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Oxygenation and Lens Preservation Strategies for Tracheal Intubation in the Contaminated Emergency Airway

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Abstract

Emergency tracheal intubation is often performed in patients whose airway conditions are unstable before the laryngoscope is inserted. Blood, emesis, secretions, or gastric contents may impair preoxygenation, obscure the laryngeal inlet, contaminate visualization devices, and compress the time available for safe decision-making. This paper examines the clinical and technical problem of contaminated airway intubation, with particular attention to first-pass success, video laryngoscope performance, apneic oxygenation, suction-assisted decontamination, and emerging device concepts that combine optical preservation with oxygen delivery. The central argument is that soiled-airway failure is not only a matter of poor glottic exposure, but also a combined physiological, optical, ergonomic, and procedural problem. Evidence from emergency department, intensive care, operating room, simulation, and prehospital studies suggests that repeated attempts are associated with adverse events, that video laryngoscopy improves several airway outcomes but remains vulnerable to lens obstruction, and that apneic oxygenation may reduce desaturation in selected contexts. Suction-assisted techniques remain necessary, although they do not fully address camera contamination once liquid or particulate material reaches the lens. An integrated approach that treats suction, laryngoscope optics, oxygen insufflation, operator workload, and staged validation as linked design problems may provide a more realistic research pathway than isolated device evaluation. Future studies should avoid assuming that improved visibility alone will translate into better clinical outcomes and should test integrated systems in contamination models, high-fidelity simulation, and carefully monitored patient cohorts.

1. Introduction

Tracheal intubation in emergency medicine and critical care is rarely a purely anatomical task. The operator must obtain a view, pass a tube, confirm placement, avoid aspiration, preserve oxygenation, minimize hemodynamic collapse, and coordinate medications and personnel while the patient's physiological reserve may already be limited. In the operating room, many intubations occur after fasting, monitoring, controlled preoxygenation, and planned induction. In contrast, emergency department, intensive care unit, and prehospital intubations often occur in patients with hypoxemia, shock, altered mental status, trauma, intoxication, gastrointestinal bleeding, cardiac arrest, or ongoing resuscitation. The airway may be filled with blood, vomitus, thick secretions, pulmonary edema fluid, or debris. These conditions place the operator in a narrow interval between incomplete preparation and urgent need for airway control. The practical goal is not only to complete intubation, but to do so before hypoxemia, aspiration, or cardiovascular deterioration worsens. This is why first-pass success has become a central quality measure in emergency airway practice, even though it is not the only clinically meaningful endpoint [28, 12, 20, 15].

The contaminated airway deserves separate attention because it changes the failure mechanisms of intubation. A difficult airway is often imagined as an anatomical problem, such as limited mouth opening, cervical immobility, obesity, airway edema, or restricted glottic exposure. A soiled airway may include any of these features, but it adds a dynamic and recurring source of visual loss. Blood may well up during attempts at suctioning. Emesis may return after the oropharynx has been cleared. Secretions may smear across a video laryngoscope lens. In this setting, a laryngoscope that provides an adequate view for a few seconds may become ineffective when the lens is coated. A patient who was preoxygenated reasonably well may desaturate after repeated withdrawal and reinsertion of equipment. The operator may alternate between suction, laryngoscopy, cleaning, and tube passage while the team watches oxygen saturation decline. These are not rare corner cases. Observational studies have reported meaningful rates of airway contamination in emergency and out-of-hospital airway management, including vomiting or regurgitation in cardiac arrest and lower first-pass success when the airway is soiled [31, 29].

The development of video laryngoscopy has improved airway management in many clinical settings. Video laryngoscopes can provide indirect visualization of the glottis, reduce the need to align oral, pharyngeal, and tracheal axes, and allow supervisors or assistants to share the view. Randomized trials and systematic reviews have reported advantages in first-

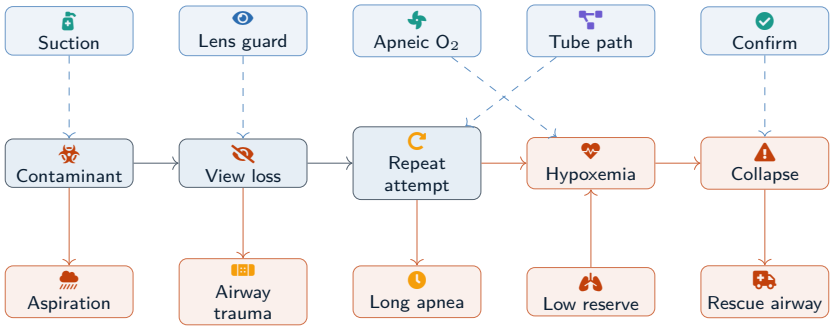


Figure 1. Contaminated emergency airways create a coupled failure pathway: recurrent material obscures the view, repeated attempts extend apnea, and physiological reserve narrows before aspiration or cardiovascular deterioration occurs. Protective actions are shown as local interventions rather than as a single device-level solution.

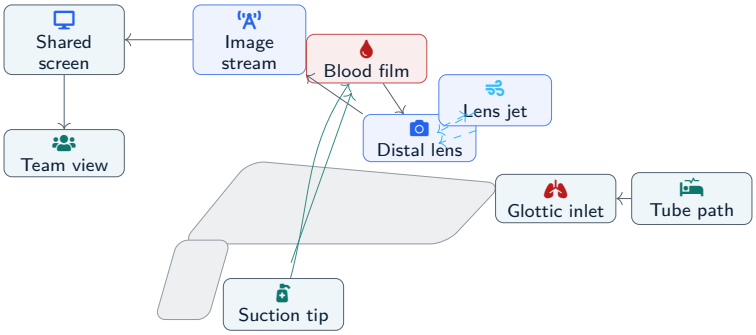


Figure 2. Video laryngoscopy concentrates visualization through a small distal optical surface. A soiled lens interrupts the shared image even when the blade is positioned correctly, so suction, lens protection, and tube-delivery geometry must be coordinated around the same narrow working space.

attempt success, glottic view, failed intubation, or selected complications, depending on device type, operator experience, and setting [26, 11, 16, 2, 23]. Yet the contaminated airway exposes a specific vulnerability of video laryngoscopy. A direct laryngoscope view may be limited by blood or secretions, but a video laryngoscope additionally depends on a small optical surface at the distal blade. Even a thin film on the camera cover can convert an otherwise useful view into an unusable image. This failure mode is familiar to clinicians who intubate patients with hematemesis, facial trauma, massive upper airway bleeding, or cardiopulmonary arrest. It is not fully solved by choosing video rather than direct laryngoscopy.

The soiled airway therefore requires a broader conceptual frame. The airway must be decontaminated, but suction alone may not protect a lens once liquid reaches it. Oxygenation must be maintained, but nasal cannula or face mask strategies may be less effective when the airway is obstructed by fluid or when repeated laryngoscopy extends apnea. The tube must be delivered, but even an excellent glottic view may not guarantee tube passage if the blade geometry, stylet shape, or bougie strategy is mismatched. The device must be usable, but added channels, tubing, valves, or flush mechanisms can increase setup time and cognitive load. The research question is not simply whether one device clears a lens in a manikin. It is whether a combined system can preserve useful visualization, support oxygenation, fit existing emergency workflows, and avoid introducing new harms.

This paper develops a narrative medical and design analysis of contaminated airway intubation. It is written as a research-oriented synthesis rather than a clinical guideline. The aim is to examine the evidence that motivates integrated oxygenation and lens-preservation strategies, identify plausible mechanisms of benefit and harm, and propose a cautious pathway for evaluation. The discussion draws on studies of first-pass success, repeated attempts, difficult airway prediction, soiled-airway outcomes, suction-assisted laryngoscopy, video laryngoscopy, apneic oxygenation, high-flow nasal oxygen, laryngeal oxygen insufflation, oxygenating laryngoscope prototypes, and safety considerations related to gas flow in the upper airway [9, 21, 14, 1]. The paper gives particular attention to the concept of a video laryngoscope blade that directs a gas jet across the camera lens while also providing oxygen insufflation, because this design class illustrates the transition from passive visualization to active airway-interface devices. However, the analysis remains neutral regarding clinical effectiveness, since concepts and simulations should not be treated as clinical proof.

2. The Contaminated Airway as a Clinical Failure Mode

The term contaminated airway is sometimes used loosely, but its clinical significance lies in the way contamination alters the sequence of airway management. Blood, vomitus, secretions, and particulate matter do not simply make the

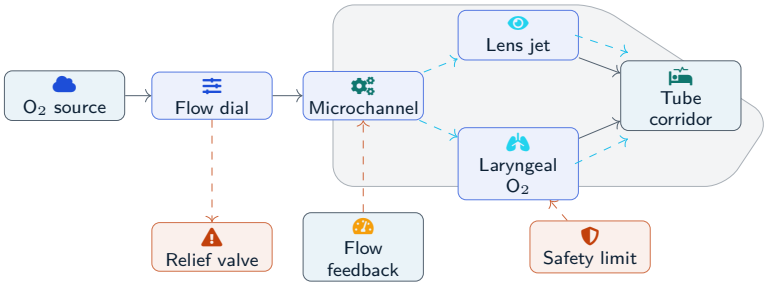


Figure 3. Integrated oxygenating and lens-preserving blade architecture separates bulk oxygen supply from distal functions. The same regulated gas path may support a camera-facing jet and laryngeal insufflation, but pressure relief, flow feedback, and safety limits remain essential because the device actively interacts with the airway.

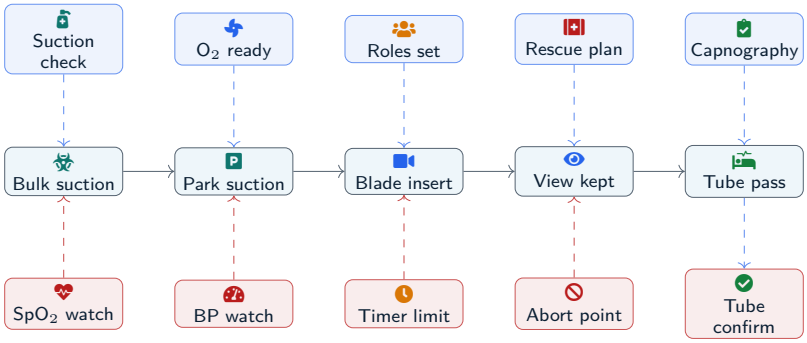


Figure 4. Suction-assisted laryngoscopy is represented as a coordinated workflow rather than a single maneuver. Preparation, decontamination, visualization, tube passage, and confirmation run alongside physiological monitoring so that a contaminated view does not encourage an unsafe prolonged attempt.

field unpleasant. They interfere with mask ventilation, reduce the effectiveness of preoxygenation, obscure anatomical landmarks, contaminate laryngoscope optics, increase aspiration risk, and prolong attempts. A small volume of saliva or mucus is normally manageable. A large volume of blood or emesis is different because it is recurrent, mobile, and often mixed with solids or clots. The field may be cleared temporarily and then refill. This is common during chest compressions, gastric insufflation, upper gastrointestinal bleeding, maxillofacial trauma, drowning, seizure, overdose, or altered consciousness. The operator must therefore treat contamination as an ongoing source of failure rather than a single obstacle removed before laryngoscopy begins.

