Clinical and Translational Considerations for Video Laryngoscopy With Concurrent Lens Protection and Apneic Oxygenation During Contaminated Emergency Intubation

Farhan Qureshi[1] **and Bilal Nawaz**[2]

[1]Department of Medicine, Khwaja Fareed University of Engineering and Information Technology, Abu Dhabi Road, Rahim Yar Khan, Punjab 64200, Pakistan
[2]Department of Health Sciences, University of Gwadar, Airport Road, Gwadar, Balochistan 91200, Pakistan

ABSTRACT

Emergency tracheal intubation in critically ill patients often fails for reasons that are partly anatomical and partly physiological. The problem becomes harder when the airway is contaminated by blood, vomitus, or dense secretions, because visualization degrades while oxygen reserve is already limited and aspiration risk is rising. Video laryngoscopy has improved first-attempt performance in many emergency settings, yet its optical advantage can collapse when the distal camera becomes obscured. At the same time, strategies for apneic oxygenation have shown mixed results in adults, and their effect appears to depend on patient selection, oxygen delivery site, and the pace of the procedure. This paper presents a structured review of the contaminated airway as a distinct emergency phenotype and examines how two technical aims, preservation of visualization and maintenance of oxygen delivery during laryngoscopy, may intersect in a single device pathway. The discussion synthesizes clinical studies on first-pass success and repeated-attempt harm, literature on suction-assisted airway decontamination, randomized and simulation-based work on apneic oxygenation, and bench-oriented reports on oxygen delivery through laryngoscope-mounted channels. Particular attention is given to aerosol generation, aspiration dynamics, gastric insufflation risk, operator workload, and staged evaluation methods for device development. The central argument is limited and practical. A dual-function video laryngoscope blade that protects the lens while providing distal oxygen delivery is physiologically plausible and clinically relevant in a narrow group of high-risk cases, but any expected benefit should be treated as contingent on careful bench testing, simulation, feasibility work, and comparative clinical study rather than assumed from concept alone.

KEYWORDS

1. Introduction

Emergency airway management in the emergency department, intensive care unit, and prehospital environment rarely consists of a single technical maneuver. It is usually an unstable sequence in which preoxygenation, hemodynamics, aspiration risk, operator positioning, suction setup, and rescue planning all compete for attention in a short time window. That basic fact matters because seemingly modest losses in speed or view can matter clinically when reserve is already small. The contaminated airway is a sharp example. Once blood or emesis enters the field, the operator is no longer merely navigating anatomy. The task becomes one of restoring information, maintaining oxygenation, and avoiding a second or third attempt in a setting where each interruption can worsen the physiology that made

Article info:
Farhan Qureshi and Bilal Nawaz. *Clinical and Translational Considerations for Video Laryngoscopy With Concurrent Lens Protection and Apneic Oxygenation During Contaminated Emergency Intubation.* Nextqueries.
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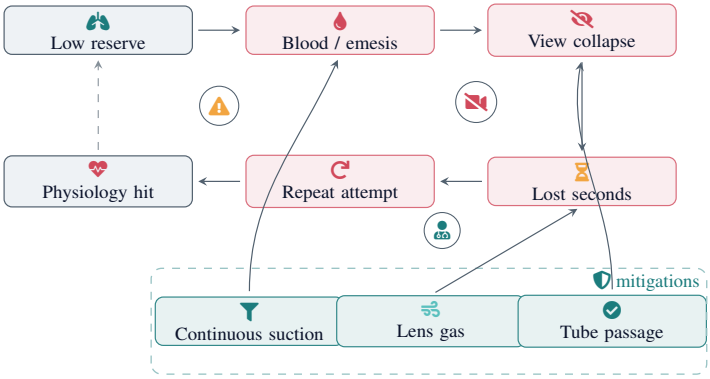

Figure 1 Contaminated emergency airway as a dynamic failure loop in which bulk material, optical loss, and physiologic fragility reinforce repeated attempts unless decontamination and lens protection preserve the first usable view.

