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A periscope-based, 3D printed indirect laryngoscope for resource limited settings: a non-randomized observational manikin trial

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Abstract

Background In the United States and other resource-rich settings, video laryngoscopy is often favored for emergency intubation over direct laryngoscopy due to ease of use and improved performance in difficult airways. Video laryngoscopes pose a significant cost barrier against adoption in low- and middle-income countries (LMICs). In this study, we designed and tested a low-cost, 3D printable, periscope-based laryngoscope that achieves an indirect view of the vocal cords without the use of a video camera. The absence of expensive video components allows this device to be manufactured for $4.41 USD, making it well-suited for resource-limited settings.

Methods The periscope-based laryngoscope was manufactured from polylactic acid (PLA) filament using a 3D printer. Manikin testing of the laryngoscope was performed by providers ranging from medical students to experienced physicians using the high fidelity Laerdal SimMan®. The novel laryngoscope was compared to commonly available direct and video laryngoscopes, and intubation times and first-pass success rates were recorded.

Results A total of 121 trials were performed. In experienced intubators, faster intubation times were seen in the direct and periscope-based laryngoscopes compared to video laryngoscopes. Mean intubation times for experienced intubators were as follows: Direct Laryngoscope = 17.45 s, Video Laryngoscope = 23.34 s, and Novel Periscope-based Laryngoscope = 11.31 s, with statistical significance ($p < 0.001$) found between the Video and Periscope-based laryngoscope times. 100% of trials resulted in successful intubation of the trachea.

Conclusion The periscope-based laryngoscope yielded intubation times and first-pass success rates that compare favorably to direct and video laryngoscopes, and it can be readily manufactured in multiple environments at a low price point without proprietary industrial technology. Next steps include human clinical trials and regulatory approvals prior to clinical adoption of the novel device.

Keywords Intubation, Laryngoscopes, Video laryngoscopes, Low-cost medical devices, Low-resource intubation, 3D printed laryngoscope

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Background

Endotracheal intubation (EI) is a procedure which serves to facilitate airway patency in patients who are unable to maintain their own airway. In the emergency department, EI is performed in critically ill patients and can be lifesaving in the short term. In U.S. emergency departments alone, 413,000 EIs are performed annually [1].

Typically, EIs are guided by a laryngoscope, which is used by clinicians to view the glottic opening and vocal cords as landmarks for correct insertion of an endotracheal tube. This visualization is necessary to avoid damage to the surrounding tissue and esophageal intubation, which are often associated with the inferior alternative of blind intubation [2].

Currently available laryngoscopes can be broadly divided into two categories: direct laryngoscopes (DLs) and indirect laryngoscopes (ILs). During DL intubation, the provider obtains a direct view of the vocal cords using a Macintosh or Miller blade [3]. IL intubation involves use of an adjunct device for visualization, most often a video laryngoscope (VL), with commonly used devices including the GlideScope® and the C-MAC® [4]. VLs have risen in popularity across developed countries due to their ease of use and low complication rates, especially when intubating difficult airways [4]. Additionally, VLs are associated with better first-pass success rates and reduced esophageal intubation compared to DL, particularly in novice clinicians [5, 6]. However, the advantages of VLs come at a significant monetary cost, including prevalent VL models priced upwards of $7000 USD and blade replacement costs which are higher than their DL counterparts [7].

As a result, VL device adoption in low and low middle income countries (LMICs) has been limited [8]. This has led to a pressing need for low-cost indirect laryngoscopy devices that provide LMIC clinicians with a similar laryngeal view as high-end VLs, especially for difficult airways and for novice clinicians. Several such devices have been developed in recent years, including the VividTrac®, the Airtraq®, and an improvised laryngoscope that attaches a borescope camera to a standard Macintosh blade [8, 9]. These options are an improvement over the high-cost gold standard VLs, but are single-use and cost $25–$100 USD per patient, with no clear advantage over DLs [8, 10]. For comparison, average DL costs are < $7 USD per patient, as they are reusable devices and do not require sophisticated video electronics [11].

This study aims to develop and test a periscope-based laryngoscope (PBL) that does not utilize costly video technology yet still confers the advantage of indirect visualization during intubation in clinical settings where few alternatives to DL exist. We hypothesized that the PBL can facilitate intubation times comparable to the current standards of practice for commercially available DL and VL models.