The relationship between contamination and first-pass success has been described in emergency department intubation. In a study comparing soiled and clean airways during GlideScope and direct laryngoscope use, first-pass success was lower in the soiled group for both device types. With the GlideScope, first-pass success was 81.4% in soiled airways compared with 91.0% in clean airways, while direct laryngoscopy showed 65.5% compared with 75.8% [29]. These figures are useful because they show that contamination does not merely reduce performance of one device category. It impairs airway management across approaches. The adjusted odds of first-pass success were lower in the soiled airway cohorts, which supports the everyday observation that fluids and debris add difficulty beyond airway anatomy alone. The difference of approximately 10% is clinically meaningful when applied to high-risk patients, since the second attempt may occur after oxygen saturation has fallen, hemodynamics have worsened, or aspirated material has entered the lower airway.

Repeated attempts are not benign. Emergency airway studies have consistently associated multiple attempts with complications such as hypoxemia, aspiration, bradycardia, esophageal intubation, airway trauma, and cardiac arrest [28, 12, 20]. The causal pathways are not always easy to separate. A patient requiring multiple attempts may have been more difficult or unstable from the outset, which means attempts partly mark underlying risk. Nevertheless, repeated laryngoscopy can directly worsen physiology by extending apnea, increasing sympathetic or vagal responses, causing bleeding or swelling, and delaying ventilation. In a contaminated airway, repeated attempts may also spread or aspirate material. If the first attempt fails because the lens is obscured and the device must be withdrawn, the second attempt may begin with a more contaminated pharynx and a more hypoxemic patient. This feedback loop explains why a modest reduction in first-pass success can matter.

Aspiration is a central concern in this setting. The Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society identified aspiration of gastric contents as a major contributor to airway-related morbidity and mortality in anesthesia and emergency airway management [7]. Although operating room and emergency airway populations differ, the finding remains relevant because it reminds clinicians that airway catastrophe is not limited to failure to place a tube. A tube placed after large-volume aspiration may still be followed by respiratory failure, pneumonitis, acute respiratory distress syndrome, infection, or death. Contamination therefore creates a dual goal: the operator

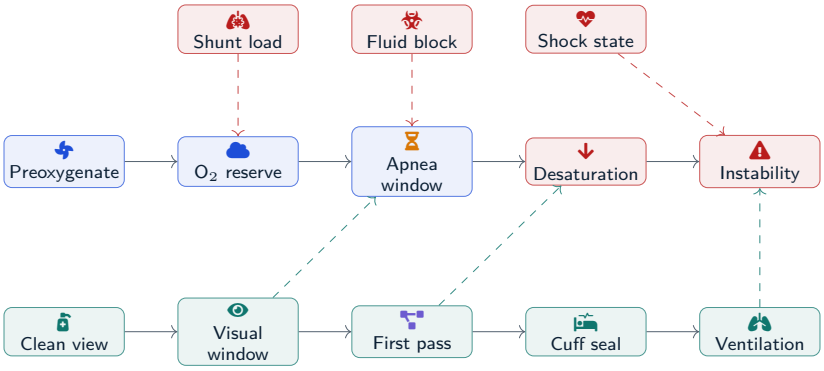


Figure 5. Peri-intubation physiology and airway technique evolve together. Oxygen reserve and apnea tolerance are degraded by shunt, contamination, and shock, while clean visualization, first-pass tube placement, cuff sealing, and ventilation shorten the interval in which hypoxemia and instability develop.

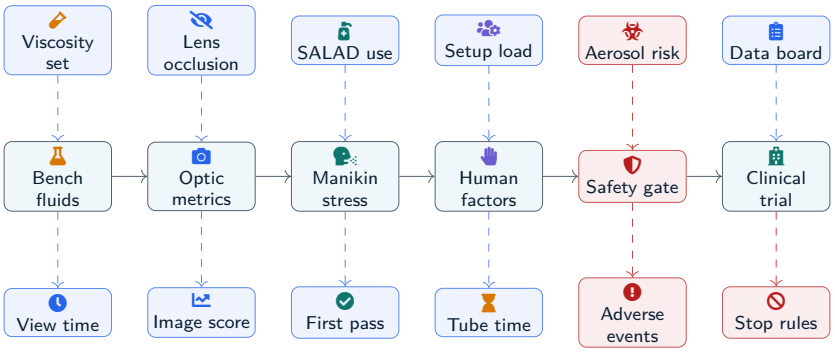


Figure 6. Evaluation pathway for an active lens-preserving oxygenating laryngoscope. Evidence begins with realistic fluid and optical testing, proceeds through soiled-airway simulation and human-factors assessment, and reaches clinical study only after safety gates address gas-flow, aerosolization, adverse-event, and stopping-rule concerns.

must gain access to the trachea while limiting the movement of contaminant into the lower airway. This dual goal explains the emphasis on proactive suction, positioning, rapid but controlled laryngoscopy, and early recognition of failed attempts.

Prehospital and resuscitation contexts may intensify the problem. Emesis during out-of-hospital cardiac arrest has been reported as a frequent event, and regurgitation may occur during chest compressions, bag-mask ventilation, or airway manipulation [31]. The resuscitation environment is crowded and time-pressured; lighting and positioning may be poor; and intubation may be attempted while compressions continue. In such cases, airway contamination is not an isolated inconvenience but part of a broader physiology of cardiac arrest. Gastric contents may enter the pharynx repeatedly, oxygen stores may already be depleted, and the team may be balancing airway attempts against interruptions to compressions. Devices that require repeated withdrawal for lens cleaning may be especially problematic when each pause affects resuscitation choreography.

Intensive care unit intubation adds another set of hazards. Critically ill patients often have low oxygen reserve, shock, metabolic acidosis, pulmonary edema, pneumonia, or acute respiratory distress syndrome. Severe complications of intubation in the ICU are well described, and risk prediction tools such as the MACOCHA score incorporate anatomical and non-anatomical predictors of difficult intubation [15, 8]. In these patients, the consequences of a contaminated airway are amplified by limited tolerance of apnea. Even a short delay from lens contamination may be enough to produce severe desaturation. The physiologically difficult airway concept emphasizes that airway management may be dangerous not because the glottis cannot be seen, but because the patient cannot tolerate the process required to see and intubate it [21]. A soiled airway is a practical example of this concept: the operator may have adequate technical skill, yet the patient's physiology and airway contents create a narrow margin.

Contamination also affects team cognition. A clean but anatomically difficult airway can often be approached using a predictable plan, such as video laryngoscopy, bougie use, external laryngeal manipulation, or rescue supraglottic airway. A heavily soiled airway creates rapidly changing visual conditions. The operator may see the cords briefly, then lose the view. The suction catheter may clog. The assistant may not know whether to suction, hand a bougie, adjust oxygen, or prepare a rescue device. The monitor may show falling saturation while the laryngoscope screen is covered with fluid. Under these conditions, cognitive load increases. A device or technique that appears simple during bench testing may not remain simple during resuscitation. Human factors therefore belong at the center of soiled-airway research rather than at the margins.

Table 1. Clinical Characteristics of Contaminated Airway Intubation

Factor	Mechanism	Clinical Consequence
Blood or emesis	Obscures anatomy and optics	Reduced first-pass success
Recurrent contamination	Refills pharynx after suction	Repeated laryngoscopy attempts
Particulate material	Clogs suction devices	Delayed airway clearance
Secretions on lens	Loss of video image quality	Device withdrawal for cleaning
Physiologic instability	Poor apnea tolerance	Rapid desaturation or collapse

Table 2. Reported First-Pass Success in Clean and Soiled Airways

Device	Clean Airway	Soiled Airway	Approximate Difference
GlideScope	91.0%	81.4%	–9.6%
Direct laryngoscopy	75.8%	65.5%	–10.3%

The contaminated airway should not be reduced to a binary label. The type, volume, viscosity, and recurrence of contamination matter. Thin secretions may be displaced by suction or airflow. Thick emesis with particulate material may clog standard suction and adhere to optical surfaces. Blood may be aspirated but can also smear across a lens in a thin film. Clots may obstruct the laryngoscope path or hide the laryngeal inlet. Gastric contents may contain solid food, acidic fluid, and mucus. These materials have different optical and flow properties. A lens-clearing gas jet that works well against droplets may fail against peanut butter-like simulated emesis. A suction catheter that clears thin fluid may clog on particulate matter. Future research should therefore avoid simplistic contamination models and should test across fluids that approximate clinically relevant viscosity and opacity.

A final feature of the contaminated airway is that conventional rescue pathways may be less reliable. A supraglottic airway may fail to ventilate if the pharynx is filled with vomitus or blood. Mask ventilation may insufflate the stomach and worsen regurgitation. Fiberoptic techniques may be impossible when the lens is obscured. Direct laryngoscopy may provide an alternative to video, but its line of sight is also impaired by fluid. Surgical airway may be required in rare cases, yet blood and distorted anatomy can complicate front-of-neck access. This is why soiled-airway management cannot rely on a single tool. It requires layered preparation: suction, positioning, oxygenation, visualization, tube-delivery aids, rescue devices, and team communication. Integrated device designs should be judged by whether they fit into this layered strategy, not by whether they appear to replace it.

3. First-Pass Success and Peri-Intubation Physiology

First-pass success is widely used in emergency airway studies because it is measurable, clinically intuitive, and associated with fewer adverse events. It is not a perfect surrogate. A rapid first-pass intubation that causes profound hypotension, unrecognized esophageal intubation, or large-volume aspiration is not a good outcome. Conversely, a deliberate second attempt after strategic repositioning may be safer than a prolonged first attempt. Still, first-pass success remains important because the period between induction and secured ventilation is physiologically fragile. Every failed attempt may extend apnea, increase airway trauma, and force a transition from controlled planning to rescue behavior. In a contaminated airway, the first attempt may be the only attempt before the field worsens substantially.

The relationship between repeated attempts and adverse events has been shown across emergency airway datasets. Hasegawa and colleagues reported an association between repeated intubation attempts and adverse events in emergency departments [12]. Sakles and colleagues similarly emphasized the importance of first-pass success in emergency department orotracheal intubation [28]. Mort's work on emergency tracheal intubation also demonstrated increased complications with multiple laryngoscopic attempts [20]. These studies differ in design, setting, and definitions, but they converge on a clinically plausible finding: more attempts generally mean more risk. The soiled airway is one of the conditions that can turn an otherwise manageable airway into a multiple-attempt airway.

Peri-intubation hypoxemia deserves particular attention. Preoxygenation aims to replace alveolar nitrogen with oxygen, increasing the oxygen reservoir during apnea. Critically ill patients may not achieve adequate denitrogenation because of shunt physiology, low functional residual capacity, agitation, poor mask seal, airway obstruction, or ongoing contamination. They may start with low saturation despite high inspired oxygen. Once apnea begins, desaturation may occur quickly. This is especially true in obesity, pregnancy, pediatric patients, acute respiratory distress syndrome, pneumonia, pulmonary edema, and shock. Contamination worsens the situation by interfering with preoxygenation and by prolonging laryngoscopy. A device that reduces lens-cleaning interruptions might therefore affect oxygenation indirectly by shortening apnea, while a device that insufflates oxygen might affect oxygenation directly by maintaining oxygen flux during laryngoscopy.

