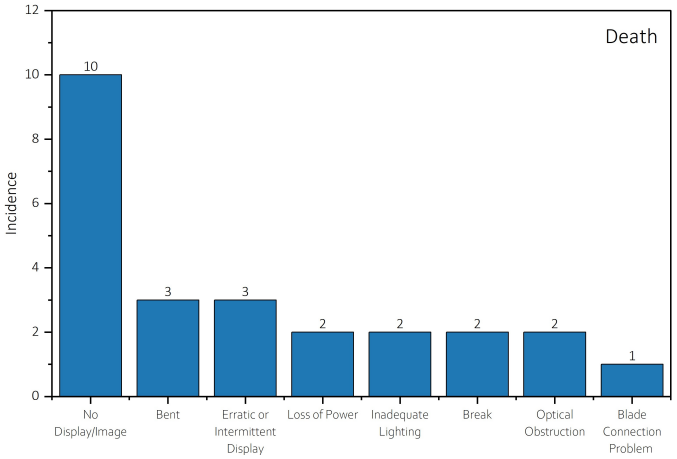


Fig. 14. Device problems that led to *Death*

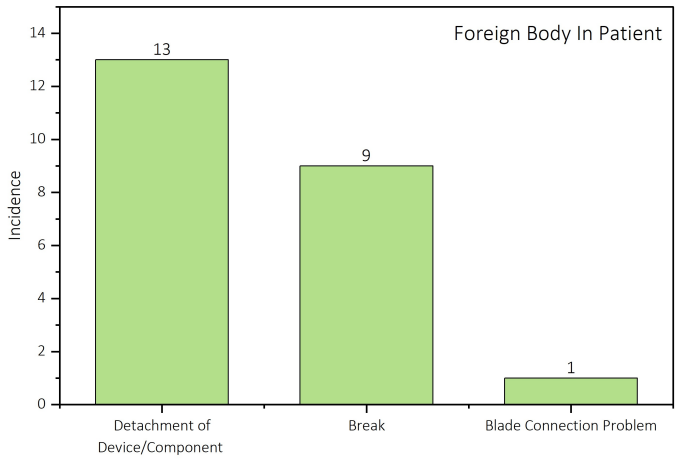


Fig. 15. Device problems that led to *Foreign Body in Patient*

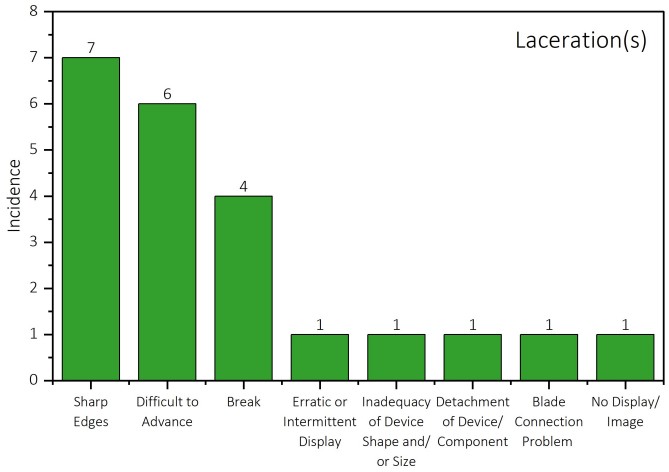


Fig. 16. Device problems that led to *Laceration(s)*

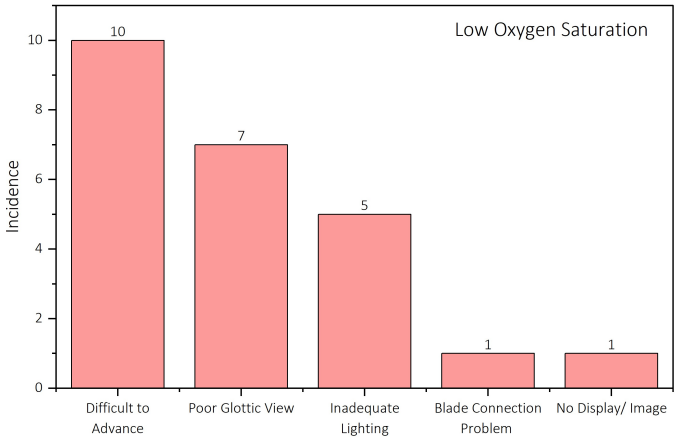


Fig. 17. Device problems that led to *Low Oxygen Saturation*

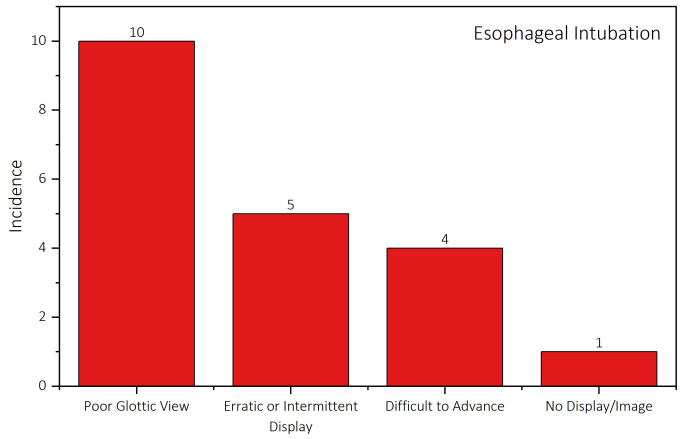


Fig. 18. Device problems that led to *Esophageal Intubation*

Fig. 19. Device problems that led to *Tissue Damage*

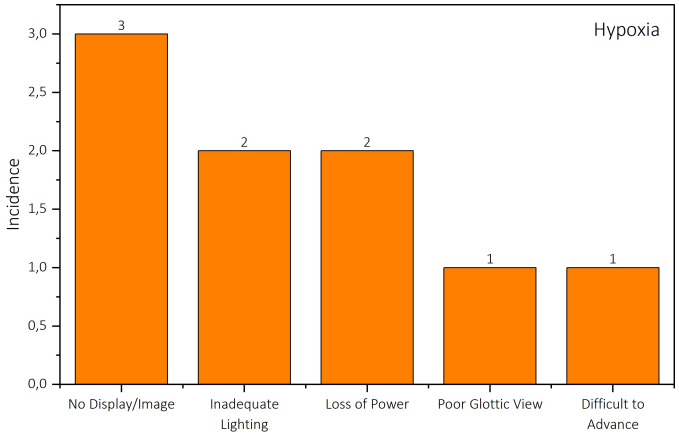


Fig. 20. Device problems that led to *Hypoxia*

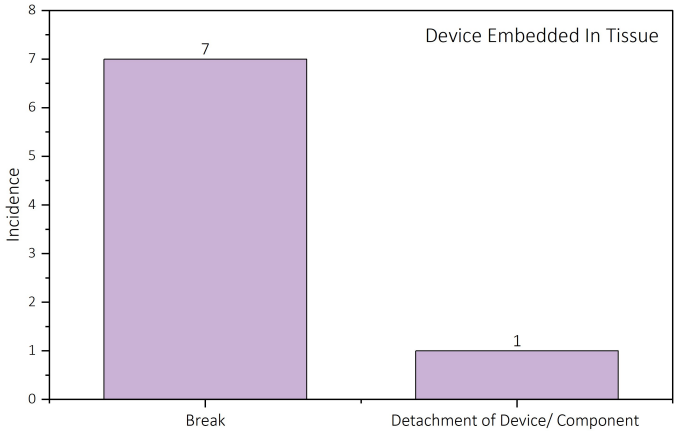


Fig. 21. Device problems that led to *Device Embedded in Tissue*

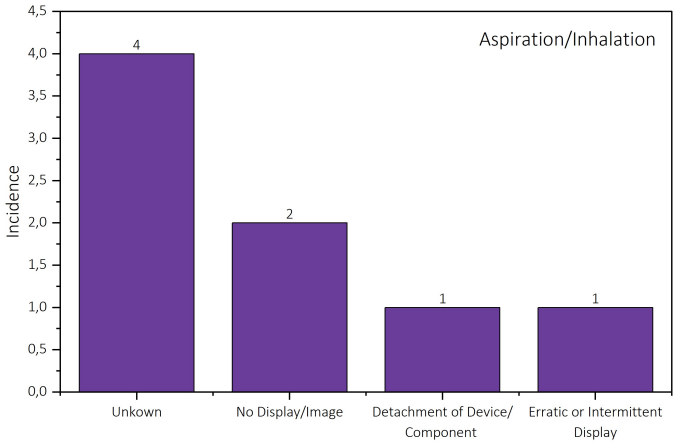


Fig. 22. Device problems that led to *Aspiration/Inhalation*

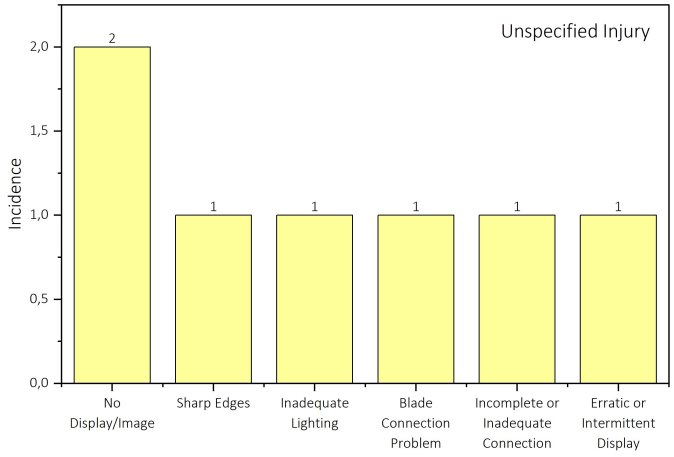


Fig. 23. Device problems that led to *Unspecified Injury*

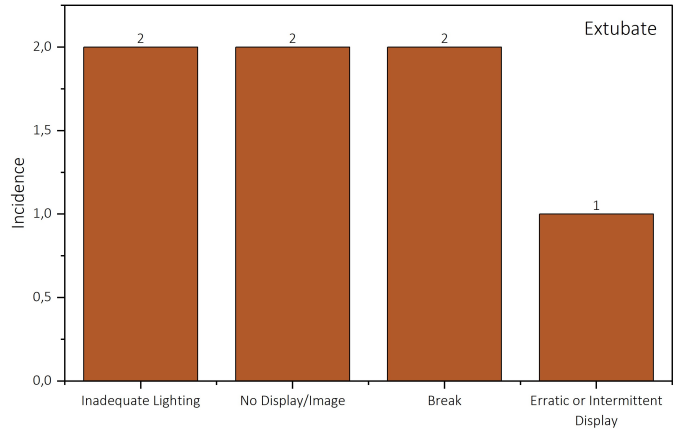


Fig. 24. Device problems that led to *Extubate*

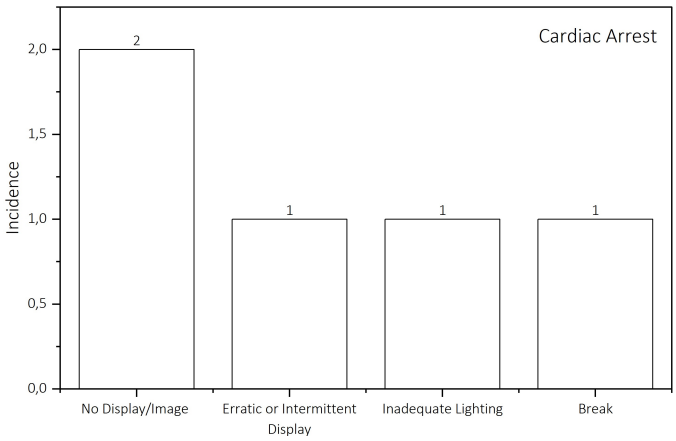


Fig. 25. Device problems that led to *Cardiac Arrest*

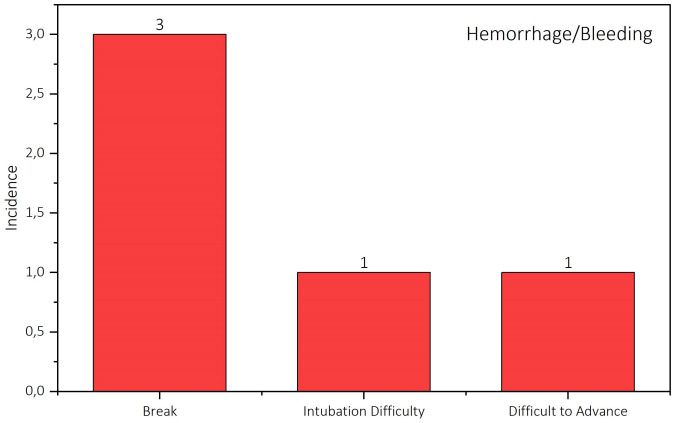


Fig. 26. Device problems that led to *Hemorrhage/Bleeding*

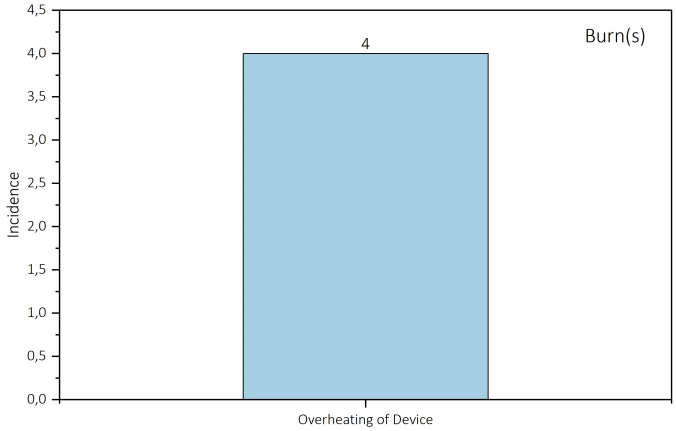


Fig. 27. Device problems that led to *Burn(s)*

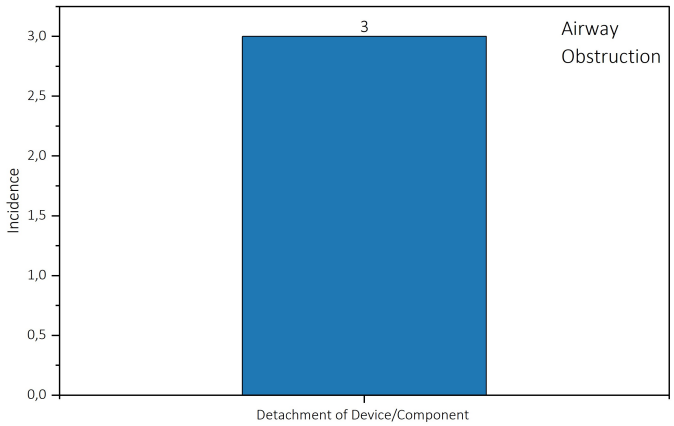


Fig. 28. Device problems that led to *Airway Obstruction*

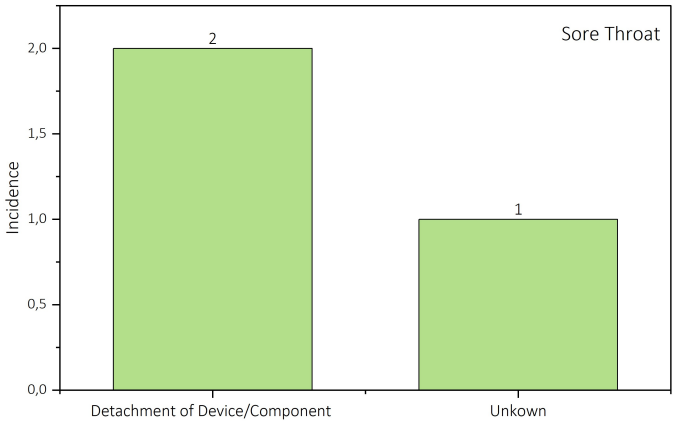


Fig. 29. Device problems that led to *Sore Throat*

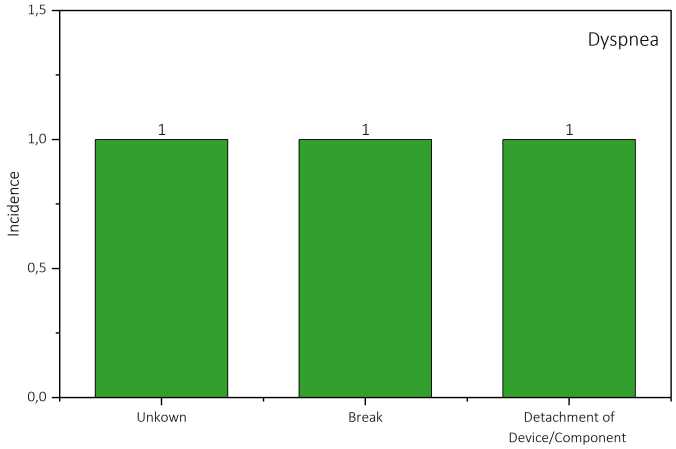


Fig. 30. Device problems that led to *Dyspnea*

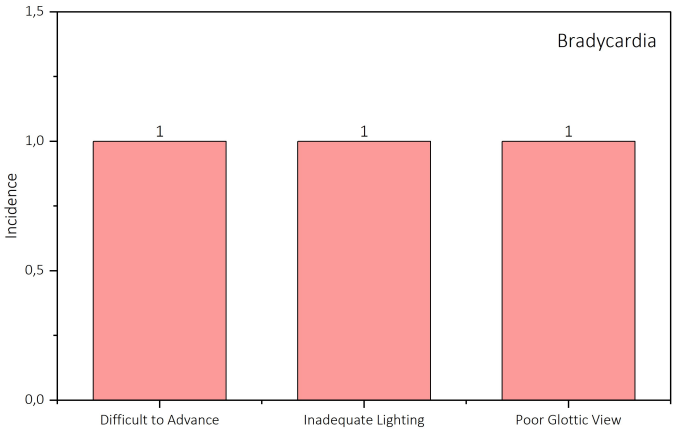


Fig. 31. Device problems that led to *Bradycardia*