Materials and methods

Design and rendering of 3D laryngoscope and blade model

The laryngoscope model was designed in Fusion 360 (Autodesk, San Rafael, CA). The cross-sectional area was minimized to maximize remaining space in the pharynx and prevent failure due to limited incisor separation distance during intubation. Custom fittings were designed for all additional components (see "Device assembly" section). The design was then split into two pieces for faster 3D printing and less required support material. The blade was designed to fit into a track in the laryngoscope column and its dimensions were optimized for typical adult airways based on standard Macintosh blade dimensions. The final model was rendered within Fusion 360 and can be seen in Fig. 1.

3D printing of laryngoscope and blade

The laryngoscope column and blade were 3D printed using 1.75 mm PLA filament (Prusa Research, Prague, Czech Republic) on an Original Prusa MINI + 3D printer (Prusa Research, Prague, Czech Republic). The print file was prepared in PrusaSlicer software (Prusa Research, Prague, Czech Republic). The following print settings were used: Layer height = 0.15 mm; Infill density = 60% for laryngoscope column, 100% for blade; Infill pattern = gyroid; Supports: auto generated on build plate only, overhang threshold = 45°. The print time was under 9 h, and 56.99 g of filament were used. The 3D printed model can be seen in Fig. 1D.

Device assembly

Once the 3D printing process was complete, the laryngoscope was assembled (see Table 1 for components). To construct the light circuit, the two wires from a coin cell battery holder (size CR2032) were soldered onto the two ends of a 3 mm white LED light and insulated with heat-shrink tubing. The laryngoscope column was then assembled by snap-fitting the two columnar 3D printed pieces. The light circuit was inserted into the laryngoscope column. Two square mirrors were inserted into slots on the laryngoscope column in a parallel configuration, and a coin cell battery was placed into the battery holder. Cyanoacrylate glue was used to secure the two column components and mirrors in place.

Intubation procedure

The steps of intubation with the PBL can be seen in Fig. 2. The blade was inserted into its track within the laryngoscope column and placed distally on the column. The laryngoscope was then gripped with the provider's