The physiologically difficult airway framework is useful because it shifts attention from anatomy alone to the patient's reserve. Mosier and colleagues described situations in which hypoxemia, hypotension, severe metabolic acidosis, and right ventricular failure create airway risk independent of laryngoscopic view [21]. A patient with massive hematemesis and shock may be easy to visualize anatomically after suction but may not tolerate a long attempt. A patient in cardiac arrest may have no oxygen reserve and may regurgitate during compressions. A patient with pneumonia may desaturate within seconds even if the laryngoscope view is good. In such

Table 3. Complications Associated with Repeated Intubation Attempts

Complication	Contributing Mechanism	Potential Outcome
Hypoxemia	Prolonged apnea	Organ injury or arrest
Aspiration	Delayed airway protection	Pneumonitis or ARDS
Bradycardia	Vagal stimulation and hypoxia	Hemodynamic instability
Airway trauma	Repeated instrumentation	Bleeding and swelling
Esophageal intubation	Loss of visualization	Delayed ventilation

Table 4. Comparison of Oxygenation Strategies During Intubation

Method	Advantages	Limitations
Low-flow nasal oxygen	Simple and accessible	Reduced efficacy with obstruction
High-flow nasal oxygen	Continuous oxygen delivery	Equipment intensive
Noninvasive ventilation	Improved preoxygenation	Gastric insufflation risk
Bag-mask ventilation	Prevents severe desaturation	Aspiration concerns
Laryngeal insufflation	Oxygen near glottis	Limited contaminated-airway data

patients, technologies that preserve oxygenation during the attempt are not luxury additions; they address a central risk of the procedure. However, the degree of benefit depends on whether oxygen can reach alveoli in the presence of airway contamination, obstruction, shunt, or ongoing aspiration.

Hemodynamic deterioration is another major peri-intubation risk. Induction agents, positive-pressure ventilation, loss of sympathetic tone, increased intrathoracic pressure, and underlying shock can combine to produce post-intubation hypotension or cardiac arrest [15]. Contaminated airways may increase this risk indirectly by prolonging attempts and delaying ventilation. In a patient with hemorrhagic shock from gastrointestinal bleeding, the airway may be contaminated precisely because the patient is bleeding, hypotensive, and at risk of collapse. The operator may face a difficult choice between attempting intubation quickly before further aspiration occurs and delaying for hemodynamic optimization. This tension should shape research outcomes. A lens-clearing device might improve image continuity, but if it adds preparation time or distracts from resuscitation, its net effect may be small or harmful. Conversely, if it reduces repeated attempts without delaying induction, it may be valuable.

Apneic oxygenation is a physiologically attractive adjunct because oxygen can continue to move into the alveoli during apnea when the airway remains patent and oxygen is available at the upper airway. Low-flow nasal cannula, high-flow nasal oxygen, and laryngeal oxygen insufflation are different methods built on related principles. Semler and colleagues conducted a randomized trial of apneic oxygenation during endotracheal intubation of critically ill adults, showing that benefit may vary by population and method [30]. Pavlov and colleagues reported in a systematic review and meta-analysis that apneic oxygenation reduced hypoxemia during emergency intubation, though heterogeneity was present [25]. Patel and Nouraei described transnasal humidified rapid-insufflation ventilatory exchange in patients with difficult airways, reporting prolonged apnea time with maintenance of saturation in a controlled setting [24]. These studies support interest in oxygenation during laryngoscopy, but they do not prove that every oxygen-delivery strategy works in a contaminated airway.

The route of oxygen delivery matters. Nasal oxygen may be simple and does not obstruct the mouth, but its effectiveness may be limited when the nasopharynx is obstructed, when the mouth is open, or when high-flow systems are unavailable. High-flow nasal oxygen can provide high inspired oxygen, some degree of positive airway pressure, dead-space washout, and continuous oxygen delivery, but it may be difficult to deploy in all emergency settings and may raise concerns about aerosol dispersion under some conditions [18, 33, 5]. Noninvasive ventilation can improve preoxygenation in hypoxemic critically ill patients, as shown in studies comparing noninvasive ventilation with conventional oxygen methods before intubation [3]. Bag-mask ventilation between induction and laryngoscopy may prevent hypoxemia in selected critically ill adults, but it may also raise concerns about gastric insufflation or aspiration when performed poorly or at excessive pressures [6, 4]. In a contaminated airway, the safest oxygenation approach may depend on whether ventilation can be delivered without forcing material toward the lungs.

Laryngeal or pharyngeal oxygen insufflation through a laryngoscope channel is conceptually different from nasal oxygen. It places oxygen closer to the glottic inlet during the attempt. Bench and simulation work has evaluated oxygenating laryngoscope prototypes and distal oxygen delivery positions [19, 13, 34]. Pediatric work has also examined deep laryngeal oxygen insufflation during laryngoscopy and its effect on desaturation kinetics [32]. These studies suggest that oxygen delivery near the larynx can increase oxygen availability during apnea, at least under specific conditions. Yet the contaminated airway introduces uncertainty. If the glottis is obstructed by fluid, if oxygen flow displaces material distally, or if gas flow aerosolizes blood or emesis, the physiological benefit may be offset by other risks. This is why integrated devices require careful preclinical testing rather than direct adoption based on oxygenation theory alone.

First-pass success and oxygenation should also be considered together rather than separately. An operator might accept a slightly longer attempt if oxygenation is maintained, but prolonged laryngoscopy can increase trauma and aspiration risk. A device that improves oxygenation but worsens tube delivery may not help. A device that clears the lens but produces distracting noise, tubing drag, or visual distortion may increase attempt duration. The most relevant outcome may be the

Table 5. Failure Modes of Video Laryngoscopy in Soiled Airways

Failure Mode	Cause	Operational Effect
Lens contamination	Blood or emesis film	Loss of usable image
Fogging	Condensation on optics	Blurred visualization
Tube delivery mismatch	Hyperangulated geometry	Delayed tube placement
Crowded oral cavity	Blade and suction conflict	Reduced maneuverability
Image dependence	Reliance on screen view	Workflow disruption

Table 6. Optical Preservation Strategies for Video Laryngoscopes

Strategy Type	Examples	Main Limitation
Passive	Anti-fog coating, warming	Limited effect on thick fluids
Reactive	Wiping or flushing lens	Interrupts laryngoscopy
Proactive	Continuous gas jet flow	Added complexity and tubing
Hybrid	Combined suction and airflow	Requires coordination

combination of first-pass success without severe hypoxemia, hypotension, aspiration, or need for device removal. Future trials should avoid evaluating single endpoints in isolation. For example, time to intubation may look favorable, but if oxygen saturation falls more often, the device may not be better. Lowest oxygen saturation may improve, but if aspiration increases, the benefit is questionable. A neutral evaluation must measure both technical and physiological outcomes.

The evidence base also warns against assuming that airway innovations generalize across settings. Video laryngoscopy may perform differently in the operating room, emergency department, ICU, and prehospital environment because operators, patients, devices, and indications differ. Apneic oxygenation may be more effective in patients with patent airways than in those with shunt physiology or obstruction. Suction techniques may work differently with simulated vomit than with real blood and food matter. An integrated lens-clearing oxygenating blade may be easy to use in a simulation center but more difficult during active hematemesis. The clinically relevant question is not whether a concept is plausible, but where it performs better, where it performs worse, and what training is required to use it safely.

4. Video Laryngoscopy and the Problem of Optical Dependence

Video laryngoscopy has changed airway management by allowing indirect visualization of the larynx. Unlike direct laryngoscopy, which depends on a line of sight from the operator's eye to the glottis, video laryngoscopy uses a camera near the distal blade and displays the image on a screen. This can improve glottic view when anterior airway anatomy, limited neck movement, or operator position makes direct alignment difficult. It also enables team members to see what the operator sees, which can improve coaching, shared situational awareness, and teaching. Systematic reviews and trials have generally found that video laryngoscopy reduces failed intubation and improves glottic visualization, though effects on first-pass success and complications vary by device type, patient population, and operator experience [11, 16, 26]. In critically ill adults, the DEVICE trial reported higher first-attempt successful intubation with video laryngoscopy compared with direct laryngoscopy in the studied setting [26].

The advantages of video laryngoscopy make its failure modes more important. When clinicians become accustomed to video-assisted views, loss of the image can be disruptive. A direct laryngoscope blade obscured by fluid may still allow the operator to adjust tissue or suction under direct vision. A video laryngoscope lens covered by blood may produce a screen that is uniformly red, brown, or blurred. The operator may then need to decide whether to continue using direct line of sight around the blade, withdraw and clean the lens, switch devices, or attempt tube passage based on partial landmarks. This decision occurs under time pressure. The strength of video laryngoscopy becomes a dependency when the image is lost.

The optical surface of a video laryngoscope is small and distal. It is positioned near the tongue base, epiglottis, vallecula, or glottic structures, depending on blade design. This position is useful for visualization but exposes the lens to secretions, fogging, blood, and vomitus. Fogging and contamination are distinct problems. Fogging occurs when moisture condenses on a cooler surface, often mitigated by warming, anti-fog coating, or pre-use preparation. Contamination occurs when fluid or particulate matter adheres to the lens. Anti-fog measures may not remove blood film, gastric contents, or thick mucus. A lens may be warm and still be unusable if it is smeared with opaque material. Therefore, the contaminated airway requires active removal or prevention of adherent material, not only anti-fogging.

Different video laryngoscope geometries may respond differently to contamination. Macintosh-style video blades preserve some resemblance to direct laryngoscopy technique and may allow the operator to obtain a direct view if the screen fails. Hyperangulated blades may improve glottic exposure in anatomically difficult airways but often require a shaped stylet and rely more heavily on the screen for tube delivery. Channelled devices guide the tube but may be bulkier and may trap secretions. Standard geometry, lens placement, light source position, and blade curvature affect how fluids contact the optical surface. These design details are rarely central in clinical trials, but they matter in soiled airways. A trial showing average video laryngoscope superiority may not tell the clinician which device is least vulnerable to lens occlusion during hematemesis.

Tube delivery is another issue. Video laryngoscopy often improves view more than it improves tube passage. A full view

Table 7. Features of Suction-Assisted Airway Decontamination

Technique Element	Intended Benefit	Limitation
Large-bore suction	Removes viscous material	Requires oral space
Continuous suctioning	Controls recurrent contamination	Coordination burden
SALAD technique	Simultaneous suction and laryngoscopy	Training dependent
Parked suction catheter	Ongoing pharyngeal drainage	May obstruct maneuvering

Table 8. Human Factors in Contaminated Airway Management

Factor	Description	Clinical Impact
Cognitive load	Rapidly changing airway conditions	Delayed decisions
Team coordination	Multiple simultaneous tasks	Workflow disruption
Visual instability	Intermittent screen loss	Increased stress
Equipment crowding	Limited oral workspace	Reduced dexterity
Time pressure	Falling oxygen saturation	Higher complication risk

of the glottis does not guarantee that the endotracheal tube will follow the necessary path. Hyperangulated blades may require rigid stylets, careful rotation, or bougie assistance. The BEAM trial showed that use of a bougie improved first-attempt intubation success among emergency department patients with at least one difficult airway characteristic compared with an endotracheal tube plus stylet [10]. Although that study was not limited to contaminated airways, it underscores that visualization and tube delivery are separate tasks. In the soiled airway, the operator may have only a brief view before contamination recurs. A bougie or stylet strategy that allows rapid use of a short visual window may be important. Integrated lens-clearing systems should therefore be assessed together with tube-delivery methods, not only as optical tools.