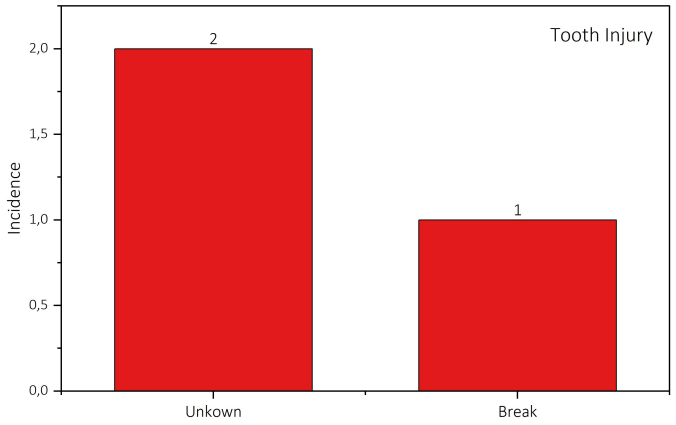


Fig. 32. Device problems that led to *Tooth Injury*

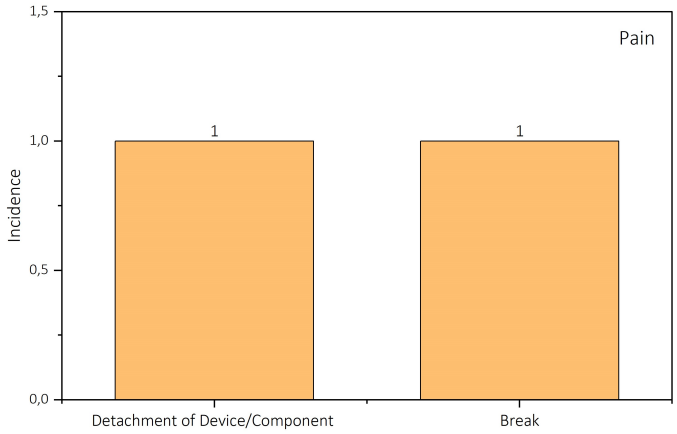


Fig. 33. Device problems that led to *Pain*

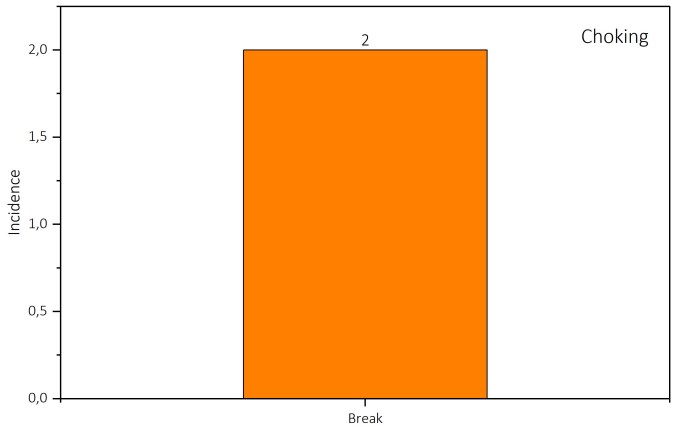


Fig. 34. Device problems that led to *Choking*

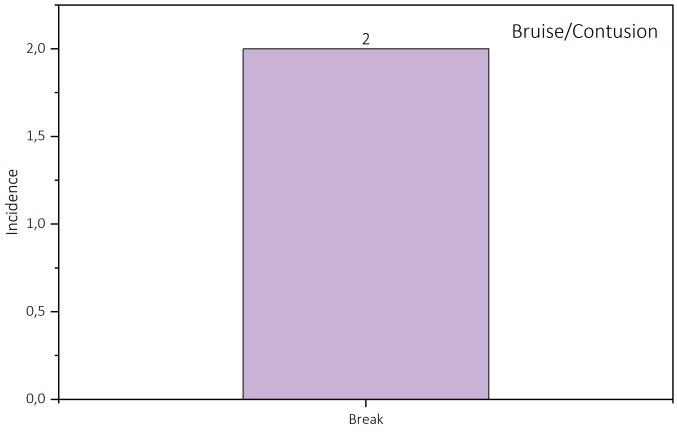


Fig. 35. Device problems that led to *Bruise/Contusion*

Fig. 36. Device problems that led to *Tracheotomy*, *Hypertension*, *Swelling*, *Discomfort*, *Hypotension*, *Coma* and *Respiratory Acidosis*

C

Background Information

This master thesis was conducted on behalf of the developer of the Goodscope, Layco Medical Devices, a Dutch startup that develops medical devices for low- and middle-income countries. At the start of this research, a preliminary prototype of the Goodscope had been developed on which several tests had been carried out [25]. However, to test the efficacy of the Goodscope, a more comprehensive study was needed in which reality could be simulated as closely as possible. A manikin study was eventually chosen to be the best setup for the evaluation of the prototype of the Goodscope used in this study. First a literature study (see Appendix B) was performed in which the most relevant endpoints for a manikin study evaluating a videolaryngoscope were determined. Because 171 manikin studies were analysed for this literature study, knowledge in the field of designing such studies was gained. Therefore, from these 171 manikin studies a top 18 was selected which were published in the journals with the highest impact factors [2, 3, 4, 5, 6, 8, 10, 11, 13, 15, 16, 18, 19, 20, 21, 22, 23, 26]. The methods of these studies were thoroughly analysed to form the basis of the first version of the research protocol.