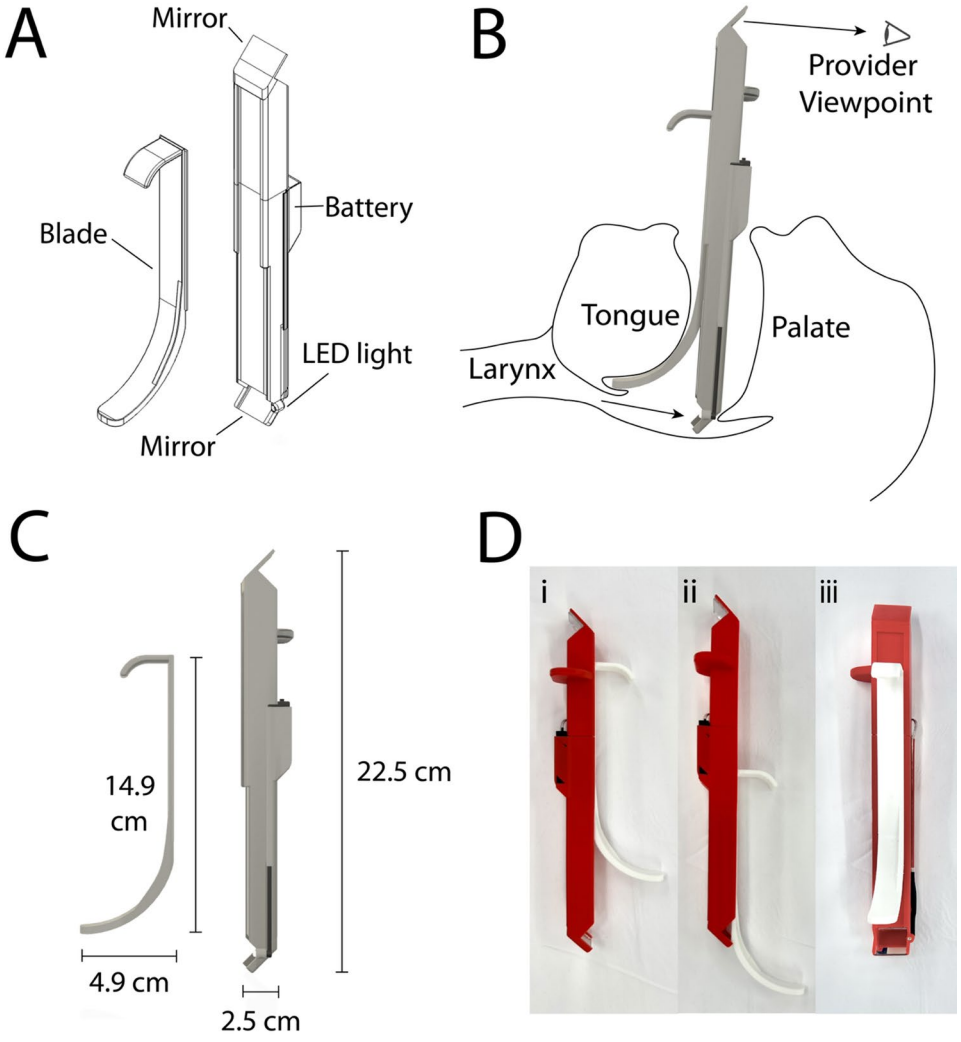

Fig. 1 Schematic of Periscope-based Laryngoscope design (**A**), diagram of device in use with anatomical landmarks (**B**). Arrows indicate direction of image projection. Device dimensions (**C**), and 3D printed device (**D**) with blade fully retracted (i), blade placed distally (ii), and a posterior view (iii)

Table 1 Cost breakdown of laryngoscope materials and cost per unit

Material	Quantity	Price
¾″ square mirror, glass	2	$0.20
PLA filament (includes support material)	56.99 g	$2.85
White LED bulb	1	$0.07
Battery holder with switch	1	$0.79
Coin cell battery, CR2032	1	$0.25
Cyanoacrylate glue	< 1 mL	~ $0.10
Heat-shrink tubing	2	$0.15
Total price/unit (USD)		$4.41

left hand and inserted into the oropharynx, with the blade seated at the midline within the vallecula (Fig. 1B). Anterior traction was held with the blade to elevate the tongue and epiglottis, while the laryngoscope column was advanced to the posterior oropharynx until a view of the vocal cords could be established through the top mirror. The laryngoscope was held in place while an endotracheal tube with stylet was guided into the oropharynx, held in the provider's right hand. The laryngoscope was used to visualize endotracheal tube insertion through the vocal cords. Once successful insertion had occurred, the laryngoscope was removed, and the cuff of the endotracheal tube was inflated.

Manikin testing procedure

The laryngoscope was tested on a Laerdal SimMan® 3G manikin and compared to an American profile Macintosh 4 blade direct laryngoscope as well as a GlideScope Hyperangle video laryngoscope. Four providers, ranging from medical students to attending emergency physicians, completed a total of 121 trials using each of the three devices with a 7.5 size endotracheal tube and flexible stylet. In trials performed by experienced clinicians with a minimum of 5 years of clinical intubation

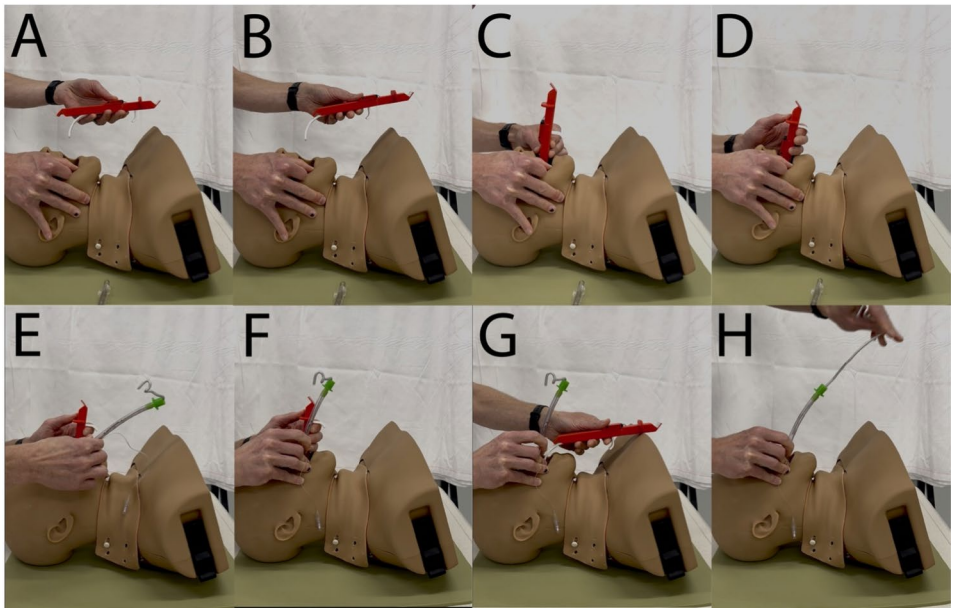

Fig. 2 Intubation of a manikin with the PBL. The oropharynx is opened (**A**), then the PBL blade is moved distally (**B**) and inserted into the oropharynx (**C**). Upward traction is pulled on the blade (**D**) and once a view of the vocal cords is established, the endotracheal tube is passed into the oropharynx (**E**, **F**). Once the tube is visualized in the larynx, the PBL is removed (**G**). The tube is then secured in place, and the stylet is removed (**H**)