Evidence comparing video and direct laryngoscopy in difficult or emergency settings should be interpreted with attention to operator training. Video laryngoscopy can improve performance for less experienced operators in some settings because the screen makes anatomy easier to recognize and allows supervision. However, it also introduces hand-eye coordination demands, depth perception issues, and device-specific techniques. Experienced direct laryngoscopists may perform well with direct blades, while experienced video laryngoscopists may exploit video advantages more effectively. Aziz and colleagues reported comparative effectiveness data for video laryngoscopy in difficult airway management, and broader reviews have emphasized device heterogeneity and learning effects [2, 23]. In contaminated airways, training must include lens failure, suction coordination, and device switching. A clinician trained only in clean manikin video laryngoscopy may be unprepared for sudden screen loss.

The COVID-19 pandemic increased attention to video laryngoscopy because it may increase distance between the operator's face and the patient's airway and improve first-pass success when performed by trained operators. Consensus recommendations emphasized planning, personal protective equipment, minimizing attempts, and using video laryngoscopy where appropriate [5]. Although infectious aerosols are not the same as blood or emesis contamination, the pandemic highlighted the interaction between airway devices and environmental safety. A lens-clearing gas jet, oxygen insufflation channel, or flush mechanism may affect aerosol generation, droplet dispersion, and contamination of nearby staff. The contaminated airway is already biologically hazardous. Active gas flow could either help by directing material away from the operator and maintaining a view, or harm by aerosolizing secretions. This uncertainty must be measured.

Current video laryngoscopes vary in their ability to manage secretions. Some devices are more compatible with simultaneous suction because of blade shape and mouth opening requirements. Some allow direct suction alongside the blade, while others crowd the oral cavity. Some have anti-fog features, disposable covers, or lens positions that are less exposed. Commercial and improvised lens-cleaning strategies have included wiping, saline flush, sheath exchange, suction near the lens, and dedicated lens-clearing designs. Napier and Zitek reported decreased time to intubation by experienced users with a lens-clearing video laryngoscope in a simulated setting [22]. Such findings are encouraging but limited. Simulation can test whether a device works under controlled contamination, but it cannot fully reproduce patient movement, bleeding patterns, airway reflexes, urgency, or consequences of aspiration.

A useful distinction can be made between passive, reactive, and proactive optical strategies. Passive strategies include anti-fog coatings, warming, lens placement, hydrophobic surfaces, and blade geometry designed to reduce contamination exposure. Reactive strategies include withdrawing and wiping the blade, flushing the lens after contamination, or using suction after the view is lost. Proactive strategies attempt to prevent contamination from adhering in the first place, such as continuous gas flow across the lens or a protective stream that deflects droplets. Each has trade-offs. Passive strategies are simple but may be insufficient. Reactive strategies may clear the image but interrupt laryngoscopy. Proactive strategies may preserve continuity but require power, oxygen or air flow, tubing, controls, and safety validation. Integrated gas-jet designs belong in the proactive category if flow is continuous or rapidly available during the attempt.

The phrase optical dependence does not mean that video laryngoscopy is flawed. It means that its benefits depend on

Table 9. Potential Benefits and Risks of Integrated Gas-Jet Blades

Feature	Potential Benefit	Potential Risk
Lens-directed gas flow	Reduced optical contamination	Aerosol generation
Oxygen insufflation	Extended safe apnea time	Distal contaminant displacement
Continuous visualization	Fewer device withdrawals	Added setup complexity
Integrated channels	Combined functionality	Increased device bulk

Table 10. Research Priorities for Contaminated Airway Devices

Research Area	Key Question	Suggested Endpoint
Lens preservation	Does image continuity improve?	Time with usable view
Oxygenation support	Is desaturation reduced?	Lowest oxygen saturation
Workflow integration	Does setup delay care?	Time to intubation
Safety evaluation	Does airflow aerosolize fluid?	Environmental contamination
Clinical effectiveness	Are attempts reduced?	First-pass success

preserving the image. In clean airways, image preservation may be easy. In soiled airways, image preservation becomes a clinical task. This shift has implications for device evaluation. Trials should record not only first-pass success, but also frequency of lens contamination, number of withdrawals for cleaning, time spent without a usable image, need to switch from video to direct view, and operator-rated image adequacy. A device may improve first-pass success by improving tube delivery even if the image is intermittently poor, or it may maintain image quality without changing intubation success if other barriers dominate. Understanding these mechanisms can prevent overinterpretation.

Video laryngoscopy is likely to remain central in emergency airway management, but contaminated airway practice should avoid overreliance on the screen. Clinicians should maintain direct laryngoscopy skills, suction techniques, bougie use, and rescue planning. At the same time, device designers should recognize that a video laryngoscope used in emergency care is not merely an optical instrument. It is inserted into a wet, mobile, biologically contaminated space during physiological stress. Treating the lens as an active interface rather than a passive window may be a reasonable direction for innovation, provided safety and usability remain central.

5. Suction-Assisted Decontamination and Its Limits

Suction is the oldest and still the most necessary intervention for the contaminated airway. Without removal of bulk fluid and debris, visualization, ventilation, and aspiration prevention are compromised. Standard airway carts usually include Yankauer suction, flexible suction catheters, and suction tubing. In heavy contamination, however, standard suction may be inadequate. Yankauer tips can clog with particulate matter, have limited flow for viscous fluid, and may require repeated repositioning. Flexible catheters may be too narrow or too soft to clear the hypopharynx rapidly. The suction source itself may be underpowered, improperly connected, or not checked before induction. In a clean airway these issues may not matter. In massive emesis, they can define the outcome of the attempt.

Large-bore suction devices and techniques have been developed to address these limitations. The DuCanto catheter is designed with a larger internal diameter and shape intended for airway decontamination. Wetsch and colleagues compared suction rates of the DuCanto catheter with Yankauer and standard suction catheters using liquids of different viscosity in a technical simulation, showing that catheter design substantially affects suction performance [35]. The finding is unsurprising from a fluid mechanics perspective, but it is clinically relevant because airway contamination is often viscous and particulate. A catheter that works well with water may perform poorly with emesis-like material. Suction device testing should therefore include realistic fluids rather than relying only on thin liquids.

The Suction-Assisted Laryngoscopy and Airway Decontamination technique formalizes the use of continuous suction during laryngoscopy. Root and colleagues described SALAD as a method for improved emergency airway management, emphasizing simultaneous suction and laryngoscopy rather than a sequential suction-then-scope approach [27]. The technique commonly involves inserting a rigid suction catheter to clear the mouth and hypopharynx, then positioning it to evacuate ongoing contamination while the laryngoscope is introduced. The suction catheter may be moved or parked in a way that permits continued decontamination as the tube is delivered. The strength of this approach is that it treats contamination as dynamic. Rather than assuming the airway remains clear after initial suctioning, SALAD anticipates continued regurgitation or bleeding.

Simulation studies of suction-assisted approaches often show improved success, shorter time to intubation, or better operator confidence after training [27]. The value of simulation is evident because real massive contamination events are unpredictable and difficult to study ethically in early device development. Simulation allows repetitive practice with standardized vomit-like fluids, controlled scenarios, and measurement of technique. It also teaches bimanual coordination, which is essential in soiled-airway management. An operator must manipulate the laryngoscope, suction catheter, tube, bougie, and sometimes external laryngeal manipulation within a con-

Table 11. Integrated Lens-Preserving Oxygenating Laryngoscope Concepts

Concept Element	Intended Function	Key Concern
Gas channel in blade	Deliver flow near distal lens	Added structural complexity
Tangential gas jet	Prevent lens contamination	Aerosol generation risk
Distal oxygen delivery	Support apneic oxygenation	Limited ventilation effect
Integrated design	Combine visibility and oxygenation	Workflow burden
Complement to suction	Preserve optics after decontamination	Cannot remove bulk emesis

Table 12. Nozzle Design Considerations for Gas-Jet Laryngoscopes

Nozzle Feature	Potential Advantage	Potential Limitation
Round nozzle	Focused high-velocity jet	Clears limited surface area
Slit nozzle	Broad gas sheet across lens	Reduced jet velocity
Multiple ports	Distributed flow coverage	Greater clogging risk
Tangential outlet angle	Shears droplets from lens	Flow alignment sensitive
Perpendicular outlet	Rapid clearing burst	Turbulent spray formation

fined space. The motor sequence differs from clean-airway intubation. Training can reduce hesitation and improve the chance that suction is used proactively rather than after visualization has already failed.

However, suction-assisted decontamination has limits. Suction removes material from where the catheter tip is placed, but it does not necessarily protect the video laryngoscope lens from droplets, smears, or splashes. During insertion, the blade may pass through contaminated material before the suction catheter clears it. During laryngoscopy, blood may run down from the oropharynx or be pushed onto the lens by tissue contact. During tube delivery, the tube or stylet may drag material across the blade. If the lens becomes coated, suction near the lens may not remove an adherent film. The operator may need to withdraw the device and wipe it, interrupting the attempt. Thus suction and lens-clearing are complementary rather than interchangeable.

There is also a practical limit to how many tools can be used in the mouth at once. A rigid suction catheter, laryngoscope blade, bougie, endotracheal tube, and Magill forceps cannot all occupy the same space without crowding. In patients with small mouth opening, facial trauma, cervical collars, or clenched jaws, device crowding becomes severe. A large-bore suction catheter improves decontamination but may reduce maneuvering space. Video laryngoscope blades vary in bulk. A hyperangulated blade and a large suction catheter may be harder to coordinate than a standard geometry blade. Integrated lens-preservation strategies could reduce the need for repeated blade removal, but if they add external tubing that snags or occupies space, they may create their own ergonomic burden.

Suction can also influence aspiration dynamics. Aggressive suctioning may remove protective fluid but may also stimulate gagging, bleeding, or vomiting in partially responsive patients. During induction, suction may reduce material available for aspiration, but it cannot guarantee lower airway protection until the cuff is inflated and tube position confirmed. If suction is delayed, bag-mask ventilation may push gastric contents distally or insufflate the stomach. If suction is continuous but poorly positioned, it may not clear the relevant area. A combined airway strategy should define who controls suction, where the suction catheter is positioned, when it is moved, and how the operator communicates loss of view. These details are often more important than the device label.

The relationship between suction and video laryngoscopy is complex. Video laryngoscopy can make suction more targeted because the screen shows where fluid accumulates. It also allows an assistant or supervisor to recognize when suction is needed. But the video blade may occupy the midline and make suction insertion more difficult, especially with limited mouth opening. Some clinicians prefer to insert suction first, then blade. Others insert the blade and suction alongside it. Some park the suction catheter in the esophagus or hypopharynx during ongoing regurgitation. These variations should be studied because device compatibility may depend on technique. A lens-clearing oxygenating blade should be tested with SALAD-like suction rather than only as a standalone device, since real practice would still require bulk decontamination.