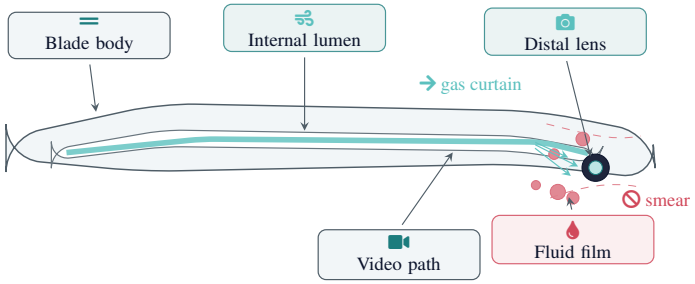

Figure 2 Macintosh-style video laryngoscope concept with an internal gas channel directed over the distal optical interface to resist droplet deposition while maintaining a familiar blade geometry.

the airway urgent in the first place.[1, 2]

The literature on first-pass success makes that point without much ambiguity. In emergency department intubation cohorts, first-pass success has repeatedly been used as a practical quality measure because additional attempts are associated with higher rates of hypoxemia, hypotension, aspiration, and procedural trauma.[1, 2] Those associations do not prove that first-pass success is the only outcome that matters, but they do explain why emergency airway research often organizes itself around that endpoint. It is not a surrogate in the weak sense. It is a marker that sits very near the consequences that clinicians actually fear. Once the airway is soiled, the probability of losing that first attempt rises, and the mechanism is often not exquisite anatomy or rare pathology. It is degraded visualization, clutter, and time lost to clearing the field.[3, 4]

The contaminated airway should therefore be treated as more than a generic difficult airway. It is a particular operational state in which anatomy, optics, and physiology interact. Sakles and colleagues reported that soiled airways in the emergency department were associated with lower first-pass success for both direct and video laryngoscopy.[3] In out-of-hospital cardiac arrest, regurgitation and emesis are common enough to be operationally important rather than anecdotal, with observational data placing the problem in roughly one third of cases in some cohorts.[5] Similar patterns appear in upper gastrointestinal hemorrhage, major facial trauma, oropharyngeal bleeding, and peri-arrest states where repeated suctioning competes with view acquisition and tube delivery. The difficulty is not only that the relevant structures are hidden. It is that the field keeps changing while the patient continues to desaturate or bleed.

Video laryngoscopy changed emergency practice because it often improves glottic visualization and increases the chance of first-attempt intubation in critically ill adults.[6] The DEVICE trial strengthened that position for many clinicians by showing a first-attempt advantage for video over direct laryngoscopy in critically ill adults.[6] Even so, contaminated airways expose a narrow weakness in the logic of video laryngoscopy. The camera sits distally, close to where blood, secretions, and vomitus accumulate. When the lens is obscured, the device loses the informational advantage that justified its use. Direct laryngoscopy can also fail in contamination because the line of sight is blocked, but the video device introduces an additional interface that can become unusable before the operator has time to recover it.[3]

Malone et al.[7] described a conceptual Macintosh-style video laryngoscope blade with a single internal gas lumen intended to direct flow across the distal lens and, secondarily, provide apneic oxygenation during laryngoscopy. That paper did not settle whether such a design improves patient outcomes. It instead identified a clinically recognizable failure mode and suggested a dual-function mechanism that might address it. The purpose of the present paper is broader and more cautious. It uses that concept as an entry point for a deeper medical analysis of the contaminated airway: why this airway behaves differently from other emergency airways, where current practice remains limited, what is known about oxygen delivery during apnea, what safety problems a gas-directed lens-protection strategy would create, and how such a device would need to be evaluated