Table 2 Results of timed manikin trials by experienced intubators

	Mean time (s)	Confidence interval (s)	Comparison to DL	Comparison to VL
Time to insert blade				
DL	3.07	[2.54, 3.60]	n/a	$p=0.28$
VL	3.62	[3.13, 4.10]	$p=0.283$	n/a
PBL	2.90	[2.51, 3.28]	$p=0.863$	$p=0.059$
Time to view vocal cords				
DL	6.90	[6.16, 7.63]	n/a	$p=0.055$
VL	5.69	[4.98, 6.40]	$p=0.055$	n/a
PBL	5.13	[4.56, 5.69]	$p<0.001$	$p=0.446$
Time to view endotracheal tube				
DL	10.58	[8.94, 12.22]	n/a	$p=0.037$
VL	13.44	[11.87, 15.01]	$p=0.037$	n/a
PBL	8.30	[7.07, 9.54]	$p=0.077$	$p<0.001$
Time to intubate				
DL	17.45	[13.36, 21.55]	n/a	$p=0.105$
VL	23.34	[19.40, 27.28]	$p=0.105$	n/a
PBL	11.31	[8.17, 14.44]	$p=0.07$	$p<0.001$

P values are the result of a Tukey–Kramer Post Hoc Analysis following a one-way ANOVA

experience in a high-volume trauma center, 24 trials were performed with the Macintosh blade, 27 trials with the GlideScope, and 41 with the PBL. During each trial, four time points were recorded from an initial start point of the provider holding the laryngoscope in their hand, based on verbal confirmation by the intubating provider: time to insertion of the laryngoscope into the oropharynx and first exerting upward traction, time to view the vocal cords, time to view the endotracheal tube using the laryngoscope, and time to intubation. Time to intubation was defined as the endotracheal tube being positioned deep to the vocal cords in what the provider determined was the correct location for a successful intubation. Each intubation was then verified by inflating the cuff of the endotracheal tube and confirming for lung inflation via bag-valve ventilation over the positioned endotracheal tube.

Data analysis and presentation

Data analysis was performed in Microsoft Excel. The Analysis of Variance (ANOVA) function was used to obtain mean intubation times and confidence intervals, followed by a Tukey–Kramer post hoc test to determine significance of differences between groups (Table 2). Data was presented as a grouped bar graph with error bars denoting confidence intervals (Fig. 3). An unpaired *T* test was used to determine significance between novice and experienced intubators (Table 3). For all p values, an alpha less than or equal to 0.05 was used to determine statistical significance.

Discussion

In the manikin intubation experiment, statistical analysis of data revealed that the periscope-based laryngoscope (PBL) performed as well as or better than both direct laryngoscope (DL) and video laryngoscope (VL) devices at all timepoints. Throughout the study, there were significant differences between laryngoscopes observed at three different time points: visualization of the vocal