Another limit is suction system reliability. Wall suction may be strong in the emergency department but variable in prehospital settings. Portable suction devices may have limited power, battery life, canister capacity, or tubing diameter. Suction tubing may kink or clog. In massive emesis, the canister may fill. If an integrated airway device assumes effective suction but is used where suction is weak, performance may differ. Conversely, a lens-clearing gas jet may preserve a camera image even when suction is imperfect, but it cannot remove liters of gastric contents. Therefore, future device research should specify suction source, tubing, catheter, fluid type, and failure handling. Otherwise, results may not translate.

Suction training should also include the decision to abandon an attempt. A clinician may persist because the screen intermittently shows anatomy, but continued laryngoscopy through contamination can worsen hypoxemia or aspiration. A planned pause for reoxygenation, suction reset, or device change may be safer than a prolonged attempt. Guidelines for difficult airway management emphasize limiting attempts and preparing rescue strategies [14, 1]. In soiled airways, attempt limits should consider not only failed tube passage but also repeated lens obstruction and inadequate decontam-

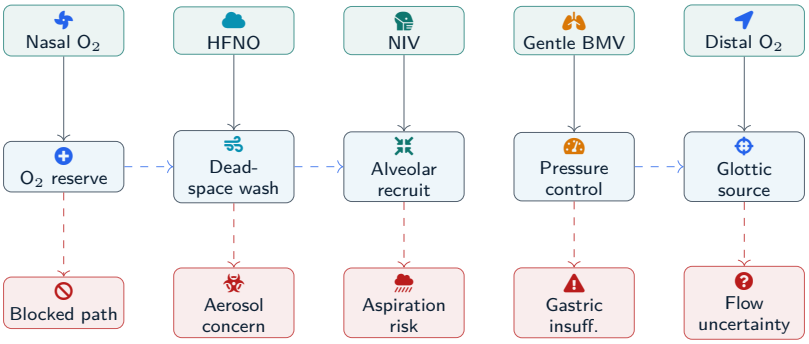


Figure 7. Apneic oxygenation strategies provide a physiological buffer during airway control, but each route depends on airway patency, pressure behavior, contamination burden, and procedural context rather than oxygen flow alone.

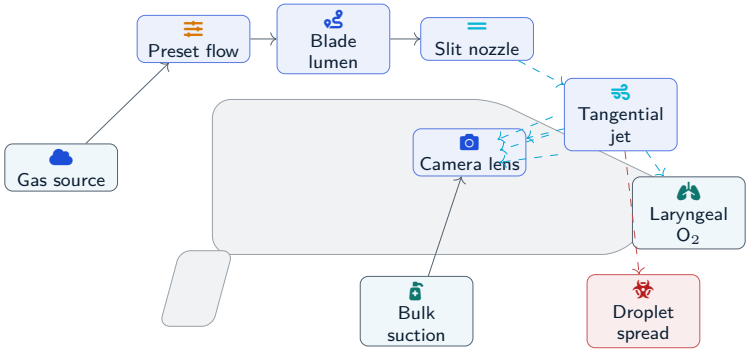


Figure 8. Integrated lens-preserving oxygenating video laryngoscope concept. A regulated gas pathway can be routed through the blade to create a tangential lens-clearing jet while residual flow contributes oxygen near the laryngeal inlet, with suction still required for bulk contamination.

ination. An integrated lens-clearing device might reduce interruptions, but it should not encourage excessively long attempts. Built-in flow should support safe practice, not justify ignoring oxygen saturation, hemodynamics, or aspiration risk.

The research community should be cautious about presenting suction-assisted techniques as solved. SALAD and large-bore catheters are important advances in training and practice, but evidence remains stronger in simulation than in large clinical trials. This does not make the technique unhelpful. Many airway practices rely on mechanistic plausibility, observational data, and simulation because randomized trials in emergencies are difficult. Still, integrated device proposals should acknowledge that the baseline standard is evolving. A new lens-clearing blade should be compared not only with standard video laryngoscopy without suction, but with best available suction-assisted practice. Otherwise, the measured benefit might reflect comparison against an outdated or incomplete control.

6. Apneic Oxygenation and Distal Oxygen Delivery During Laryngoscopy

Apneic oxygenation rests on a physiological observation: oxygen continues to move from alveoli into blood during apnea, and if oxygen is present in the airway and the pathway to alveoli remains open, gas movement can help maintain oxygenation for a period. Carbon dioxide clearance is limited during true apnea, so apneic oxygenation does not replace ventilation. It may, however, prolong the time before desaturation. In emergency airway management, even an additional minute of acceptable oxygen saturation can change the procedure. It may allow suctioning, repositioning, bougie placement, tube confirmation, or transition to a rescue device without severe hypoxemia. The contaminated airway is a setting where this reserve is particularly valuable, because attempts may be interrupted by cleaning and suctioning.

Low-flow nasal cannula during intubation is simple, inexpensive, and widely available. It can be placed before induction and left in place during laryngoscopy. Semler and colleagues evaluated apneic oxygenation by nasal cannula during intubation of critically ill adults in a randomized trial [30]. The results did not show a uniform large benefit across all outcomes, reminding clinicians that apneic oxygenation is not magic and that patient selection matters. Pavlov and colleagues, in a systematic review and meta-analysis, found that apneic oxygenation reduced the incidence of hypoxemia during emergency intubation, although included studies varied in design, oxygen delivery method, and patient population [25]. The most reasonable interpretation is that apneic oxygenation is often low-risk and potentially useful, but its effect size depends on preoxygenation quality, airway patency, oxygen flow, shunt fraction, and duration of apnea.

High-flow nasal oxygen offers a more intensive version of the concept. Patel and Nouraei described transnasal humidified rapid-insufflation ventilatory exchange in patients with difficult airways and reported prolonged apnea time without de-

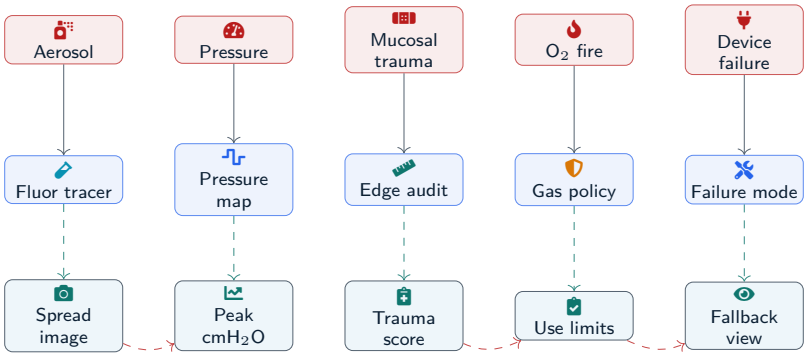


Figure 9. Safety evaluation links each active gas-flow hazard to a measurable control domain. Aerosol dispersion, pressure behavior, mucosal injury, oxygen-enriched conditions, and device malfunction require explicit testing before contaminated-airway use.

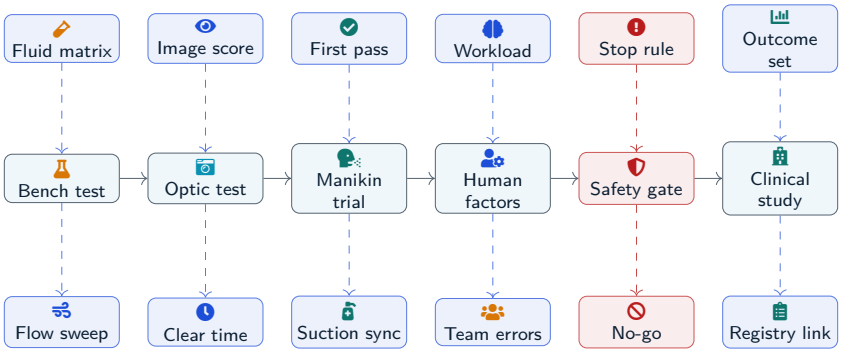


Figure 10. Research pathway for contaminated-airway device development. The sequence moves from fluid and optical characterization to operator simulation, human-factors testing, safety gating, and selected clinical evaluation using endpoints that combine visualization, oxygenation, workflow, and harm.

saturation below 90% in their series [24]. High-flow nasal systems can deliver warmed, humidified oxygen at high flows, generate some positive airway pressure, wash out nasopharyngeal dead space, and provide continuous oxygen during laryngoscopy. Studies in ICU patients have explored high-flow nasal cannula during preoxygenation and intubation, with mixed findings depending on comparator, severity of hypoxemia, and protocol [18, 33]. In a heavily contaminated airway, high-flow nasal oxygen may still be useful, but its effectiveness may be limited if the upper airway is blocked by fluid or if the patient requires immediate suction and airway protection.

Noninvasive ventilation before intubation may improve oxygenation in hypoxemic patients by recruiting alveoli and increasing oxygen reserves. Baillard and colleagues studied noninvasive ventilation for preoxygenation of hypoxemic critically ill patients, showing improved oxygenation compared with conventional methods in that context [3]. However, noninvasive ventilation may be challenging in patients with active vomiting, facial trauma, altered mental status, or high aspiration risk. Positive pressure delivered through a mask can insufflate the stomach if pressures are excessive or airway pressures are poorly controlled. Bouvet and colleagues used ultrasonography to detect gastric insufflation related to face-mask pressure-controlled ventilation and showed that airway pressure matters [4]. This is relevant to contaminated airways because aspiration risk and oxygenation needs often coexist. The clinician may need oxygenation support but must avoid worsening regurgitation.

Bag-mask ventilation during the apneic interval has also been reconsidered. Traditional rapid sequence intubation often discouraged ventilation after induction to reduce aspiration risk. More recent evidence suggests that gentle bag-mask ventilation can reduce hypoxemia in critically ill adults without necessarily increasing aspiration when performed appropriately [6]. The key is controlled technique, appropriate pressure, and patient selection. In an actively vomiting patient, bag-mask ventilation may be hazardous or impossible. In a hypoxemic patient without active emesis, it may be beneficial. This nuance matters because device-based oxygen insufflation may be perceived as safer than bag-mask ventilation, yet gas flow through a laryngoscope channel still interacts with airway pressure and contaminant movement. The pressure, flow, direction, and duration of insufflation should therefore be measured.