While developing the research protocol, several medical centres were approached to participate in this manikin study. The first centre that was the Reinier de Graaf Gasthuis in Delft. However, this medical centre did not have a manikin on which a difficult airway could be simulated. Therefore, they referred to the skills centre of the LUMC that incorporated a more advanced airway simulator, the SimMan 3G. Next to the LUMC, more centres had to be included to reach a minimum of 48 participants. These centres had to be in possession of a SimMan 3G, otherwise, the results of the different centres were not consistent and could therefore not be merged. The Amsterdam UMC, UMCG, Erasmus MC, and UMC Utrecht were approached for a possible collaboration. Although all were willing to participate, only the UMCG and Amsterdam UMC had a SimMan 3G available for this manikin study and used the GlideScope as their standard device.

After it became clear that the UMCG, Amsterdam UMC and LUMC were willing to collaborate in this study, the method of the preliminary research protocol was tested by conducting a pilot study, as described in section C.1. By conducting this pilot study, it became clear that several changes had to be made which resulted in the final version of the research protocol used for this study, detailed in section C.2. The rationale of the study design is detailed in section C.3.

Before the study could be carried out, ethical approval had to be obtained from the medical ethics committee (METC Leiden, The Hague, Delft). To apply for this, several documents had to be provided, including the research protocol, letter of informed consent (see section C.4), and the short questionnaire used for this study (see section C.5). The final letter of approval from the medical ethics committee is added in section C.6.

C.1. Pilot Study

Prior to writing the final version of the research protocol for this study (see section C.2), a small-scale pilot study was performed. This pilot study aimed to test the functioning of the preliminary research protocol, as described in the methods section below, to determine whether the procedure was accurate and to modify it when needed.

C.1.1. Methods

The pilot study was performed in the skills-lab of the Leiden University Medical Center (LUMC). Due to time constraints, only four participants could be included. Although one of the inclusion criteria was that all participants should have at least 2 years of intubation experience, one participant with less than 2 years of experience was included. After a 5-minute introduction was given to the participants, they had to perform at least one successful intubation with a Macintosh direct laryngoscope to become acquainted with the SimMan 3G manikin. The manikin was placed on an operating table and a molton and intubation pillow were placed underneath the head of the manikin to obtain a sniffing position, as depicted in figure C.1. Because the prototype of the Goodscope had not yet been completed at the time of the pilot study, only the GlideScope was used. Each participant performed tracheal intubation with the GlideScope in two different airway scenarios on a high-fidelity manikin. The easy scenario was defined as a normal airway and the difficult airway was defined as maximal tongue swelling. The order of airway scenarios was randomized (www.random.org). Before the start of the intubation attempt the manikin, laryngoscope blade, and ETT (7mm) were lubricated. Moreover, a stylet (Single-use Stylet Large 0270-1005 – Verathon Inc.) was placed in the ETT before the start of the intubation attempt. Optimisation manoeuvres such as the use of gum elastic bougie and BURP were not allowed.

The primary endpoint was time to successful intubation and the secondary endpoints were time to glottic view, time to ventilation, number of intubation attempts, successful intubation rate, and ease of intubation. For the time measurements, timing commenced when the tip of the GlideScope passed the manikin's teeth. Timing stopped when a view of the glottis was observed on the monitor, when the ETT past the vocal cords, and when a capnographic waveform was observed for time to glottic view, time to successful intubation, and time to ventilation respectively. A failed intubation attempt was defined as any that lasted over 120 sec, esophageal intubation, or when the GlideScope was removed from the manikin's mouth and reinserted for another attempt before the intubation was successful. Moreover, an observer indicated whenever pressure was exerted on the teeth by the participant. If so, the GlideScope and (if applicable) the ETT had to be removed from the mouth of the manikin and the intubation attempt had to start over. However, restarting the intubation attempt, because of exerting pressure on the teeth, did not count as a failed attempt. Lastly, an assistant helped the participant with the intubation by handing over the necessary tools and removing the stylet. No statistical analysis was performed and all results are described as means.

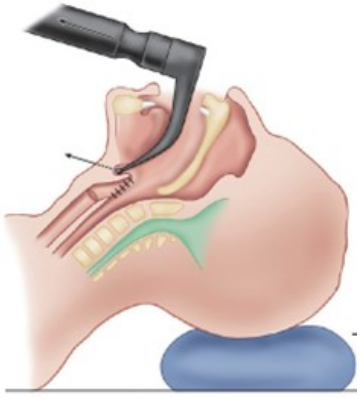


Figure C.1: The sniffing position

C.1.2. Results

Three residents in anaesthesia and one anaesthetist were included in this pilot study. The raw data of the pilot study is depicted in table C.1. The means of time to glottic view, time to successful intubation,

and time to ventilation were 4.5, 12.5, 24.8 seconds respectively in the easy scenario and 10.8, 25.5, 39.3 seconds respectively in the difficult scenario. The successful intubation rate of the first attempt was 100% in both the easy and difficult airway scenarios. Lastly, the intubation attempts performed were scored as mean = 4.5 in the easy airway scenario and as mean = 3.75 in the difficult airway scenario.

Participant #	Time to glottic view (s), mean	Time to successful intubation (s), mean	Time to ventilation (s), mean	Number of intubation attempts, mean	Ease of intubation, mean
Participant 1 - easy	3	20	36	1	4
Participant 1 - difficult	17	26	41	1	4
Participant 2 - easy	2	8	20	1	5
Participant 2 - difficult	4	12	26	1	4
Participant 3 - easy	5	12	24	1	5
Participant 3 - difficult	12	42	53	1	3
Participant 4 - easy	8	10	19	1	4
Participant 4 - difficult	10	22	37	1	4

Table C.1: Raw data of all endpoints

C.1.3. Discussion

The goal of this pilot study was to assess the functioning of the method of the preliminary research protocol. Although the method worked well, there were some parts that worked less accurate. First of all, the participants had difficulties holding the head of the manikin in the sniffing position as depicted in figure C.1. Due to the low weight of the head of the manikin, the head bounced back into normal position once the participant released the head to take the ETT from the assistant. After experimenting with various combinations of the intubation pillow and the moltons, the manikin's optimal posture was obtained with only the intubation pillow underneath the head. So, it was decided to change this in the research protocol. Second, because the manikin, the blade, and the ETT were lubricated before the first intubation of every new participant, the GlideScope became too slippery to hold properly after the second participant. Therefore, it was difficult to keep a grip on the GlideScope while intubating. As a result, it was decided to just lubricate the airway of the manikin and clean all of the equipment for every new participant. Third, BURP was applied and the stylet was bent by the participants to ease the intubation process. However, in the 5 min introduction, it was stated that both were not allowed. Therefore, special attention should be given in the 5 min introduction to the fact that the optimization manoeuvres are not permitted. Fourth, because the intubation attempt had to start over each time the participant touched the teeth of the manikin as indicated by the observer, some participants got frustrated after having to start over several times. Although no problems arise from lightly touching the teeth of a patient, applying pressure on them might cause damage. Because a manikin is not a true representation of a human, the teeth are touched more rapidly and readily. Therefore, it was chosen to change the research protocol and to allow the participants to touch the teeth of the manikin while intubating. Nevertheless, they will be encouraged in the introduction to avoid touching the manikin's teeth as much as possible. Lastly, because the successful intubation rate of the first attempt was 100% it was considered that the intubation procedure was too easy. Moreover, three of the four participants were residents in anaesthesia with minimal videolaryngoscopy intubation experience, hence for the more experienced anaesthetist it will be too easy as well. Therefore, in the research protocol, the maximum intubation time of 120 seconds was lowered to 60 seconds. So, if intubation lasts longer than 60 seconds, the intubation is reported as failed and the participant must start over. A duration of 60 seconds was chosen because specialists stated that if intubation lasts more than 60 seconds, they frequently switch to a different intubation technique such as a gum elastic bougie, s-guide, etc.

Next to testing the preliminary research protocol, various difficult intubation scenarios were tested on the manikin to see whether the proposed scenario would be the most realistic. Maximal tongue swelling was found to be the most representative scenario since intubation was not too easy or difficult.

Because next to the GlideScope also the Goodscope will be used in the final study, this pilot study is not fully representative. However, since the purpose of this study was to test the functioning of the method, much insight was gained.

C.1.4. Conclusion

This pilot study aimed to test the functioning of the method of the preliminary research protocol to determine whether the procedure is accurate and, if required, to modify it. This pilot study was conducted in the skillslab of the LUMC and four participants were included. All participants performed two intubations with the GlideScope on the manikin in two different airway scenarios (easy and difficult) in a randomized order. Intubation times were faster in the easy airway scenario compared to the difficult airway scenario. However, the successful intubation rate was similar in both scenarios. The easy airway scenario was given a higher ease of intubation score than the difficult scenario. Much insight was gained into the functioning of the method and few adjustments were made. First, the manikin's position of the head was optimized by placing only an intubation pillow underneath the head. Second, it was decided to only lubricate the airway of the manikin and to clean all the equipment for every new participant. Third, it was chosen to allow the participants, although not recommended, to touch the teeth of the manikin with the videolaryngoscope while intubating. Lastly, the maximum intubation time of 120 seconds was lowered to 60 seconds. Besides these adjustments, the method was deemed to be accurate and could be used for the research protocol of the manikin study.

C.2. Research Protocol

This section details the final version of the research protocol as was provided to the Institutional Review Board of the Leiden University Medical Centre and was used for the manikin study.

RESEARCH PROTOCOL

Comparison of the Goodscope versus GlideScope for time to intubation in a randomized crossover manikin study

Study protocol "Comparison of the Goodscope versus GlideScope for time to intubation in a randomized crossover manikin study"

PROTOCOL TITLE 'Comparison of the Goodscope versus GlideScope for time to intubation in a randomized crossover manikin study'

Protocol ID	**NL 22.100**
Short title	**The Goodscope project**
EudraCT number	***N/A***
Version	**1.0**
Date	**24-03-2022**
Coordinating investigator/project leader	***Roos Willemijn Wiltink*** ***Department of BioMechanical Engineering Faculty of Mechanical, Maritime and Materials Engineering (3mE) at the TU Delft*** ***r.w.wiltink@student.tudelft.nl*** ***+31683045847***
Principal investigator(s)	***Dr. Christian Hubert Martini*** ***Department of Anesthesiology*** ***Leiden University Medical Center*** ***c.h.martini@lumc.nl*** ***+31 71 5298903*** ***Prof. dr. Jenny Dankelman*** ***Department of BioMechanical Engineering Faculty of Mechanical, Maritime and Materials Engineering (3mE) at the TU Delft*** ***J.Dankelman@tudelft.nl*** ***+31 6 20926227*** ***Drs. Micha Erwteman*** ***Department of Anesthesiology***

	Amsterdam University Medical Center ***m.erwteman@amsterdamumc.nl*** ***Drs. A.J.D.W.R. Ramaker*** ***Department of Anesthesiology*** ***University Medical Center Groningen*** ***a.j.d.w.r.ramaker@umcg.nl***
Independent expert (s)	***Dr. Remco Zoethout*** ***Department of Anesthesiology*** ***Leiden University Medical Center*** ***r.w.m.zoethout@lumc.nl*** ***+31 71 529 8646***

PROTOCOL SIGNATURE SHEET

Name	Signature	Date
Head of Department: **Dr. E.Y. Sarton** **Head of department Anesthesiology** **Leiden University Medical Center**		
Principal Investigator: **Dr. Christian Hubert Martini** **Department of Anesthesiology** **Leiden University Medical Center**		

TABLE OF CONTENTS

LIST OF ABBREVIATIONS AND RELEVANT DEFINITIONS

DL	**Direct laryngoscopy**
ETT	**Endotracheal tube**
IC	**Informed Consent**
IQR	**Inter-quartile range**
LMICs	**Low- and middle-income countries**
LUMC	**Leiden University Medical Centre**
PII	**Personally Identifiable Information**
PIRD	**Personally Identifiable Research Data**
UMC	**University Medical Centre**
UMCG	**University Medical Centre Groningen**
VL	**Videolaryngoscopy**
WMA	**World Medical Association**
WMO	**Medical Research Involving Human Subjects Act; in Dutch: Wet Medisch-wetenschappelijk Onderzoek met Mensen**

SUMMARY

Introduction and Rationale: A new low-cost video laryngoscope (Goodscope) has been designed specifically for Low- and Middle-Income Countries (LMICs), consisting of a handheld part with a battery-operated camera and light source, to which various disposable blades can be attached. The aim of this study is to evaluate the efficacy of the Goodscope compared with the GlideScope, both featuring a hyperangulated blade design, when used by experienced anaesthetists, in a randomized cross-over manikin study in a low and high difficulty level airway scenario. We hypothesize that the intubation times, success rate and ease of intubation with the Goodscope will be non-inferior to the GlideScope in a manikin setup.