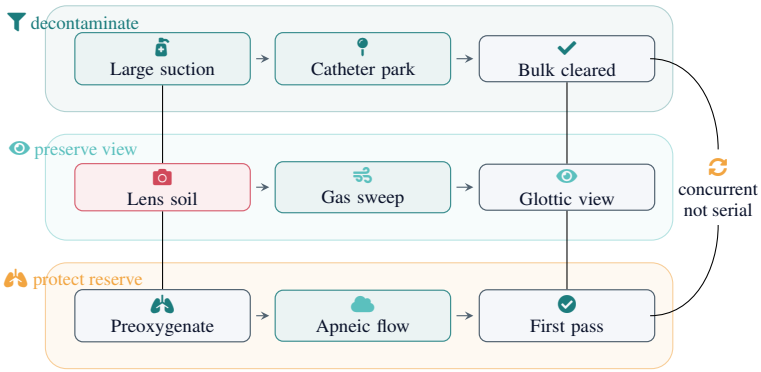

Figure 3 Integrated contaminated-airway workflow combining suction-assisted decontamination, gas-directed lens clearing, and oxygen reserve support as concurrent tasks rather than separate sequential maneuvers.

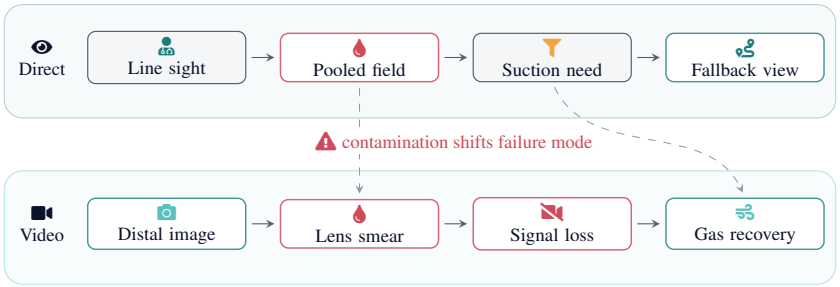

Figure 4 Different visualization failure modes in direct and video laryngoscopy, showing how contamination can convert the usual video advantage into an optical-interface problem unless lens recovery is available.

before claims of practical usefulness could be taken seriously.

2. Clinical Burden of the Contaminated Emergency Airway

The contaminated airway is often described in pragmatic terms, sometimes even as an airway that is simply "messy." That language is convenient, but it hides the extent to which contamination changes the task itself. Blood and emesis do not merely conceal structures. They convert a linear procedure into an iterative one. The operator advances the blade, suction is applied, the camera or direct view improves briefly, fresh material arrives, the view collapses again, and the sequence repeats. This is why the soiled airway should be understood as a dynamic airway. The geometry of the laryngeal view changes from moment to moment, and the amount of information available to the operator can fall abruptly. In that setting, delays of only a few seconds matter because they often accumulate at exact moments when the patient has the least oxygen reserve or the highest aspiration risk.[3, 4]

The physiological context also deserves more emphasis than it often receives. Patients with hematemesis may have shock, low hemoglobin, acidemia, or coagulopathy before intubation begins. Trauma patients may have facial disruption, active bleeding, cervical precautions, and reduced pulmonary reserve. Patients in cardiac arrest may have ongoing chest compressions, passive regurgitation, and absent protective reflexes, which together create a setting in which decontamination is recurrent rather than one-time.[5] In these groups, a contaminated airway is not just harder to see through. It is attached to a patient who often decompensates rapidly during apnea. A device or technique that reduces an interruption of ten or fifteen seconds may therefore matter more in these patients than in a routine elective airway. That does not prove benefit, but it explains why the problem keeps returning in emergency medicine, anesthesiology, and prehospital care.

The relationship between contamination and outcome is partly mediated through repeated attempts. Sakles and colleagues linked multiple emergency department intubation attempts with a higher burden of complications, and Hasegawa and colleagues found a similar association in multicenter prospective data.[1, 2] The practical implication is easy to state but harder to achieve. If contamination lowers first-pass success, and repeated attempts are harmful, then even modest strategy changes that preserve the first view or shorten the time to tube passage are worth studying. The soiled airway therefore pressures clinicians toward arrangements that reduce task switching. Every additional motion, such as removing a video blade to wipe the lens and then reinserting it, is not only wasted time. It also means another opportunity for anatomy to shift, contaminants to reaccumulate, or oxygen saturation to fall.