Distal oxygen delivery through the laryngoscope has a specific rationale. During laryngoscopy, the blade tip is close to the laryngeal inlet. Oxygen delivered near that region may produce a higher local oxygen fraction than nasal cannula flow, especially when the mouth is open and entrainment of room air occurs. Mitterlechner and colleagues evaluated a dual-use laryngoscope to facilitate apneic oxygenation in simulation, supporting the feasibility of oxygen delivery through a laryngoscope channel [19]. Herff and colleagues compared an oxygenation laryngoscope with nasal standard and nasal high-flow oxygenation in a technical simulation of apneic oxygena-

Table 13. Gas Source and Flow Strategy Trade-Offs

Parameter	Potential Benefit	Main Limitation
Oxygen source	Supports apneic oxygenation	Fire and oxidizer concerns
Medical air source	Reduced oxygen enrichment	No oxygenation advantage
Continuous low flow	Prevents fogging and film	Increased gas consumption
High-flow burst	Clears acute contamination	Aerosolization risk
Single-flow mode	Simpler operation	Less adaptable performance

Table 14. Physiological Effects of Distal Oxygen Delivery

Physiological Aspect	Expected Effect	Important Limitation
Apneic oxygenation	Delays desaturation	Does not provide ventilation
Dead-space washout	Limited carbon dioxide reduction	Hypercapnia still develops
Distal oxygen placement	Higher local oxygen fraction	Reduced effect with obstruction
Continuous insufflation	Maintains oxygen flux	May prolong apnea duration
Open-mouth laryngoscopy	Less room-air entrainment	Flow direction varies with anatomy

tion, reporting favorable oxygen concentrations in the simulation model for laryngoscope-based delivery [13]. Wetsch and colleagues later examined apneic oxygenation using a prototype oxygenation laryngoscope, reinforcing the idea that delivery location and device design matter [34]. These are not definitive clinical outcome studies, but they provide a mechanistic basis for further evaluation.

Pediatric laryngoscopy studies provide additional physiological insight. Steiner and colleagues studied deep laryngeal oxygen insufflation during laryngoscopy in children and reported slower desaturation slopes when oxygen insufflation was used [32]. Children differ from adults in airway size, oxygen consumption, functional residual capacity, and desaturation speed. Still, the study supports the general principle that oxygen delivery close to the larynx can alter desaturation kinetics. This may be relevant to adult emergency care when apnea time is limited. However, pediatric success does not automatically translate to adult contaminated airways, where blood, emesis, and airway obstruction may alter oxygen flow and safety.

An oxygenating laryngoscope raises questions that nasal oxygen does not. The blade moves during laryngoscopy, so the oxygen outlet may shift relative to the glottis. The flow could be directed toward the lens, glottis, epiglottis, posterior pharynx, or esophagus depending on angle and anatomy. If the outlet is used for lens clearing, the flow may be tangential to the lens rather than directly aimed at the glottic inlet. This could reduce oxygenation efficiency but improve image preservation. If the flow is increased to clear viscous contamination, it may create turbulence, aerosolization, or drying. If the flow is continuous, it may conserve image quality but consume oxygen and add noise. If flow is activated only when the lens is obscured, it may require another hand movement or button press. These design choices show why oxygenation and lens clearing should be studied as coupled functions rather than assumed to be independently optimized.

Oxygen concentration is not the only physiological variable. Carbon dioxide accumulation continues during apnea. High-flow nasal oxygen and THRIVE may provide some carbon dioxide clearance through flow-dependent mechanisms and dead-space washout, but carbon dioxide still rises. Laryngoscope-channel oxygen insufflation may offer less dead-space washout and should not be treated as ventilation unless measured. In prolonged attempts, hypercapnia and acidosis may matter, especially in patients with intracranial pathology, severe metabolic acidosis, pulmonary hypertension, or right ventricular failure. A device that allows longer attempts by maintaining saturation could inadvertently encourage prolonged apnea and carbon dioxide accumulation. This reinforces the need for attempt limits and end-tidal or blood gas evaluation in research.

Fire risk is usually low in emergency airway management but cannot be ignored when oxygen-enriched flows are introduced. The operating room has ignition sources such as electrocautery and lasers. Emergency department intubation usually does not involve active surgical ignition near the airway, but post-intubation procedures may occur. Oxygen-enriched environments increase oxidizer concentration and can support combustion. Devices that deliver oxygen through or near a laryngoscope should be compatible with standard airway fire precautions. This is especially relevant if the same device is considered for operating room use. The safer research approach is to define acceptable gas sources, use conditions, and contraindications rather than broadly claiming universal applicability.

In contaminated airway management, apneic oxygenation should be understood as a buffer, not a replacement for effective laryngoscopy and suction. Oxygen delivery may slow desaturation, but it does not secure the airway, prevent aspiration, or remove obstruction. If contamination is severe, the main intervention remains decontamination and tube placement. The promise of integrated oxygenation is that it may reduce the physiological penalty of necessary decontamination and lens preservation. The risk is that it may add complexity or create false reassurance. A balanced research agenda should test whether distal oxygen delivery improves outcomes under realistic contaminated conditions, with careful measurement of pressure, aerosol, aspiration markers, oxygen saturation, carbon dioxide, and operator behavior.

Table 15. Safety Concerns for Integrated Gas-Flow Laryngoscopes

Safety Issue	Mechanism	Potential Outcome
Aerosolization	Gas shears contaminated fluid	Staff exposure risk
Gastric insufflation	Excess upper airway pressure	Regurgitation or aspiration
Mucosal trauma	Nozzle or blade irregularities	Bleeding and edema
Fire risk	Oxygen-enriched environment	Airway combustion hazard
Silent device failure	Unrecognized flow interruption	Delayed rescue action

Table 16. Human Factors in Gas-Flow Laryngoscope Use

Human Factor	Operational Challenge	Clinical Effect
Flow activation	Extra procedural step	Increased cognitive load
Tubing management	External line interference	Restricted blade movement
Assistant coordination	Shared suction and flow tasks	Communication burden
Prolonged confidence	Persistent laryngoscopy attempts	Delayed rescue transition
Noise and distraction	Continuous gas flow sound	Reduced situational awareness

7. Integrated Lens Preservation and Oxygenating Video Laryngoscope Concepts

The concept of combining lens preservation with oxygen delivery arises from the recognition that contaminated airway intubation involves simultaneous visual and physiological failure. A standard video laryngoscope improves the view only while the lens remains clear. A nasal cannula may support oxygenation only while oxygen can reach the airway. A suction catheter removes bulk material but may not keep the optical surface clean. An integrated lens-preserving oxygenating laryngoscope attempts to link these needs through a single device pathway. The most direct form is a gas channel within or along the blade, connected to oxygen or medical air, terminating near the distal lens, and oriented to sweep gas across the lens surface. If the gas stream clears droplets, reduces film formation, and continues into the pharynx, it could theoretically preserve visualization and provide apneic oxygenation during the same attempt.

Malone et al. described a conceptual video laryngoscope blade with an internal gas lumen that terminates near the distal lens region and directs a high-velocity jet tangentially across the camera lens, with primary intent to prevent or clear lens contamination and secondary intent to provide apneic oxygenation through the same gas pathway [17]. The report frames the device as a complement to suction rather than a replacement for decontamination, which is an important distinction. A gas jet cannot reasonably be expected to remove large-volume emesis, clots, or thick particulate matter from the hypopharynx. Its plausible role is narrower: maintaining the optical surface after suction has reduced bulk contamination, or clearing thin films and droplets that would otherwise require withdrawal and wiping. This narrower claim is more credible than suggesting that a gas jet solves the soiled airway by itself.

The mechanical basis of lens clearing depends on the interaction between gas velocity, droplet adhesion, fluid viscosity, lens surface properties, nozzle geometry, and blade orientation. A tangential jet may shear liquid from the lens, displace droplets toward the edge, or prevent new droplets from settling. A perpendicular jet might clear material but could splash contaminants outward or obscure the image with turbulent spray. A continuous low-to-moderate flow may reduce fogging and prevent gradual film formation, while a brief higher-flow burst may clear acute contamination. The correct balance cannot be inferred from general principles alone. It requires bench testing with standardized contaminants, high-speed imaging, optical clarity metrics, and repeated cycles of contamination and clearing. The performance target should not be a perfectly clean lens, but a usable image sufficient for safe tube placement.

Nozzle design is central. A round nozzle may produce a focused jet that clears a small area. A slit nozzle may create a sheet of gas across the lens. Multiple small ports may distribute flow but could clog or reduce velocity. The outlet angle determines whether gas sweeps across the lens, flows toward the glottis, or exits the mouth. The nozzle must be positioned so that tissue contact does not block it. It must also avoid sharp edges or structures that could injure mucosa. If the blade is disposable, the gas lumen must be manufacturable at low cost and resistant to blockage. If reusable, cleaning and sterilization become more complicated. Device developers should avoid assuming that adding a channel to an existing blade is trivial. Small changes to blade thickness, stiffness, curvature, or surface texture can alter laryngoscopy technique.

Gas source selection affects both usability and safety. Oxygen is available in emergency and operating room settings and could support apneic oxygenation. Medical air might preserve the lens while conserving oxygen or reducing oxidizer exposure, but it would not provide the same oxygenation benefit. A system that works with either oxygen or air may be flexible, but clinicians must understand which gas is connected. Flow control should be simple. If the operator must adjust a flowmeter, activate a button, and intubate simultaneously, cognitive load increases. A foot pedal, thumb trigger, assistant-controlled valve, or preset flow regulator each has advantages and drawbacks. Human factors testing should evaluate not only whether operators like the device, but whether they activate it correctly under stress, whether tubing interferes with blade insertion, and whether assistants understand their role.

The lens-preservation function may require different flow than the oxygenation function. A high-velocity jet across the lens

Table 17. Bench Testing Variables for Lens-Clearing Devices

Testing Variable	Purpose	Example Measure
Fluid viscosity	Assess clearing performance	Time to usable image
Nozzle geometry	Evaluate flow distribution	Optical clarity score
Gas flow rate	Determine effective range	Residual contamination
Blade orientation	Simulate clinical positioning	Image recovery consistency
Suction presence	Study flow interaction	Droplet movement pattern

Table 18. Simulation Outcomes for Contaminated Airway Studies

Outcome Category	Representative Metric	Research Purpose
Technical performance	First-pass success	Evaluate airway effectiveness
Optical performance	Time with usable image	Assess lens preservation
Workflow performance	Number of withdrawals	Measure interruption burden
Physiological effect	Lowest oxygen saturation	Assess oxygenation support
Operator factors	Workload and errors	Evaluate usability

may be optimal for clearing but may not deliver maximal oxygen to the alveoli. A lower continuous flow toward the laryngeal inlet may support oxygenation but may not clear viscous film. Combining both functions through one channel may require modes: baseline flow for oxygenation and fog prevention, with brief pulses for clearing. Yet modes add complexity. A single-flow design may be safer and easier but less adaptable. Research should identify whether one clinically practical flow range can provide both adequate optical and oxygenation performance. If not, designers must decide whether the primary intended use is lens clearing, oxygenation, or both. Regulatory classification and clinical claims will depend on this decision.

The relationship between gas flow and suction is also important. A gas jet could displace droplets away from the lens but toward the pharynx, where suction must remove them. If suction is not present, material could move distally or laterally. Ideally, the flow field would direct contaminants away from the lens and toward a suctionable region without projecting them toward the operator. This is a fluid dynamics problem, but also a procedural problem. The suction catheter location, blade position, patient head angle, and oral cavity geometry all affect contaminant movement. Bench models should therefore include simultaneous suction conditions, not only isolated lens-clearing tests. Simulation studies should evaluate whether operators can coordinate suction and gas flow without prolonging attempts.