Study design: This is a multi-centre randomized cross-over manikin study. Each participant will perform tracheal intubation with two different videolaryngoscopes (GlideScope and Goodscope) in two different airway scenarios on a high-fidelity manikin (Laerdal SimMan 3G).

Study population: The research population will be drawn from the department of anaesthesiology of the LUMC, Amsterdam UMC, and UMCG. All participants will be anaesthetists/residents in anaesthesia with a minimal intubation experience of 2 years.

Main study parameters/endpoints: The primary end-point is time to successful intubation, measured from the moment the videolaryngoscope passes the manikin's teeth until the endotracheal tube (ETT) has visually passed the vocal cords. Secondary end-points are Time to glottic view, Time to ventilation, Number of intubation attempts, Successful intubation rate and Ease of intubation expressed on a 5-point Likert Scale.

1. INTRODUCTION AND RATIONALE

When patients undergo general anaesthesia (e.g. for surgical procedures) endotracheal intubation is usually required to secure the airway and facilitate mechanical ventilation of the lungs. Most commonly the endotracheal tube is inserted through the larynx/glottis under direct vision facilitated by a handheld laryngoscope. However, it is shown that DL fails in approximately 6% of adult surgical patients.[1] Although direct laryngoscopy (DL) remains the standard for routine endotracheal intubations, videolaryngoscopy (VL) is becoming increasingly popular. Human trials have proven the benefits of VLs with regard to a better view of the glottis, a reduction in the number of inadvertent oesophageal intubations and higher intubation success rate.[2] [3] Unfortunately, current VLs were designed for use in Western practice and are therefore expensive (costing between $5,000 and $10,000). They consist of A) a handheld part which contains the actual (hyperangulated) blade of the laryngoscope and a camera fitted to the tip of the blade, B) a costly display that can either be externally attached to a mobile chart or built into the laryngoscope. Because components are not detachable, they cannot be repaired or replaced if broken. Furthermore, the handheld parts of many VL devices are made of single use materials, requiring a new device for each patient. This is a non-sustainable, environmental unfriendly solution which imposes a large burden on natural resources. Even if multi-usage components are being used, they are only suitable for Western cleaning protocols, which are primarily based on autoclave cleaning. As a result, existing video laryngoscopes do not meet the needs, budgets, and protocols of Low and Middle-Income Countries (LMICs). Consequently, only 46% of LMIC hospitals have a VL, compared to 93% of High-income country hospitals.[4] Therefore, a low-cost video laryngoscope (Goodscope) has been developed specifically for LMICs. It consists of a handheld part, which contains a battery-operated camera and light source, to which various disposable blades can be attached. The Goodscope can be wirelessly connected to a smartphone/monitor on which an intuitive interface application can be used for video view. The product has a modular design and complies with the hospital cleaning protocols for LMICs.
The aim of this study is to evaluate the efficacy of the Goodscope compared with the GlideScope ((Verathon, Amsterdam) a VL that is commonly used across The Netherlands and the rest of Europe), both featuring a hyperangulated blade design, when used by experienced anaesthetists, in a randomized cross-over manikin study in a low and high difficulty level airway scenario. We hypothesize that the intubation times, success rates and ease of intubation with the Goodscope will be non-inferior to the GlideScope in a manikin setup. We chose a manikin study because the Goodscope is a new device whose performance has not been examined in real life situations in patients undergoing surgical procedures.

2. STUDY DESIGN AND POPULATION

2.1 Summary of Study Design

This is a multi-centre randomized cross-over manikin study. Each participant will perform tracheal intubation with two different videolaryngoscopes (GlideScope and Goodscope) in two different airway scenarios on a high-fidelity manikin (Laerdal SimMan 3G):

- Low difficulty: normal airway
- High difficulty: maximal tongue swelling

So, every participant will perform a total of four intubations. The order of use of the videolaryngoscopes and the type of airway scenario will be randomized. The duration of the study is estimated to be 15 min per participant and the study will be performed in the months March and April of the year 2022. Written consent to participate in the study will be obtained from all participants and the data will be presented in an anonymous fashion without any ability to retrieve the identity of the participants.

2.2 Study Population

The research population will be drawn from the department of anaesthesiology of the LUMC, Amsterdam UMC, and UMCG. It is expected that the planned number of participants can be recruited since an estimated total number of 200 anaesthetists/residents in anaesthesia are employed in the above-mentioned medical centres. Of the 200 it is likely that at least 50% will be willing to participate in this study which would be sufficient according to the sample size calculation. Since the data will be presented in an anonymous fashion no sociodemographic data of the participants will be gathered.

2.3 Inclusion Criteria

In order to be eligible to participate in this study, a participant must meet all of the following criteria:

- Participants must have at least 2 years of intubation experience
- The participant must be anaesthetists/residents in anaesthesia

2.4 Sample size calculation

The size of the study population was calculated with the formula for sample size calculation for continuous outcome non-inferiority trials[5]:

$n = f(\alpha, \beta) \times 2 \times \sigma^2 / d^2$

Because we want to show the non-inferiority of the Goodscope the null hypothesis is that the time to successful intubation with the Goodscope is inferior to the GlideScope. The alternative hypothesis is that the successful intubation time with the Goodscope is non-inferior to the GlideScope. A non-

.

inferiority limit (d) of 10 sec was chosen by clinical experts to be the largest difference in successful intubation time that is clinically acceptable. This limit was based on clinical expert advice rather than on historical data as this is the first assessment of the Goodscope and therefore no historical data exists [6]. Based on previous studies a standard deviation (σ) of 15 sec in successful intubation time was calculated by taking the standard deviation of the medians of intubation times as reported in several comparable studies.[7] [8] [9] [10] [11] [12] [13] [14] However, as study populations and study designs differ greatly this calculated standard deviation is rather an estimation and is expected to be smaller in a single study. With these numbers, it was calculated that with a level of significance (α) of 0.05 and a power (β) of 90%, a minimum of 39 participants are required to be 90% sure that the lower limit of a one-sided 95% confidence interval will be above the non-inferiority limit of -10. However, because the non-inferiority limit was not based on historical data and the standard deviation was not accurately calculated it is chosen to include a minimum of 48 participants in this study to compensate for the estimations made. In figure 1, the effect of the standard deviation and the non-inferiority limit on the sample size is shown. Because 48 participants will be included, every randomized sequence (easy/difficult airway and Goodscope/GlideScope) will be included twice such that a potential learning effect can be analysed.

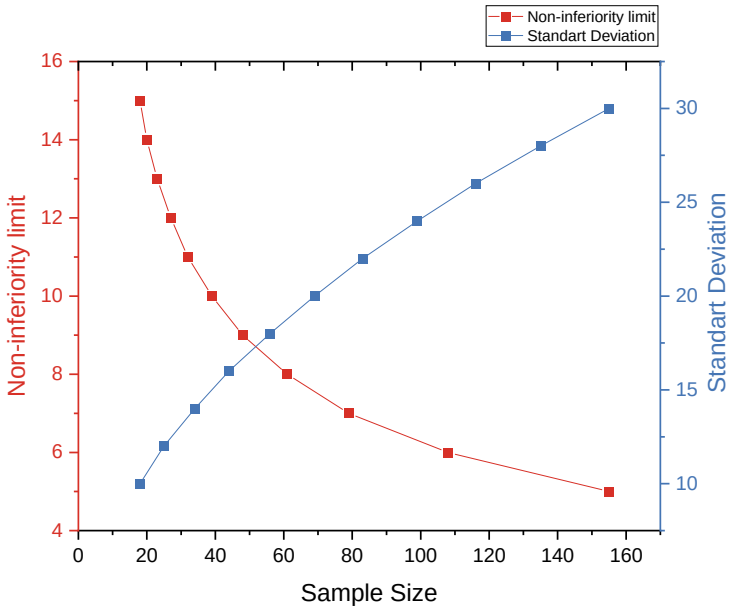


Fig 1: Graph Non-inferiority limit vs Standard Deviation

3. INVESTIGATIONAL AND COMPARATOR PRODUCT

The investigational product used in this study is the Goodscope with a hyperangulated blade. This is a newly designed innovative low-cost videolaryngoscope that meets the needs of LMICs. For instance, this laryngoscope is more intuitive to use for inexperienced medical staff by shortening the handle to reduce the force exerted on patients. Moreover, the Goodscope can be cleaned using a number of different protocols and is wirelessly connected to a separate (smartphone) screen. The comparator product is the GlideScope Spectrum single-use video laryngoscope that features a hyperangulated blade design to improve laryngeal views and to reduce the lift force that is applied on patients during intubation. [15] [16]

The GlideScope was selected as the comparator videolaryngoscope because it has proven efficacy,[17] [18] [19] is frequently used in Dutch hospitals, and is similar to the Goodscope in terms of use.

4. METHODS

4.1 Study parameters/endpoints

4.1.1 Main endpoint

The primary end-point is time to successful intubation, measured from the moment the videolaryngoscope passes the manikin's teeth until the endotracheal tube (ETT) has visually passed the vocal cords.

4.1.2 Secondary endpoints

The secondary end-points are:

- Time to glottic view
- Time to ventilation
- Number of intubation attempts
- Successful intubation rate
- Ease of intubation expressed on a 5-point Likert Scale

4.1.3 Other study parameters

Each participant in this study has a minimum of two years intubation experience. However, in order to gain more insight into the effect of intubation experience on the results, the intubation experience on patients of each participant will be noted by the investigator at the end of the experiment. This will be noted as follows:

- less than 40 intubations
- between 40 and 80 intubations
- 80 intubations or more

4.2 Randomisation, blinding and treatment allocation

All participants will intubate the manikin a total of four times, using both devices in two different airway scenarios:

- Low-difficulty Goodscope
- Low-difficulty GlideScope
- High-difficulty Goodscope
- High-difficulty GlideScope

The order in which the participants will intubate the manikin will be determined by using a closed envelope technique. Each possible sequence of the four scenarios will appear twice in the closed envelopes for a participant count of 48. If more than 48 participants are included in this study they will be randomly assigned to a sequence. Before intubation, each participant will pick an envelope with their intubation sequence without opening it. The investigator will open the envelope and inform the participant with which device he/she has to start. However, the participant will not be informed what the sequence of the airway scenarios will be to reduce bias.