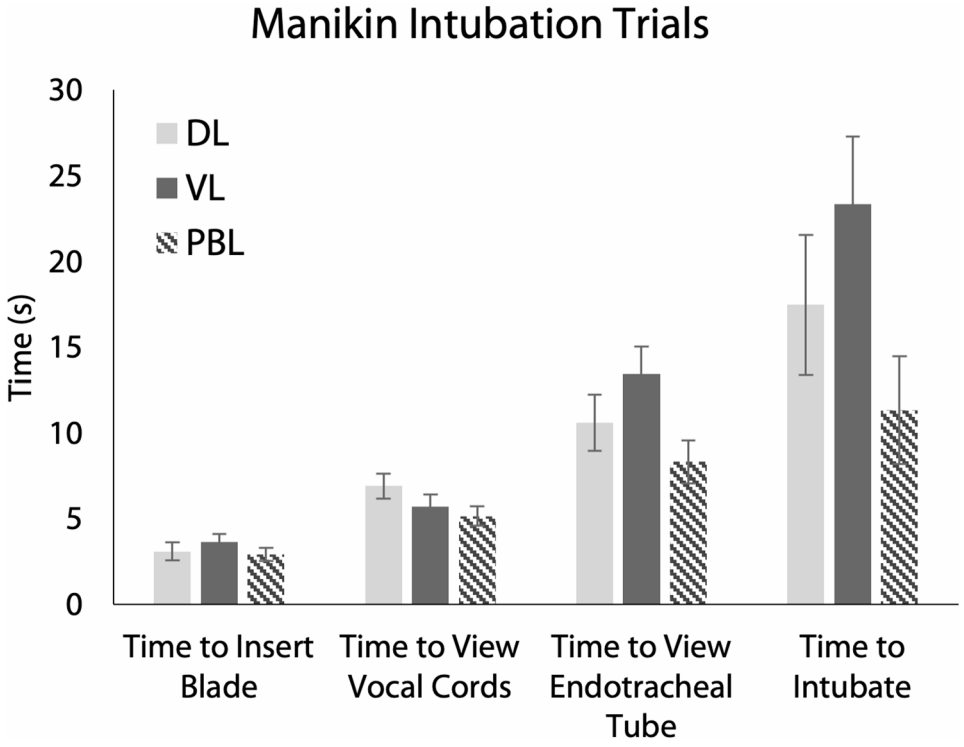

Fig. 3 Intubation times in a manikin trial are comparable between the periscope-based laryngoscope (PBL), video laryngoscope (VL) and direct laryngoscope (DL). Error bars denote 95% confidence intervals

Table 3 Comparison of timed manikin trials of the periscope-based laryngoscope between novice and experienced intubators

	Novice		Experienced		*p* value
	Mean time (s)	Confidence interval (s)	Mean time (s)	Confidence interval (s)	
Time to insert blade	2.691	[2.36, 3.02]	2.898	[2.65, 3.15]	0.308
Time to view vocal cords	5.885	[5.14, 6.63]	5.130	[4.76, 5.50]	0.069
Time to view endotracheal tube	10.873	[9.66, 12.08]	8.272	[7.49, 9.05]	0.001
Time to intubate	13.541	[12.17, 14.91]	11.309	[9.67, 12.95]	0.036

cords, visualization of the endotracheal tube using the laryngoscope, and intubation completion time (see Table 2 for statistical results), and no significant differences in time to insert the laryngoscope blade. For both viewing the endotracheal tube and completing intubation, PBL times were statistically significantly better than VL times ($p < 0.001$, Fig. 3).

These findings are particularly encouraging because prolonged intubation time has been linked to higher morbidity and mortality [12]. No failed intubation attempts occurred with any of the devices used in this study. Previous literature has shown varying results when comparing VL, IL, and DL effectiveness for intubation. While intubation times differ widely across trials and testing conditions, many studies suggest comparable or even superior performance of VL and IL devices over DL [6, 13, 14]. By demonstrating comparable performance to DL devices and improved performance over VL devices in this study, the PBL shows promise as a suitable alternative in settings where using VL may be impractical or unfeasible.

It is important to note provider experience when interpreting these results. While three of the providers had several years of intubation experience with both VLs and DLs, they had no prior experience with the PBL, yet PBL intubation times were the same or better than DL and VL devices. Additionally, a medical student with no prior intubation experience (novice intubator in Table 3) achieved mean PBL intubation times within two seconds of trials performed by experienced physicians (mean novice PBL intubation time = 13.54 s vs. experienced PBL intubation time = 11.31 s, $p = 0.036$). These findings suggest that the PBL is ideally suited for novice or less-experienced airway managers, such as providers in resource-limited settings with little to no access to training equipment and instruction [15].

The PBL confers several advantages over currently available devices in resource-limited settings, which are largely dominated by DLs [16]. In particular, the same benefits of indirect view and ease of use that distinguish VL may also apply to the PBL. VL has also been shown to

reduce forces applied to the airway and orofacial anatomical structures during intubation as it does not require a direct view of the vocal cords [17]; because the PBL offers a similar indirect view, the forces and subsequent airway trauma may be comparably reduced. Finally, VL is often the preferred tool for novice clinicians and patients with difficult airways, so in the absence of VL, a laryngoscope with an indirect view would be beneficial to intubation success in these populations [5, 18]. When compared to other non-video IL devices, the PBL uses a similar, though less complex, system of mirrors as the Airtraq laryngoscope that is available commercially. The Airtraq has similarly been shown to be superior to DL in human trials, particularly with novice airway managers, however its use has not been reported in low resource settings [14].