Existing lens-clearing and oxygenating devices offer partial precedents. Napier and Zitek's report of a lens-clearing video laryngoscope in simulation supports the idea that active lens cleaning can reduce time to intubation for experienced users under controlled conditions [22]. Mitterlechner, Herff, Wetsch, and Steiner provide evidence that oxygen delivery through or near the laryngoscope can maintain higher oxygen concentrations or slow desaturation in simulation or selected clinical contexts [19, 13, 34, 32]. These lines of evidence are complementary but incomplete. Lens-clearing studies do not prove oxygenation benefit. Oxygenating laryngoscope studies do not prove contaminated lens performance. The integrated device class must be evaluated on the combined endpoint, because success requires both functions to operate together.

An integrated device may also change operator behavior. If the lens remains clearer, the operator may keep the blade in place rather than withdrawing to clean it. This could shorten time to intubation. It could also increase the duration of a single attempt if the operator persists through difficulty because the view is partially maintained. Attempt duration should therefore be measured. A device that reduces the number of attempts but increases the duration of the first attempt might have mixed effects. Similarly, improved oxygen saturation might encourage longer apnea. Training protocols should specify when to stop an attempt despite available oxygen and image. A technology that increases tolerance for difficulty can be useful, but it must not erode disciplined airway management.

There are possible patient groups in which such a device might be more or less useful. Massive hematemesis, facial trauma with bleeding, and cardiac arrest with regurgitation are plausible high-yield contexts because both lens contamination and hypoxemia risk are common. Routine elective intubation is unlikely to require lens-clearing gas flow. Pediatric use would require separate evaluation because airway size, mucosal vulnerability, and oxygen consumption differ. Patients with airway burns, friable tumors, severe epiglottitis, or distorted anatomy may have specific risks. In obstetrics, aspiration risk and rapid desaturation are relevant, but device size and urgency require careful assessment. In prehospital care, portability and oxygen supply constraints matter. The research pathway should define intended settings rather than assuming one device fits all airway management.

The device could also interact with infection control. Gas flow across contaminated fluid can produce aerosols or droplets. During COVID-19, airway guidance emphasized minimizing aerosol-generating procedures, using appropriate personal protective equipment, and selecting techniques that improve first-pass success [5]. The aerosol risk of a lens-clearing gas jet should be measured using particle counters, fluorescent tracers, and realistic airway models. The direction of flow matters. A jet directed into the mouth and toward suction may have different dispersion than a jet directed outward. A system with filters or controlled exhaust might reduce risk but add complexity. Until data are available, such devices should

Table 19. Stages of Contaminated Airway Device Evaluation

Research Stage	Primary Goal	Typical Environment
Bench characterization	Test optical and flow mechanics	Laboratory models
Simulation studies	Evaluate operator interaction	High-fidelity manikins
Cadaveric assessment	Examine tissue interaction	Anatomical specimens
Clinical feasibility	Assess safe real-world use	ICU or emergency airway cases
Comparative trials	Measure patient-centered benefit	High-risk populations

Table 20. Potential Clinical Contexts for Integrated Devices

Clinical Setting	Potential Advantage	Key Limitation
Massive hematemesis	Frequent lens contamination	Severe aspiration risk
Cardiac arrest	Continuous regurgitation control	Limited oxygen reserve
Facial trauma	Shared visualization support	Restricted oral access
ICU hypoxemia	Oxygenation during attempts	Physiologic instability
Prehospital airway care	Portable integrated function	Oxygen supply constraints

be considered within aerosol-generating airway precautions.

Manufacturability and cost will influence adoption. A disposable video laryngoscope blade with an internal gas lumen may be feasible using injection molding, but quality control must ensure channel patency and correct nozzle orientation. The device must connect reliably to oxygen tubing without leaks. It must not detach during laryngoscopy. It must be packaged so that emergency setup is intuitive. A reusable design must allow cleaning of internal channels, which may be difficult if contaminated with blood or emesis. Cost is not a secondary concern because emergency departments and prehospital systems use airway devices frequently. If the added feature substantially increases cost, it may be reserved for high-risk cases, requiring clinicians to predict contamination before opening the device. Yet contamination is sometimes unexpected. A low-cost design would permit broader availability, but only if safety and performance are maintained.

Integrated lens preservation and oxygenation should be seen as part of a larger shift in airway device design. Traditional laryngoscopes were mechanical exposure tools. Video laryngoscopes became optical exposure tools. Future devices may become active airway-interface tools that manage visibility, oxygenation, suction, guidance, and data capture. This shift is promising but should remain clinically grounded. A device that does many things poorly is less useful than a device that performs one essential function reliably. The contaminated airway is an appropriate proving ground because it exposes the limitations of passive optics, but it is also unforgiving. The research question should be framed modestly: can integrated gas flow reduce lens-related interruptions and support oxygenation without increasing harm or workflow burden?

8. Safety Evaluation and Human Factors

Safety evaluation for integrated gas-flow laryngoscopes must begin before patient use. The most obvious risks include aerosolization of contaminated material, mucosal trauma, pressure-related insufflation, oxygen-enriched fire conditions, device failure, and distraction. Less obvious risks include false reassurance, prolonged attempts, tubing entanglement, unclear role assignment, and poor compatibility with suction or bougie use. Medical device research sometimes focuses on whether a mechanism works under ideal conditions. For emergency airway devices, the more relevant question is whether the mechanism works when the operator is hurried, the patient is unstable, and the environment is noisy. Human factors are therefore a safety domain, not an optional usability add-on.

Aerosolization and droplet dispersion are immediate concerns. A gas jet directed across a lens in a contaminated airway may shear liquid from the surface, but that liquid must go somewhere. It may move toward the blade, patient, suction catheter, glottis, or operator. The direction and size distribution of droplets will depend on gas velocity, nozzle shape, fluid properties, and airway geometry. Bench testing should use fluorescent liquids, high-speed imaging, particle counting, and simulated suction to map dispersion patterns. It should test thin blood analogues, thick emesis analogues, mucus-like fluids, and particulate mixtures. Testing only water would underestimate risk and overstate clearing performance. Outcomes should include image recovery time, residual optical obstruction, droplet spread distance, aerosol particle generation, and contamination of operator-facing surfaces.

Pressure and insufflation risks require separate study. Oxygen insufflation near the glottis may increase upper airway pressure, especially if the mouth is partially sealed by the device, if the glottis is closed, or if airway obstruction exists. Excess pressure could contribute to gastric insufflation, regurgitation, or barotrauma, though the risk depends on flow and resistance. Bouvet and colleagues demonstrated that gastric insufflation during facemask pressure-controlled ventilation can be detected and is related to pressure conditions [4]. A laryngoscope gas jet is not the same as mask ventilation, but pressure behavior should not be assumed safe. Bench models should measure distal pressure under open airway, closed glottis, esophageal alignment, and obstructed conditions. Clinical pilot studies should monitor for gastric insufflation, regurgitation, aspiration, and ventilation difficulty after intubation.

Mucosal safety is also relevant. A high-velocity jet may dry or irritate mucosa, but brief exposure is unlikely to be a major

issue at appropriate flows. More concerning is mechanical design. The nozzle or channel opening should not create sharp edges or protrusions. It should not trap tissue. It should not weaken the blade or alter the blade tip in a way that increases trauma. Blood in the airway may come from the original condition, but airway device trauma can worsen bleeding and contamination. Trials should record dental injury, mucosal bleeding, airway edema, and operator-rated force. Device designers should avoid adding structures near the distal tip that interfere with epiglottis control or vallecular placement.

Oxygen-related fire risk depends on environment. In emergency medicine and ICU intubation, ignition sources are uncommon during the intubation itself. In operating rooms, airway surgery, electrocautery, and laser procedures can create ignition risk when oxygen concentration is high. An oxygenating blade used for routine intubation before surgery may be safe if flow is discontinued before ignition sources are active, but this requires protocols. Medical air could be used for lens clearing when oxygen enrichment is undesirable, but then oxygenation benefit is reduced. Device labeling and training should specify gas compatibility, flow limits, and procedural contexts. Fire safety should not be exaggerated, but it should be acknowledged and controlled.

Device failure modes should be deliberately created during testing. The gas source may be unavailable, disconnected, or connected to the wrong flow. The channel may clog with blood or emesis. The nozzle may be blocked by tissue. The valve may stick open or closed. Tubing may detach. A disposable blade may have a manufacturing defect. The laryngoscope should remain usable as a conventional video laryngoscope if the gas function fails, unless the failure physically obstructs the view. The operator should be able to recognize failure quickly. If the lens-clearing system fails silently, the clinician may waste time expecting a clearing pulse. Simple visual or tactile confirmation of flow may be useful, but alarms may add complexity.

Human factors testing should include novices, experienced emergency physicians, anesthesiologists, intensivists, paramedics, respiratory therapists, and nurses where appropriate. Different users interact with airway devices differently. An emergency physician may prefer assistant-controlled suction. An anesthesiologist may prefer precise flow control. A paramedic may prioritize portability and rapid setup. The device should be tested in scenarios with gloves, personal protective equipment, noise, time pressure, limited lighting, and simultaneous resuscitation tasks. Metrics should include setup time, errors, missed connections, tubing interference, activation timing, perceived workload, and adherence to attempt limits. It is not enough to ask users whether they liked the device after a successful simulation.

Training requirements should be explicit. If a device requires special technique, it should not be marketed as a simple replacement for a standard blade without training. Simulation can teach operators when to activate flow, how to coordinate suction, how to avoid prolonged attempts, and how to respond to lens-clearing failure. Training should also include direct laryngoscopy fallback and rescue airway planning. The Difficult Airway Society and American Society of Anesthesiologists guidelines emphasize planning, limiting attempts, and having rescue strategies [14, 1]. Integrated device training should reinforce these principles rather than suggesting that a new blade eliminates the need for a difficult airway plan.

Outcome selection in clinical studies should reflect both benefit and harm. Technical outcomes may include time to glottic view, time to tube placement, first-pass success, number of attempts, number of blade withdrawals for cleaning, proportion of time with usable image, and need to switch device. Physiological outcomes may include lowest oxygen saturation, incidence of oxygen saturation below 90%, hypotension, cardiac arrest, and post-intubation ventilation difficulty. Safety outcomes may include aspiration, regurgitation, airway trauma, dental injury, aerosol contamination, and device malfunction. Patient-centered outcomes such as ventilator-free days or mortality may be difficult to attribute in early studies but could be included in larger trials. Operator outcomes, including workload and errors, should not be neglected.

Comparators must be chosen carefully. A new integrated device compared with standard video laryngoscopy without optimized suction may appear beneficial, but the relevant clinical comparator may be video laryngoscopy with SALAD technique, large-bore suction, nasal apneic oxygenation, and bougie availability. Conversely, if the device is intended for settings where advanced suction is unavailable, a simpler comparator may be justified. Studies should clearly describe background airway management. This includes preoxygenation method, suction device, blade type, stylet or bougie use, induction drugs, operator experience, and rescue plans. Without these details, results cannot be interpreted or reproduced.