4.3 Study procedures

Before the beginning of the trial, every participant will receive a standardised, 5 min demonstration by one of the investigators of both the GlideScope and the Goodscope. To

reduce learning curve effects, practicing with these devices before the attempts will not be allowed. However, before starting the trial, each participant will be required to perform one successful intubation in a normal airway scenario on the SimMan 3G manikin using a standard Macintosh direct laryngoscope. This allows each participant to become acquainted with the mannikin airway, which will be set in an easy difficulty level. Thereafter, each participant will be randomised to a given difficulty level and intubation device. For this study, the SimMan 3G manikin will be used which is proven to be a high-fidelity manikin with good anatomical proportions of the oral cavity.[20] The head of the mannikin will be placed on an intubation pillow in the standardized 'sniffing' position that is routinely used for intubation. Before each new participant, the airway of the manikin will be lubricated and the videolaryngoscope blade and the ETT (7 mm parker flextip) will be cleaned to avoid slipperiness. For both videolaryngoscopes the use of a stylet (Verathon Single-use Stylet Medium) is necessary because of the hyperangulation of the VL blades. Therefore, the stylets will be placed inside the ETT before the start of the trial to shape the ETT to the pre-desired form. The curve of the stylet may not be altered by the participants because the manufacturer has already bent it into the desired form. If the stylet becomes bent due to repeated handling, a new one will be used. Other optimisation manoeuvres such as application of external laryngeal pressure and the use of gum elastic bougie will not be allowed. The intubation procedure will start from the moment the videolaryngoscope passes the manikin's teeth and ends when ventilation is confirmed. In all four scenarios all primary and secondary end-points will be measured. These will be determined as follows:

- Time to glottic view: measured with a stop-watch by the investigator from the moment the videolaryngoscope passes between the manikin's teeth until a view on the vocal cords is obtained. The observer will indicate when to start and stop timing.
- Time to successful intubation: measured with a stop-watch by the investigator from the moment the videolaryngoscope passes between the manikin's teeth until the ETT has visually passed the vocal cords. The observer will indicate when to start and stop timing.
- Time to ventilation: measured with a stop-watch by the investigator from the moment the videolaryngoscope passes between the manikin's teeth until ventilation is confirmed by observing a consistent capnographic waveform. The observer will indicate when to start and stop timing.
- Number of intubation attempts: The total number of intubation attempts needed to obtain a successful intubation is counted by the investigator. A failed intubation attempt is defined as either oesophageal intubation, any that lasted over 60 seconds, or where the device was removed from the manikin's mouth and reinserted for another attempt. More than three intubation attempts are not reported individually but as "four intubation attempts or more".
- Successful intubation rate: The rate of successful intubations is defined as the percentage of intubations that is successful in each attempt. For every attempt, the investigator reports if the intubation was successful. If all data has been gathered, the successful intubation rate can be calculated per number of attempts by dividing the total number of successful intubations over the total number of intubations performed by all participants in that intubation attempt.
- Ease of intubation: If intubation was successful, the participant is asked to give a score according to the average ease of intubation of all intubation attempts with that particular videolaryngoscope in combination with the specific airway scenario. This

score is given according to a 5-point Likert scale (1 = very easy, 2 = easy, 3 = moderate, 4 = difficult, 5 = very difficult).

For the end-points time to glottic view, time to intubation, time to ventilation, and ease of intubation only the data obtained from a successful intubation will be included in the study.

4.4 Withdrawal of individual subjects

Subjects can leave the study at any time for any reason if they wish to do so without any consequences. The investigator can decide to withdraw a subject from the study for urgent medical reasons.

5. SAFETY REPORTING

Because the nature of this study is a manikin study and therefore no patients participate in this study, there are no risks of adverse events.

6. STATISTICAL ANALYSIS

Results will be analysed using IBM SPSS Statistics version 27. For all variables, missingness will be tabulated and reported. For continuous variables, normality and outliers will be analysed and reported. It is expected that outcomes from the same participant will be more similar than outcomes from different participants and they are not expected to be independent of one another. Prior to applying the statistical test to the continuous data, it will be checked for normality.

6.1 Primary endpoint: Time to intubation

The primary outcome parameter, time to intubation measured in seconds, is a continuous parameter and will be presented quantitatively by median and inter-quartile range (IQR). If data is not normally distributed, this parameter will be analysed using the Wilcoxon Signed-rank test. However, in case of normal distribution it will be analysed using a paired t-test.

6.2 Secondary endpoints: Time to glottic view, time to intubation, Number of intubation attempts, Successful intubation rate and Ease of intubation.

Secondary parameters exist of both continuous (Time to glottic view and Time to intubation) and integer / proportion (Number of intubation attempts, Successful intubation rate and Ease of intubation) parameters. Continuous data will be analysed using the Wilcoxon Signed-rank test if the data is not normally distributed and the data will be analysed using the paired t-test if the data is normally distributed. Integer data / proportions will be analysed using the Chi square test. The results will be summarized by median and inter-quartile range for each parameter. The difference between groups will be presented as a ratio. Successful intubation rate is the only parameter that needs to be calculated after the experiment is executed, all other parameters do not need further calculation. The successful intubation rate will be calculated per number of intubation attempts. For example, the success rate of the first intubation attempt will be calculated as follows:

Successful intubation rate of first attempt (%) = (Total number of successful intubations performed in the first attempt) / (Total number of first attempt intubations performed) * 100

6.3 Bias

No unforeseen bias is to be expected.

7. ETHICAL CONSIDERATIONS

7.1 Regulation statement

The study will be conducted according to the principles of the WMA Declaration of Helsinki (2013) and in accordance with the Medical Research Involving Human Subjects Act (WMO). Considering that this study is not a medical scientific study and does not subject individuals to actions or impose rules of conduct on them.

7.2 Recruitment and consent

Written consent to participate in the study will be obtained from all participants prior to the start of the study by the investigator through an informed consent form. This form will provide information about the study including an opening statement which will outline the purpose of the research and what participants will do. Each form will be signed by the investigator and the participant prior to the experiment.

8. ADMINISTRATIVE ASPECTS, MONITORING AND PUBLICATION

8.1 Handling and storage of data and documents

All data will be collected in the electronic data capture system Castor (2022). Only the project leader and principal investigator will have access to the source data and all data will be stored for 15 years. Because no personal identifiable information is collected from the participants and all data will be stored anonymously, the subject's privacy is protected.

9. STRUCTURED RISK ANALYSIS

Because the nature of this study is a manikin study and therefore no patients participate in this study, there are no risks involved.

10. REFERENCES

[1] R. M. Cooper, "Preparation for and management of "failed" laryngoscopy and/or intubation," Anesthesiology, vol. 130, pp. 833–849, 5 2019.

[2] M. Michailidou, T. O'Keeffe, J.M. Mosier, et al., A comparison of video laryn-goscopy to direct laryngoscopy for the emergency intubation of trauma pa-tients, World J. Surg. 39 (3) (2015) 782e788, https://doi.org/10.1007/s00268-014-2845-z

[3] A. De Jong, N. Molinari, M. Conseil, et al., Video laryngoscopy versus directlaryngoscopy for orotracheal intubation in the intensive care unit: a system-atic review and meta-analysis, Intensive Care Med. 40 (5) (2014) 629e639, https://doi.org/10.1007/s00134-014-3236-5

[4] Armstrong, Laura, et al. "An international survey of airway management education in 61 countries." British Journal of Anaesthesia (2020).

[5] Julious SA. Sample sizes for clinical trials with Normal data. Statist. Med. 2004; 23:1921-1986.

[6] Althunian, T. A., De Boer, A., Groenwold, R. H. H., & Klungel, O. H. (2017). Defining the noninferiority margin and analysing noninferiority: An overview. British Journal of Clinical Pharmacology, 83(8), 1636–1642. https://doi.org/10.1111/bcp.13280

[7] Pieters, B. M. A., Wilbers, N. E. R., Huijzer, M., Winkens, B., & Van Zundert, A. A. J. (2016). Comparison of seven videolaryngoscopes with the Macintosh laryngoscope in manikins by experienced and novice personnel. Anaesthesia, 71(5), 556–564. https://doi.org/10.1111/anae.13413

[8] Russell, T., Lee, C., Firat, M., & Cooper, R. M. (2011). A Comparison of the Forces Applied to a Manikin during Laryngoscopy with the Glidescope® and Macintosh Laryngoscopes. Anaesthesia and Intensive Care, 39(6), 1098–1102. https://doi.org/10.1177/0310057x1103900619

[9] Hodd, J. A. R., Doyle, D. J., Gupta, S., Dalton, J. E., Cata, J. P., Brewer, E. J., James, M., & Sessler, D. I. (2011). A Mannequin Study of Intubation with the AP Advance and GlideScope Ranger Videolaryngoscopes and the Macintosh Laryngoscope. Anesthesia & Analgesia, 113(4), 791–800. https://doi.org/10.1213/ane.0b013e3182288bda

[10] Shin, D. H., Choi, P. C., & Han, S. K. (2011). Tracheal intubation during chest compressions using Pentax-AWS®, GlideScope®, and Macintosh laryngoscope: a randomized crossover trial using a mannequin. Canadian Journal of Anesthesia/Journal canadien d'anesthésie, 58(8), 733–739. https://doi.org/10.1007/s12630-011-9524-4

[11] Moritz, A., Holzhauser, L., Fuchte, T., Kremer, S., Schmidt, J., & Irouschek, A. (2021). Comparison of Glidescope Core, C-MAC Miller and conventional Miller laryngoscope for difficult airway management by anesthetists with limited and extensive experience in a simulated Pierre Robin sequence: A randomized crossover manikin study. PLOS ONE, 16(4), e0250369. https://doi.org/10.1371/journal.pone.0250369

[12] Pius, J., & Noppens, R. R. (2020). Learning curve and performance in simulated difficult airway for the novel C-MAC® video-stylet and C-MAC® Macintosh video laryngoscope: A prospective randomized manikin trial. PLOS ONE, 15(11), e0242154. https://doi.org/10.1371/journal.pone.0242154

[13] Moritz, A., Leonhardt, V., Prottengeier, J., Birkholz, T., Schmidt, J., & Irouschek, A. (2020). Comparison of Glidescope® GoTM, King VisionTM, Dahlhausen VL, I-ViewTM and Macintosh laryngoscope use during difficult airway management simulation by experienced and inexperienced emergency medical staff: A randomized crossover manikin study. PLOS ONE, 15(7), e0236474. https://doi.org/10.1371/journal.pone.0236474

[14] Suzuki, K., Kusunoki, S., Sadamori, T., Tanabe, Y., Itai, J., & Shime, N. (2019). Comparison of video and conventional laryngoscopes for simulated difficult emergency tracheal intubations in the presence of liquids in the airway. PLOS ONE, 14(7), e0220006. https://doi.org/10.1371/journal.pone.0220006

[15] Measurement of forces applied during Macintosh direct laryngoscopy compared with GlideScope video laryngoscopy. Russell T, Khan S, Elman J, Katznelson R, Cooper RM. Anaesthesia. 2012 Jun; 67(6):626-31. doi: 10.1111/j.1365-2044.2012.07087.x. Epub 2012 Feb 21.

[16] Cooper, R.M., Pacey, J.A., Bishop, M.J. et al. Early clinical experience with a new videolaryngoscope (GlideScope) in 728 patients. Can J Anaesth 52, 191 (2005).