In addition to the efficacy of the PBL and its potential advantages over DL, it is important to note its greater affordability for a low-resource setting in comparison with VL and IL models. While commercially available VL models can cost over $7000 USD [7], and single-use IL models can be upwards of $100 USD, the PBL used in this study cost $4.41 USD to manufacture. This is on par with, or less expensive than, other 3D printed laryngoscopes reported in the literature [10, 19–21]. Because the PBL can be produced via 3D printing, point-of-care and local fabrication are also feasible; 3D printers have already been deployed in low resource settings specifically for manufacturing of medical equipment [22]. Additionally, many VL models require a power source which can be a barrier to adoption in areas that experience frequent power outages or have unreliable or inconsistent power supply [23]. The PBL runs on a single coin cell battery which can be sourced in bulk and stored for extended periods of time. Risk of electronic failure is also lower, as the only electronic component of the PBL is the LED light source connected to a battery rather than a video camera and screen. Thus, the PBL could arguably become a more sensible alternative to VL or IL in resource-limited settings.

Another consideration in designing the PBL was the materials used. PLA is a low-cost plastic resin that is well-studied and easily implemented in 3D printing applications, including medical devices. It is able to be sterilized using gamma irradiation or glutaraldehyde without impacting its structure, though other sterilization methods may alter its chemical and mechanical properties [24–26]. It is worth noting that current guidelines require laryngoscope disinfection, not sterilization, so there may be a variety of ways to reuse this device [27]. In this study, we did not attempt to sterilize or disinfect the PBL, so further work must be done to develop a reuse protocol, particularly considering the variety of components present. Additionally, the mechanical properties of the device were not assessed. PLA is a rigid plastic, but mechanical properties will vary based on the amount of infill used during 3D printing. There are rigorous mechanical standards (ISO 7376: 2020) that exist for the rigidity and strength of laryngoscope blades, and the PBL must be further tested to ensure adherence to these standards [28].

Overall, this study was an important first step in validating the PBL towards future clinical use. However, the primary goal of the study was the development of the PBL and minimizing time for intubation. A number of other factors must be considered before clinical adoption, including patient safety, in vivo performance, device strength, reusability, and sterilizability. Manikin trials are often used in product development as they are standardized, which allows for a controlled experiment to compare devices [10, 29].

Limitations of this study include that manikin intubation is not as complex and representative of airway diversity, but has similar overall success rates as in live patients [30]. Although the Laerdal SimMan is a leading model for anatomical approximation, there are significant differences in anatomy and tissue compliance between manikin models and live patients [31, 32]. Additionally, assessment of device performance on difficult airways, an important use case, could not be accomplished with the Laerdal SimMan, and may have negatively impacted the intubation time using the VL due to its hyperangulated design which is suited for more difficult airways. Further, our manikin trial could not assess any damage to tissues or disruption of the view by bodily fluids which may result from the use of this device in a human patient. Therefore, manikin trials such as this are not a replacement for human trials and the PBL requires further testing and verification prior to clinical adoption. Our study had a small number of intubators who were all involved in device development and randomization of intubation device order was not performed, both of which limit the study's generalizability and may introduce bias into its results. Finally, our cost estimate does not factor in additional supplies, such as endotracheal tubes, stylets, gloves, and ventilation equipment.

Conclusion

In this study, we have designed, refined, and tested a novel periscope-based laryngoscope for use in resource-limited settings. Manikin testing demonstrates statistically equal intubation times using the PBL compared to direct laryngoscopes and faster times compared to video laryngoscopes. While more testing needs to be performed, the PBL is a promising, low-cost, easily manufacturable alternative to direct laryngoscopes where video laryngoscope availability is limited.

Abbreviations

ANOVA	Analysis of variance
DL	Direct laryngoscope
EI	Endotracheal intubation
IL	Indirect laryngoscope
LMIC	Low- and middle-income countries
PBL	Periscope-based laryngoscope
PLA	Polylactic acid
VL	Video laryngoscope

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12245-025-00962-9.

Supplementary Material 1

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Author contributions

AB, AQ, and WF conceived the project. All authors were involved in device development. AQ, PS, SM, and ES created CAD drawings. AB, AQ, WF, and PS conducted manikin trials. PS prepared the original manuscript. All authors were involved in manuscript editing and review. All authors read and approved the final manuscript.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare no competing interests.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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