Regulatory and ethical considerations follow from intended claims. A device claiming to clear a lens may require different evidence than one claiming to provide apneic oxygenation or reduce hypoxemia. A device used only in simulation has a different risk profile than one used in unstable patients with active bleeding. Early clinical feasibility studies should begin in carefully selected cases, with backup devices available and strict stopping criteria. It may be ethically reasonable to test such a device first in patients with anticipated contamination but not extreme instability, or in elective settings with simulated contamination on the device rather than patient airway, depending on the question. The path should proceed from bench to simulation to feasibility to comparative effectiveness, rather than jumping directly from concept to broad clinical adoption.

One subtle safety issue is the possibility of overclaiming. Airway devices often gain attention through dramatic scenarios, but clinical adoption should be based on measured performance. A lens-clearing oxygenating blade may be useful, but it will not remove the need for suction, preparation, skilled operators, or rescue strategies. It may fail against thick particulate matter. It may be unnecessary in clean airways. It may be most useful in a narrow group of high-risk cases. Neutral language matters because exaggerated claims can lead to inappropriate use. The proper scientific posture is to treat the concept as plausible and testable, not proven.

9. Research Pathway for Contaminated Airway Device Development

A staged research pathway is appropriate for devices intended to manage contaminated airway intubation. The first stage should be bench characterization. Before manikin or patient testing, investigators should measure whether the lens-preservation mechanism works under controlled conditions.

A standardized optical test could apply measured volumes of simulated blood, mucus, and emesis to the lens, then quantify time to usable image after gas activation. Image quality could be assessed using resolution charts, contrast targets, or automated pixel-based clarity measures. Testing should vary fluid viscosity, particulate content, angle of blade orientation, gas type, flow, nozzle geometry, and suction presence. A device that clears thin fluid but fails with thick emesis may still be useful, but its intended use should be defined accordingly.

Bench testing should also measure oxygen delivery. A simulated airway and lung model can estimate oxygen concentration near the glottis and in a test lung under different flow conditions. Studies of oxygenating laryngoscope prototypes provide examples of technical simulation methods [19, 13, 34]. However, models should incorporate the specific geometry of the lens-clearing device. If the gas outlet is aimed primarily across the lens, oxygen delivery may differ from a device aimed directly toward the larynx. Investigators should also test open-mouth conditions, suction flow, partial obstruction, and different head positions. The goal is not to prove clinical oxygenation benefit at the bench stage, but to determine whether the device can plausibly increase oxygen availability without excessive pressure.

The second stage should be contamination simulation with human operators. High-fidelity airway manikins can be modified to produce continuous regurgitation or bleeding analogues. Operators can be randomized to standard video laryngoscopy, video laryngoscopy with optimized suction, lens-clearing video laryngoscopy, and integrated lens-clearing oxygenation devices. Outcomes should include first-pass success, time to intubation, time to first usable view, time with obscured image, number of device withdrawals, suction coordination, oxygen saturation in a physiological model if available, and operator workload. Scenarios should include thin fluid, thick emesis, blood-like fluid, and particulate matter. The study should include both experienced and less experienced operators, since device benefit may depend on skill level. Napier and Zitek's simulation work suggests that experienced users may benefit from lens-clearing design, but broader evaluation is needed [22].

Simulation should not be limited to ideal device use. Stressors should be introduced deliberately: failed gas connection, clogged suction, unexpected lens occlusion, limited mouth opening, cervical immobilization, and need for bougie use. The operator should be forced to decide when to continue, when to withdraw, and when to switch devices. Team-based simulation is particularly important because airway management is rarely a solo procedure. The assistant may control suction, oxygen flow, cricoid pressure if used, external laryngeal manipulation, medication timing, or monitoring. A device that requires the assistant to manage another control may affect team performance. These effects are invisible in single-operator bench trials.

The third stage should be cadaveric or animal tissue evaluation where appropriate, recognizing ethical and logistical constraints. Such models can better approximate tissue contact, mucosal contamination, and anatomical variability than plastic manikins. They may allow assessment of trauma risk, nozzle blockage by tissue, and realistic blade handling. However, they may not reproduce active bleeding, vomiting, or physiology. They should be used selectively to answer mechanical and anatomical questions before patient testing. If cadaveric studies are unavailable, advanced synthetic airway models with realistic tissue compliance and fluid dynamics may be used.

The fourth stage should be clinical feasibility. Early patient studies should focus on whether the device can be set up, inserted, activated, and used without obvious safety problems. They should not be powered to show mortality or rare complications. Inclusion criteria might involve adult emergency or ICU intubations with anticipated contamination risk, or elective surgical patients where oxygenation and lens-clearing functions can be evaluated under controlled conditions without active contamination. The choice depends on regulatory approval and ethical review. Feasibility outcomes should include successful device use, image quality, need for backup device, adverse events, operator ratings, and protocol adherence. Investigators should define stopping rules for device malfunction, poor view, hypoxemia, or hemodynamic instability.

The fifth stage should be comparative effectiveness in selected high-risk populations. A randomized trial might compare integrated lens-preserving oxygenating video laryngoscopy with standard video laryngoscopy plus best-practice suction and apneic oxygenation in patients with suspected contaminated airway. Stratification by setting, operator experience, and contamination severity would be needed. Outcomes should include first-pass success without severe hypoxemia, number of attempts, time to intubation, lowest oxygen saturation, aspiration events, and serious adverse events. Because contamination is heterogeneous, a large sample may be required. Alternatively, a registry-based comparative study could collect detailed data across institutions before a randomized trial. The study design should avoid enrolling only clean or mildly contaminated airways if the device is intended for severe contamination.

Contamination severity scoring would improve research quality. Current documentation often records the presence or absence of blood, vomit, or secretions, but this may be too crude. A practical scale could include volume, viscosity, recurrence, lens involvement, suction difficulty, and effect on view. It should be simple enough for emergency documentation but detailed enough for research. Standardized video review might help, though video may be unavailable when the lens is obscured. Operator report is subjective but still useful. Without severity scoring, studies may compare unequal groups. A device tested mostly in mild secretions may not apply to massive hematemesis.

Economic evaluation should not be delayed until after widespread adoption. The cost of disposable blades, oxygen tubing, flow controllers, training, and maintenance must be weighed against potential reductions in attempts, complications, and rescue interventions. If the device is used only rarely, staff may be unfamiliar when needed. If used routinely, cost increases may be substantial. A targeted approach could stock the device in emergency airway carts for patients at high risk of contamination, but prediction is imperfect. Cost-effectiveness modeling could explore different adoption strategies. Such modeling should use conservative assumptions because early device studies often overestimate benefit.

Implementation research is equally important. Airway devices fail when they are unavailable, unfamiliar, or poorly integrated into workflow. A hospital adopting an integrated lens-clearing

oxygenating blade would need protocols for storage, setup, gas connection, flow selection, suction coordination, cleaning or disposal, documentation, and training. Prehospital systems would need to address oxygen supply, ruggedness, battery requirements if any, and environmental conditions. Simulation-based competency could be incorporated into airway training. Quality assurance could track first-pass success, complications, and device malfunctions. The device should be treated as part of an airway system rather than a standalone object.

Research should also consider equity and resource variability. High-flow nasal oxygen, advanced video laryngoscopes, and disposable specialized blades may not be available in all settings. A low-cost lens-clearing gas channel compatible with standard oxygen sources could be attractive in resource-limited environments, but only if manufacturing quality and safety are reliable. Conversely, complex devices may widen disparities if they are adopted only in well-resourced centers. Studies should report setting and resource requirements clearly. If a technique depends on expensive equipment, this should be acknowledged. If a design can be produced cheaply, evidence should still support its performance.

Finally, the research pathway should preserve humility. Many airway innovations look promising in simulation. Fewer show clear patient-centered benefit across clinical settings. This does not mean innovation should stop. It means claims should match evidence. A well-designed integrated lens-preserving oxygenating laryngoscope may reduce specific failure modes in contaminated airway management. It may not change outcomes in all emergency intubations. Its benefit may depend on suction technique, operator training, and patient selection. The purpose of rigorous staged evaluation is not to slow innovation unnecessarily, but to prevent premature confidence in a device used during one of the most consequential procedures in acute care.

10. Conclusion

Contaminated airway intubation remains a difficult clinical problem because it combines several hazards at once. The operator is not only trying to see the glottis. The operator is trying to preserve oxygenation, avoid aspiration, remove fluid, maintain a usable optical path, deliver the tube, and stop the attempt before physiological deterioration becomes severe. Blood, emesis, and secretions create a dynamic environment in which the view can disappear after it has been obtained. This is why soiled-airway management cannot be reduced to choosing video or direct laryngoscopy. It requires a coordinated strategy that includes suction, oxygenation, device selection, tube-delivery planning, and team communication.

Video laryngoscopy has improved many aspects of airway management, but its dependence on a clear distal lens is a specific weakness in contaminated conditions. A video blade that performs well in clean airways may fail abruptly when the camera is smeared. Suction-assisted techniques remain essential and should be considered the foundation of contaminated airway care, but suction does not always protect or restore the camera surface. Apneic oxygenation can provide a useful physiological buffer, yet it does not secure the airway or remove contamination. These realities support interest in integrated approaches, while also setting boundaries around what any single device can reasonably achieve.

Gas-flow lens preservation with concurrent oxygen insufflation is a plausible design direction. Its potential value lies in addressing two linked problems: loss of visualization and loss of oxygen reserve during prolonged or interrupted laryngoscopy. The concept should be evaluated as a complement to suction and established difficult airway practice, not as a replacement. The most appropriate claims at this stage are cautious ones. Such a device may reduce lens-related interruptions, may support oxygenation during attempts, and may fit high-risk contexts such as hematemesis, trauma, and cardiac arrest. It should not be assumed to reduce complications, aspiration, or mortality until those outcomes have been studied.

Safety evaluation should be as rigorous as performance testing. A gas jet that clears a lens may aerosolize contaminated material, alter pressure conditions, move fluid toward the glottis, or distract the operator. Added tubing or controls may increase workload. Improved oxygenation may unintentionally encourage prolonged attempts. These risks are manageable only if they are measured and incorporated into training. Bench studies, high-fidelity simulation, feasibility studies, and comparative clinical trials should use realistic contamination models and clinically meaningful outcomes. The research pathway should include both technical metrics and patient-centered safety endpoints.

The broader lesson is that emergency airway innovation should treat the airway as a system. Visualization, oxygenation, suction, ergonomics, and operator behavior are inseparable during contaminated airway management. Progress is more likely when devices are tested within real workflows rather than isolated from them. A future airway cart may include video laryngoscopes with active lens management, large-bore suction, reliable apneic oxygenation options, and standardized team protocols. Whether integrated oxygenating lens-preserving blades become part of that cart will depend on evidence that they improve the conduct of intubation without adding unacceptable risk or complexity.

For now, the most defensible approach is careful development rather than broad assumption. Clinicians should continue to prioritize preparation, suction readiness, first-pass planning, oxygenation, and rescue strategies. Researchers should define contamination severity, measure optical failure directly, and compare new devices against best current practice. Device designers should keep controls simple, preserve familiar blade mechanics, and test failure modes deliberately. If these principles guide future work, integrated airway technologies may contribute meaningfully to safer management of the contaminated emergency airway, while remaining grounded in the practical constraints of acute care.

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