[17] Kim JT, Na HS, Bae JY, Kim DW, Kim HS, Kim CS, Kim SD.GlideScope video laryngoscope: a randomized clinical trial in203 paediatric patients. Br J Anaesth 2008;101:531–4

[18] Lai HY, Chen IH, Chen A, Hwang FY, Lee Y. The use of the GlideScope for tracheal intubation in patients with ankylosing spondylitis. Br J Anaesth 2006;97:419–22

[19] Lim HC, Goh SH. Utilization of a GlideScope videolaryngoscope for orotracheal intubations in different emergency air-way management settings. Eur J Emerg Med 2009;16:68–73

[20] Jordan GM, Silsby J, Bayley G, Cook TM. Evaluation of fourmanikins as simulators for teaching airway management procedures specified in the Difficult Airway Society guidelines,and other advanced airway skills.Anaesthesia2007;63:708–12.

C.3. Study Design Rationale

In this section, a rationale will be given for the choices made regarding the final study protocol and design.

C.3.1. Aim and Hypotheses of the Study

The extensive experimental tests that were performed on the Goodscope's predecessor [25], showed promising results. However, the prototype of the Goodscope, used in this manikin study, has undergone several design changes compared to the version evaluated by Straathof. Among which the most important being a hyperangulated blade instead of a conventional Macintosh blade. Hence, further evaluation of the Goodscope was needed. Not only an evaluation of the basic components of the Goodscope such as the light, camera and field of view, but also on the efficacy of the Goodscope in clinical practice. Therefore, the aim of this study was to evaluate the efficacy of the Goodscope compared to the GlideScope.

Because the Goodscope has advantages over currently available standard videolaryngoscopes, in terms of costs and reusability rather than in terms of efficacy, a non-inferiority design was deemed appropriate [7]. Therefore, the hypothesis of this study was that the efficacy of the Goodscope will be non-inferior to the GlideScope.

C.3.2. Randomised Crossover Manikin Study

This study incorporated a crossover design since, following the sample size calculation of n = 48, it was not considered feasible to include double the number of participants. Because of the crossover design, participants intubated the same manikin five times, one time with the Macintosh laryngoscope and two times with both the Goodscope and the GlideScope, which may have led to learning curve effects. To minimise these effects, all participants were randomly assigned to an intubation sequence (1: Goodscope - easy scenario, 2: Goodscope - difficult scenario, 3: GlideScope - easy scenario and 4: GlideScope - difficult scenario) using block randomisation. Since 24 different intubation sequences could be generated, every sequence was included at least twice.

Because the efficacy of the Goodscope could not be tested in clinical practice on patients due to certification constraints, a manikin study was found to be the most realistic alternative. Extra attention was given to using a realistic airway model. Therefore the SimMan 3G was chosen on which, next to the normal airway, several difficult airway scenarios can be simulated. When only the easy airway scenario (the normal airway of a manikin) would be included, the results were not expected to provide sufficient insight since all participants were experienced with videolaryngoscopy. Therefore, next to the easy scenario, a difficult scenario had to be included. Because literature suggests that tongue swelling substantially increases the intubation difficulty in comparison to other simulated difficult airways [14], and maximal tongue swelling was found to be the most realistic scenario in the pilot study, it was chosen as the difficult airway scenario in this study. The SimMan 3G was chosen for this study since tongue swelling could be simulated and it was found to be an acceptable realistic airway model [9, 12]. Due to the sample size, multiple medical centres had to be included in this study. Because equal intubation experience of the participant group in the study design had to be ensured, only medical centres that used the GlideScope as their standard videolaryngoscope and that had a SimMan 3G manikin could be included. Eventually, the LUMC, Amsterdam UMC and UMCG were found to meet both requirements and were therefore included.

C.3.3. Participant group

The Goodscope is primarily designed for LMICs in which fewer clinicians are familiar with videolaryngoscopy. However, in this study, the Goodscope was evaluated by experienced users only. This group of participants was chosen because, in this first evaluation of the Goodscope, the goal was to demonstrate the efficacy of the Goodscope. If less experienced participants were included, there would be a risk that the emphasis would be on the participants' experience rather than on the efficacy of the videolaryngoscope. To ensure the same level of experience among all participants, they were only included if they were anaesthetists or residents in anaesthesia with a minimal clinical intubation experience of 2 years. Although anaesthesia assistants frequently have extensive experience with direct laryngoscopy, they were not included in this study since their experience with videolaryngoscopy is not as comprehensive as for anaesthetists and residents in anaesthesia. Based on clinical expert advice, a minimal

clinical intubation experience of 2 years was chosen since residents in anaesthesia were expected to be sufficiently experienced after 2 years.

C.3.4. Protocol

After testing the first version of the research protocol in the pilot study it was evident that a clear introduction to the research protocol was desired since the participants undertook various actions that were not permitted by the preliminary research protocol (see section C.1). Therefore, a standardised introduction of 5 minutes was given to each participant after they had picked a sealed envelope containing their intubation sequence and signed the informed consent form (see section C.4). This introduction included the following:

- The reason for this study: In this study, we want to evaluate the efficacy of the Goodscope compared to the GlideScope.
- What was expected from them: You are going to intubate the manikin four times, two times with the Goodscope and two times with the GlideScope. The order in which you are going to intubate the manikin is in the sealed envelope you just picked. The executive investigator will tell you when you may use which device.
- The goal of the intubations: The goal is to successfully intubate the manikin as if it were a patient. So, it is important to be especially careful not to apply too much force to the teeth to keep the intubation as realistic as possible.
- When to start/stop the intubation: You can start intubating the manikin if the executive investigator indicates it. However, you may already hold the videolaryngoscope in your hand. The intubation stops when ventilation is confirmed by observing a consistent capnographic waveform on the monitor.
- When the participant had to start over: A few situations may occur in which the intubation has to start over. If the executive investigator indicates this, you are asked to remove the videolaryngoscope and ETT (if applicable) from the mouth of the manikin and to prepare for a new intubation attempt. You are asked to start only when the executive investigator indicates it.
- What was allowed and what was not allowed during intubation: You are allowed to intubate the manikin as if it were a patient with help of an assistant who will aid you during the intubations. The assistant will hand you all necessary materials and will remove the stylet from the ETT when you indicate so. You may alter the position of the manikin's head throughout the entire intubation. However, the intubation pillow must remain underneath the head of the manikin. You are not allowed to use any additional optimisation manoeuvres, such as BURP or a bougie and no one (except for the assistant) can help you during the intubation. The stylet inside the ETT is bent into the optimal shape and therefore you are not allowed to manipulate the angle of the stylet.
- What happened after each intubation: After ventilation is confirmed, you are asked to grade the ease of the intubation according to a 5-point Likert scale in which 1 = very easy, 2 = easy, 3 = moderate, 4 = difficult, 5 = very difficult.
- A closing note: Before we start with the experiment you are asked to intubate the manikin one time using a direct Macintosh videolaryngoscope to get used to the manikin.

It was chosen to allow each participant to practice intubation one time using a direct Macintosh laryngoscope in order to give each participant a fair chance of getting used to the anatomy of the manikin without getting accustomed to both videolaryngoscopes.

As recommended by the manufacturer of the SimMan 3G, lubricant was used to reduce the friction in the airway of the manikin. Because it was found in the pilot study that little cleaning of the materials in combination with using too much lubricant caused the devices to become slippery, it was chosen to solely lubricate the airway of the manikin and to clean all equipment before each new participant.

The manikin was placed in the sniffing position since this is the standard position used in the included medical centres. This position is commonly recommended and found to lower the intubation difficulty in predicted difficult airways [24, 1]. Extra attention was given to not exerting much force on the teeth of the manikin since it was observed in the pilot study that the flexible teeth of the manikin deformed if force was exerted on them. It was expected that in reality, clinicians are more careful with the teeth since there is a chance to break them. To keep the simulation close to reality, dentures with rigid teeth were used instead of flexible teeth used in the pilot study. Instead of not allowing the participants to

touch the teeth, participants were told in the introduction to avoid exerting force on the teeth of the manikin, since it was found in the pilot study that not allowing them to touch the teeth was frustrating.

An assistant aided the participants during the intubations since this is the standard intubation procedure in all medical centres included. To reduce the chance of deviating results, the same assistant aided all participants.

C.3.5. Materials

During the preparations for this manikin study, the design of the prototype of the Goodscope changed. The most important design change made, is the switch from a conventional Macintosh blade design to a hyperangulated blade design. This change was initiated in the first meetings with the LUMC about the manikin study since clinical experts of the LUMC indicated that they would recommend a hyperangulated blade design. However, it was not clear if this meaning was broadly supported. Therefore, a questionnaire was sent to the Erasmus MC, LUMC, Reinier de Graaf Gasthuis, Amsterdam UMC and UMCG regarding the preference of the blade type of a videolaryngoscope. Of the 74 anaesthesiologists who completed the questionnaire, 62% indicated that a hyperangulated blade would be their primary choice (see figure C.2).

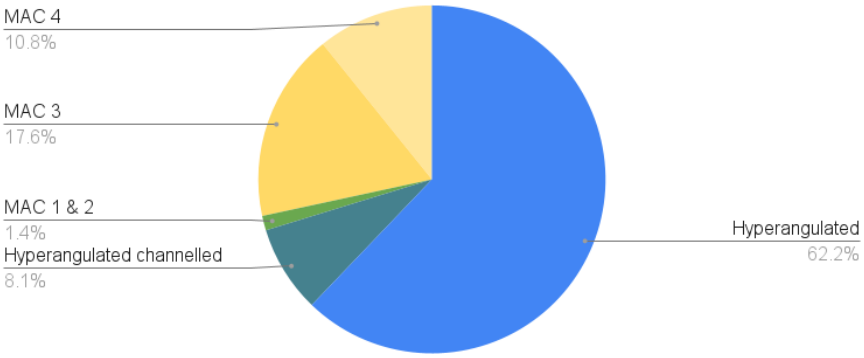


Figure C.2: Count of the question: 'If you could choose one blade for a video laryngoscope, which would it be?'

Although hyperangulated blades are mainly recommended for difficult airways [27], this questionnaire suggested that anaesthesiologists think that it can be more broadly used. As a result, the design of the Goodscope has been changed to a hyperangulated blade design. The final prototype design used in this manikin study is depicted in figure C.3.

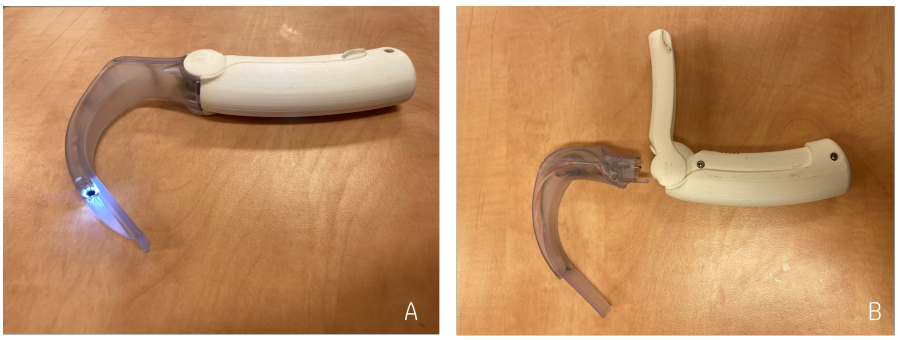


Figure C.3: Prototype of the Goodscope used in this study with blade attached (A) and detached (B)

Both the Goodscope and the GlideScope were connected to their own monitor on which the video was streamed. The GlideScope was connected via a string whereas the Goodscope was wirelessly connected. The type and size (7.5 mm) of the ETT used in the study were chosen because of availability in the medical centres. A rigid stylet was used instead of a single-use stylet because it is less flexible and, therefore, maintained the desired shape. An overview of all materials used in this study is detailed in figure C.4.

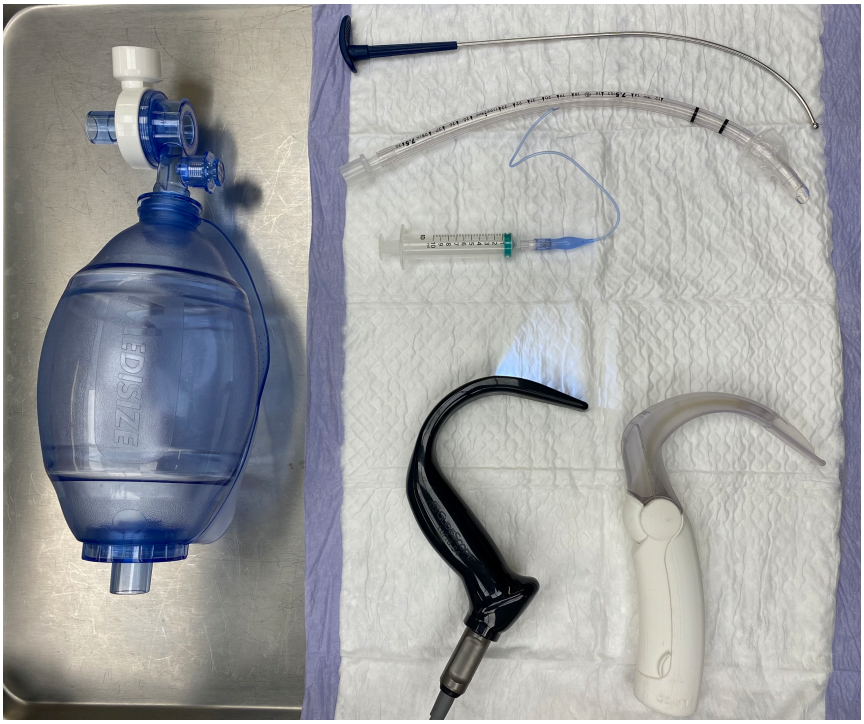


Figure C.4: An overview of the materials used in this study

C.3.6. Measurements

The endpoints used in this manikin study were selected on the basis of the literature study that was performed. However, in this literature study, no recommendations were given on which endpoint should be used as the primary endpoint. Since the power of the study is calculated based on the primary endpoint, it is desirable that the primary endpoint addresses the aim of the study [17]. According to the literature study, time to intubation/ventilation was found to best identify the device problems of videolaryngoscopes and therefore address the aim of this study. Based on clinical expert advice, time to successful intubation was eventually chosen as the primary endpoint.

The definitions of the endpoints used were based on previous studies and on clinical expert advice. Several definitions were adapted in response to the pilot study. The starting point of all time measurements, the blade passing the teeth of the manikin, was chosen because it was expected that this definition would include the least effects on participant behaviour. Time to glottic view was measured until the vocal cords were observed by the executing investigator, similar to the definitions of the majority of studies in the top 18. Time to successful intubation stopped when the ETT had passed the vocal cords. This was based on clinical expert advice rather than on the definitions of the studies in the top 18 since only 4 of the 12 studies that included time to successful intubation used the same definition. The first inflection of the capnographic waveform was defined as the end of time to ventilation since this was advised to be the most secure way of confirming ventilation. A failed intubation was defined as esophageal intubation, an intubation that lasted longer than 60 sec or the participant removing the videolaryngoscope from the manikin's mouth and reinserting it for another attempt before the ETT had passed the vocal cords. A time limit of 60 sec was chosen because clinical experts indicated that they would switch to another device if intubation was not completed after 60 sec. Moreover, as described in the pilot study, primarily a time limit of 120 sec was chosen. However, this was found to be too easy for the participants.

C.3.7. Statistics

The sample size calculation was performed based on expert advice from the statistical help desk of the TU Delft and from a statistician of the Biomedical Data Sciences department of the LUMC. Because the formula used for this sample size calculation was based on approximations of the normal distribution, the standard deviation was included in the formula. However, the majority of the studies that reported

the time to successful intubation with the GlideScope used the median and the IQR instead of the mean and the standard deviation. Therefore, it was chosen to use the standard deviation of the medians found in these studies since no other data was available. Because the sample size calculation was an estimation, the minimum of participants for this study was increased to 48 participants.

The final version of the research protocol indicated that the data obtained from the categorical parameters (number of intubation attempts and ease of intubation) would be analysed using the Chi-square test. However, since these parameters were ordinal, the Wilcoxon Signed Ranks Test was used instead.

C.4. Informed Consent

Proefpersoneninformatie voor deelname aan medisch-wetenschappelijk onderzoek

Vergelijking van de Goodscope versus GlideScope

Officiële titel: Vergelijking van de Goodscope versus GlideScope voor tijd tot intubatie in een gerandomiseerd cross-over mannequin onderzoek.

Inleiding

Beste Deelnemer,

Met deze informatiebrief willen we u vragen of u wilt meedoen aan medisch-wetenschappelijk onderzoek. Meedoen is vrijwillig. Als u wilt meedoen, kunt u het toestemmingsformulier invullen dat u vindt in bijlage B. We willen eerst weten of u geschikt bent om mee te doen. Als u de volgende vragen met ja kunt beantwoorden bent u geschikt om deel te nemen aan dit onderzoek:

- Bent u anesthesioloog of anesthesist (in opleiding)?
- Heeft u een minimale intubatie ervaring (op patiënten) van 2 jaar?

1. Algemene informatie

U wordt uitgenodigd om deel te nemen aan een onderzoek genaamd “Comparison of the Goodscope versus Glidescope for time to intubation in a randomized crossover manikin study”. Dit onderzoek wordt uitgevoerd door Roos Wiltink van de TU Delft, Dr. C. Martini van het LUMC en Prof. Dr. J. Dankelman van de TU Delft.

2. Wat is het doel van het onderzoek?

Het doel van deze studie is de tijd tot succesvolle intubatie te evalueren van een nieuwe low-cost videolaryngoscoop in vergelijking met de GlideScope in een gerandomiseerde cross-over mannequinstudie in luchtwegscenario’s van verschillende moeilijkheidsgraad.

3. Wat is de achtergrond van het onderzoek?

Huidige videolaryngoscopen zijn ontwikkeld voor de westerse medische wereld en zijn daardoor prijzig (rond de $15.000). Deze videolaryngoscopen hebben vaak een kostbaar beeldscherm geïntegreerd in de laryngoscoop, onderdelen zijn niet demonteerbaar en het materiaal is vaak niet geschikt voor westerse schoonmaakprotocollen waardoor de apparaten vaak single-use zijn. De bestaande videolaryngoscopen sluiten daardoor niet aan op de behoeften, budgetten en protocollen van Low Middle Income Countries (LMIC’s) waardoor slechts 46% van de ziekenhuizen in LMIC over een videolaryngoscoop beschikt, in tegenstelling tot 93% van de ziekenhuizen in High Income Countries (HIC’s). Daarom is de Goodscope ontwikkeld, een herbruikbare low-cost videolaryngoscoop.

4. Hoe verloopt het onderzoek?

Doet u mee met het onderzoek? Dan duurt dat in totaal ongeveer 15 min.
Voordat u begint aan het intuberen van de mannequin zal gevraagd worden hoeveel intubaties u in totaal op patiënten hebt uitgevoerd. Vervolgens zal u gevraagd worden om de mannequin in totaal vier keer te intuberen (twee keer met zowel de GlideScope als de Goodscope in verschillende moeilijkheidsgraden) op dezelfde wijze als u een patiënt zou intuberen. Loting bepaalt in welke volgorde u deze vier intubaties zal uitvoeren. Tijdens het intuberen zal de onderzoeker verschillende parameters meten. Na elke succesvolle intubatie zal gevraagd worden hoe u het gemak van de intubatie zou scoren op een 5-punts schaal.

5. Wanneer stopt het onderzoek?

Als alle onderzoeken voorbij zijn stopt het onderzoek. Als u zelf wilt stoppen met het onderzoek mag dat op ieder moment. Meld dit dan meteen bij de onderzoeker. U hoeft er niet bij te vertellen waarom u stopt. Ook als de onderzoeker het beter vindt voor u om te stoppen kan het onderzoek vroegtijdig voor u afgebroken worden.

6. Wat doen we met uw gegevens?

De verkregen data zal anoniem verzameld worden. Ook zal er geen persoonlijke of tot op de persoon herleidbare data verzameld worden. De data zal gebruikt worden voor een afstudeeronderzoek van de TU Delft en een eventuele toekomstige publicatie.

7. Krijgt u een vergoeding als u meedoet aan het onderzoek?

U krijgt geen vergoeding als u meedoet aan dit onderzoek.

8. Heeft u vragen?

Vragen over het onderzoek kunt u stellen aan Roos Wiltink of Chris Martini. Wilt u advies van iemand die er geen belang bij heeft? Ga dan naar Remco Zoethout.

9. Hoe geeft u toestemming voor het onderzoek?

Wilt u meedoen? Dan vult u het toestemmingsformulier in dat u bij deze informatiebrief vindt. U en de onderzoeker krijgen allebei een getekende versie van deze toestemmingsverklaring.

Dank voor uw tijd.

Bijlage A: contactgegevens

Uitvoerende onderzoeker
Naam: Roos Wiltink
Tel: +316 830 45 847
Mail: r.w.wiltink@student.tudelft.nl

Onafhankelijk onderzoeker
Dr. Remco Zoethout
Tel: +31 71 529 8646
Mail: r.w.m.zoethout@lumc.nl

Hoofdonderzoeker
Dr. C. Martini
Tel: +31 71 529 8903
Mail: c.h.martini@lumc.nl

Bijlage B: toestemmingsformulier proefpersoon

Behorende bij: Vergelijking van Goodscope versus GlideScope

- Ik heb de informatiebrief gelezen. Ook kon ik vragen stellen. Mijn vragen zijn goed genoeg beantwoord. Ik had genoeg tijd om te beslissen of ik meedoe.
- Ik weet dat meedoen vrijwillig is. Ook weet ik dat ik op ieder moment kan beslissen om toch niet mee te doen met het onderzoek. Of om ermee te stoppen. Ik hoef dan niet te zeggen waarom ik wil stoppen.
- Ik geef de onderzoekers toestemming om mijn gegevens te verzamelen en gebruiken. De onderzoekers doen dit alleen om de onderzoeksvraag van dit onderzoek te beantwoorden.
- Ik weet dat voor de controle van het onderzoek sommige mensen al mijn gegevens kunnen inzien. Die mensen staan in deze informatiebrief. Ik geef deze mensen toestemming om mijn gegevens in te zien voor deze controle.
- Ik wil meedoen aan dit onderzoek.

Mijn naam is (proefpersoon): ……..
Handtekening: …… Datum : __ / __ / __

Ik verklaar dat ik deze proefpersoon volledig heb geïnformeerd over het genoemde onderzoek.

Naam onderzoeker (of diens vertegenwoordiger):……
Handtekening:…… Datum: __ / __ / __

C.5. Questionnaire Intubation Experience

Vragenlijst voor vergelijking van de Goodscope versus GlideScope

Deze vragen zullen door de onderzoeker verbaal gesteld worden aan de participant.

Vraag 1 zal gesteld worden voordat de participant begint met intuberen:

1. Wat is het aantal intubaties dat u in totaal in uw werkende leven heeft uitgevoerd op patiënten?

    A. Minder dan 40
    B. 40 tot 80
    C. 80 of meer

Vraag 2 zal na elke succesvolle intubatiepoging met de verschillende combinaties van videolaryngoscoop en luchtwegscenario gesteld worden:

2. Hoe gemakkelijk heeft u alle intubatiepogingen tot en met de succesvolle intubatiepoging ervaren met de desbetreffende videolaryngoscoop in combinatie met het luchtwegscenario op een schaal van 1 tot 5? Waarin 1 erg makkelijk is en 5 erg moeilijk?

    1. Erg makkelijk
    2. Makkelijk
    3. Gemiddeld
    4. Moeilijk
    5. Erg moeilijk

C.6. Letter of Approval Medical Ethics Committee

Leids Universitair Medisch Centrum

afdeling Anesthesiologie research
postzone H5-P
afzender mw. dr. M. van Velzen
bezoekadres Albinusdreef 2, 2333 ZA Leiden
telefoon 071 526 4558
fax 071 526 6230
e-mail M.van_Velzen@lumc.nl

onze referentie 2022-018
uw referentie
datum 31 maart 2022
onderwerp Beoordeling onderzoek
aantal pagina's 2

aan Afdeling Anesthesiologie
t.a.v. dr. C.H. Martini
Postzone H5-P

Beste heer,

De niet-WMO commissie van divisie 1 van het LUMC heeft het door u voorgelegde onderzoek "**Comparison of the Goodscope versus GlideScope for time to intubation in a randomized crossover manikin study**" (2022-018) in goede orde ontvangen. Het onderzoek is besproken tijdens de vergadering van 31 maart 2022.

De commissie heeft de volgende documenten ontvangen:
Aanbiedingsbrief 24-03-2022
IMDD versie 1 24-03-2022
Informatiebrief deelnemers en toestemmingsformulier versie 1 24-03-2022
Niet-WMO vragenlijst versie 1 24-03-2022
Onderzoeksprotocol versie 1 24-03-2022
Vragenlijst Goodscope versie 2 24-03-2022
030-RM-03.xlsx - Risk Analysis

Uw onderzoek valt niet onder de reikwijdte van de Wet medisch-wetenschappelijk onderzoek met mensen (WMO). Het betreft geen onderzoek waarbij personen aan handelingen worden onderworpen of onderzoek waarbij hen gedragsregels worden opgelegd. Voor de uitvoering ervan is daarom geen positief oordeel van een erkende toetsingscommissie vereist. We hebben geen bezwaar tegen dit onderzoek.

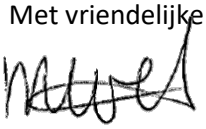
U bent zelf ervoor verantwoordelijk dat uw onderzoek wordt uitgevoerd binnen de kaders van de geldende wet- en regelgeving, zoals de WGBO en de AVG. We adviseren u contact op te

afdeling	Anesthesiologie research	aan	Afdeling Anesthesiologie
onze referentie	2022-018		
datum	31 maart 2022		
onderwerp	Beoordeling onderzoek		
aantal pagina's	2 van 2		

nemen met de Functionaris Gegevensbescherming van uw instelling om de gegevensverwerking voor dit onderzoek te bespreken.

Wij wensen u veel succes bij de uitvoer van uw onderzoek.

Met vriendelijke groet,



mw. dr. M. van Velzen
Secretaris nWMO-div1 commissie

References

[1] Yuki Akihisa et al. “Effects of sniffing position for tracheal intubation: a meta-analysis of randomized controlled trials”. In: *The American Journal of Emergency Medicine* 33 (11 Nov. 2015), pp. 1606–1611. ISSN: 0735-6757. DOI: 10.1016/J.AJEM.2015.06.049.

[2] E. Burdett et al. “Randomized controlled trial of the A.P. Advance, McGrath, and Macintosh laryngoscopes in normal and difficult intubation scenarios: A manikin study”. In: *British Journal of Anaesthesia* 107 (6 2011), pp. 983–988. DOI: 10.1093/bja/aer295.

[3] Shi Hao Chew et al. “Intubation with channeled versus non-channeled video laryngoscopes in simulated difficult airway by junior doctors in an out-of-hospital setting: A crossover manikin study”. In: *PLoS ONE* 14 (10 Oct. 2019). ISSN: 19326203. DOI: 10.1371/JOURNAL.PONE.0224017.

[4] P. Decamps et al. “Comparison of four channelled videolaryngoscopes to Macintosh laryngoscope for simulated intubation of critically ill patients: the randomized MACMAN2 trial”. In: *Annals of Intensive Care* 11 (1 2021). DOI: 10.1186/s13613-021-00916-3.

[5] P.-L. Declercq et al. “Usefulness of video-laryngoscopy with the Airway Scope for intubation performance and learning: an experimental manikin controlled study”. In: *Annals of Intensive Care* 6 (1 2016). DOI: 10.1186/s13613-016-0182-0.

[6] J.K. Gordon et al. “Direct versus indirect laryngoscopy using a Macintosh video laryngoscope: a mannequin study comparing applied forces Laryngoscopie directe versus indirecte à l’aide d’un vidéolaryngoscope Macintosh: une étude sur mannequin comparant les forces appliquée”. In: *Canadian Journal of Anesthesia* 67 (5 2020), pp. 515–520. DOI: 10.1007/s12630-020-01583-x.

[7] Seokyung Hahn. “Understanding noninferiority trials”. In: *Korean Journal of Pediatrics* 55 (11 2012), pp. 403–407. ISSN: 17381061. DOI: 10.3345/kjp.2012.55.11.403.

[8] F. Herbstreit et al. “Learning endotracheal intubation using a novel videolaryngoscope improves intubation skills of medical students”. In: *Anesthesia and Analgesia* 113 (3 2011), pp. 586–590. DOI: 10.1213/ANE.0b013e3182222a66.

[9] R. Hesselfeldt, Michael S. Kristensen, and L. S. Rasmussen. “Evaluation of the airway of the SimMan™ full-scale patient simulator”. In: *Acta Anaesthesiologica Scandinavica* 49 (9 Oct. 2005), pp. 1339–1345. ISSN: 00015172. DOI: 10.1111/j.1399-6576.2005.00856.x.

[10] J.A.R. Hodd et al. “A mannequin study of intubation with the AP advance and glidescope ranger videolaryngoscopes and the macintosh laryngoscope”. In: *Anesthesia and Analgesia* 113 (4 2011), pp. 791–800. DOI: 10.1213/ANE.0b013e3182288bda.

[11] I. Hunter et al. “Retention of laryngoscopy skills in medical students: a randomised, cross-over study of the Macintosh, A.P. Advance™, C-MAC® and Airtraq® laryngoscopes”. In: *Anaesthesia* 71 (10 Oct. 2016), pp. 1191–1197. ISSN: 13652044. DOI: 10.1111/ANAE.13589.

[12] G. M. Jordan et al. “Evaluation of four manikins as simulators for teaching airway management procedures specified in the Difficult Airway Society guidelines, and other advanced airway skills”. In: *Anaesthesia* 62 (7 July 2007), pp. 708–712. ISSN: 00032409. DOI: 10.1111/J.1365-2044.2007.05069.X.

[13] N. Komasawa et al. “Direct laryngoscopy training is important for videolaryngoscopy skill acquisition”. In: *British Journal of Anaesthesia* 118 (2 2017), pp. 269–270. DOI: 10.1093/bja/aew458.

[14] C. H. Maharaj et al. “Evaluation of intubation using the Airtraq® or Macintosh laryngoscopy - A manikin study”. In: *Anaesthesia* 61 (5 May 2006), pp. 469–477. ISSN: 00032409. DOI: 10.1111/j.1365-2044.2006.04547.x.

[15] Andreas Moritz et al. “Comparison of glidescope core, C-MAC miller and conventional miller laryngoscope for difficult airway management by anesthetists with limited and extensive experience in a simulated Pierre Robin sequence: A randomized crossover manikin study”. In: *PLoS ONE* 16 (4 April 2021 Apr. 2021). ISSN: 19326203. DOI: 10.1371/JOURNAL.PONE.0250369.

[16] Andreas Moritz et al. “Comparison of Glidescope Go, King Vision™, Dahlhausen VL, I-View™ and Macintosh laryngoscope use during difficult airway management simulation by experienced and inexperienced emergency medical staff: A randomized crossover manikin study”. In: *PLoS ONE* 15 (7 July July 2020). ISSN: 19326203. DOI: 10.1371/JOURNAL.PONE.0236474.

[17] Peter R. Nelson. “Primary and Secondary Endpoints”. In: *Clinical Trials Design in Operative and Non Operative Invasive Procedures*. Ed. by Kamal M.F. Itani and Domenic J. Reda. Cham: Springer International Publishing, 2017, pp. 11–20. ISBN: 978-3-319-53877-8. DOI: 10.1007/978-3-319-53877-8_2. URL: https://doi.org/10.1007/978-3-319-53877-8_2.

[18] B.M.A. Pieters et al. “Comparison of seven videolaryngoscopes with the Macintosh laryngoscope in manikins by experienced and novice personnel”. In: *Anaesthesia* 71 (5 2016), pp. 556–564. DOI: 10.1111/anae.13413.

[19] James Pius and Ruediger R. Noppens. “Learning curve and performance in simulated difficult airway for the novel C-MAC® video-stylet and C-MAC Macintosh video laryngoscope: A prospective randomized manikin trial”. In: *PLoS ONE* 15 (11 November Nov. 2020). ISSN: 19326203. DOI: 10.1371/JOURNAL.PONE.0242154.

[20] K. Raymondos et al. “The intubation scoop (i-scoop) - A new type of laryngoscope for difficult and normal airways”. In: *Anaesthesia* 69 (9 2014), pp. 990–1001. DOI: 10.1111/anae.12754.

[21] T. Russell et al. “A comparison of the forces applied to a manikin during laryngoscopy with the GlideScope® and Macintosh laryngoscopes”. In: *Anaesthesia and Intensive Care* 39 (6 2011), pp. 1098–1102. DOI: 10.1177/0310057x1103900619.

[22] M. Schieren et al. “Comparison of forces acting on maxillary incisors during tracheal intubation with different laryngoscopy techniques: a blinded manikin study”. In: *Anaesthesia* 74 (12 2019), pp. 1563–1571. DOI: 10.1111/anae.14815.

[23] D.H. Shin, P.C. Choi, and S.K. Han. “Tracheal intubation during chest compressions using Pentax-AWS, GlideScope, and Macintosh laryngoscope: A randomized crossover trial using a mannequin”. In: *Canadian Journal of Anesthesia* 58 (8 2011), pp. 733–739. DOI: 10.1007/s12630-011-9524-4.

[24] Kandel S Bhattarai B Shrestha SK. “Comparison of sniffing position and simple head extension for visualization of glottis during direct laryngoscopy”. In: *Kathmandu Univ Med J* 9 (1 2011), pp. 58–63.

[25] Robin Straathof et al. “Design and evaluation of a low-cost video laryngoscopic device for LMICs”. 2020.

[26] Kei Suzuki et al. “Comparison of video and conventional laryngoscopes for simulated difficult emergency tracheal intubations in the presence of liquids in the airway”. In: *PLoS ONE* 14 (7 June 2019). ISSN: 19326203. DOI: 10.1371/JOURNAL.PONE.0220006.

[27] A. van Zundert et al. “Videolaryngoscopy allows a better view of the pharynx and larynx than classic laryngoscopy”. In: *British Journal of Anaesthesia* 109.6 (2012), pp. 1014–1015. DOI: 10.1093/bja/aes418.