Suction-assisted laryngoscopy and airway decontamination, now widely referred to as SALAD, emerged for that reason.[4] The technique formalizes something many emergency clinicians had already done in fragments: suction remains in the airway during laryngoscopy, large-bore suction is favored when available, and decontamination is treated as concurrent with visualization rather than a preliminary step that can be completed

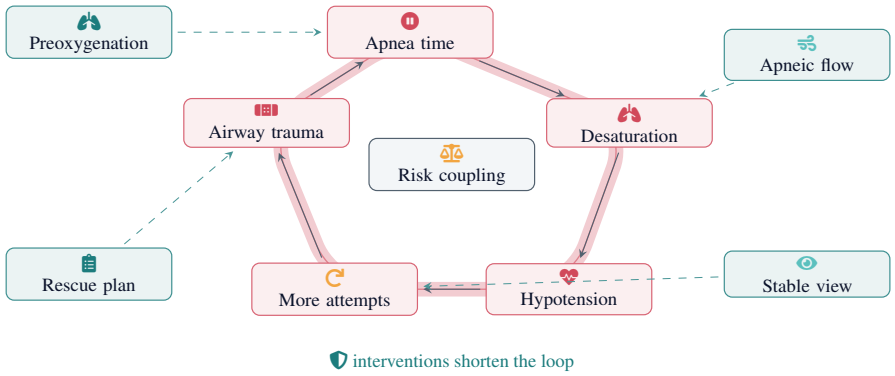

Figure 5 Physiologic risk coupling during contaminated-airway intubation, where prolonged apnea and repeated attempts amplify cardiopulmonary instability unless view preservation and oxygen delivery reduce loop duration.

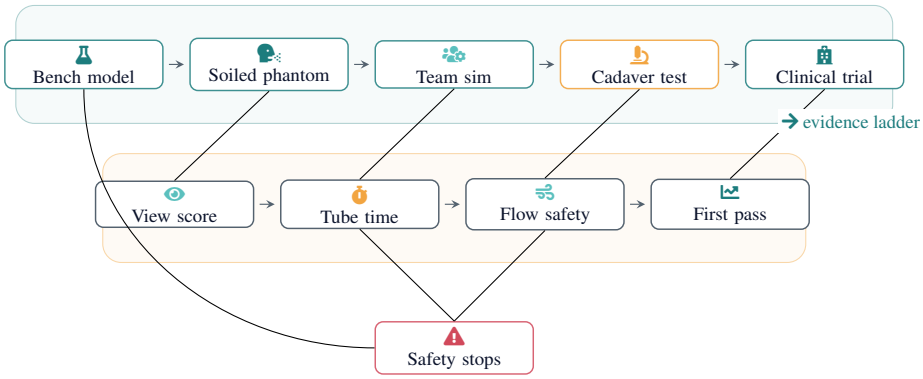

Figure 6 Evaluation pathway for a gas-directed lens-protection laryngoscope, progressing from controllable contamination models to clinical endpoints while safety limits govern each transition.

once. The importance of SALAD is not merely that it improves field management in training scenarios. It also changes how one thinks about devices. A contaminated airway device that ignores suction is almost certainly incomplete, because suction is what reduces bulk contamination. The question is what remains after suction has done everything it can and visualization still fails because a thin film or droplet layer reaches the distal camera. That narrow failure mode is where lens protection becomes clinically interesting rather than merely clever.[4]

The epidemiology of contamination makes a selective rather than universal viewpoint reasonable. Not every emergency airway is soiled, and not every contaminated airway is equally difficult. Thin blood behaves differently from clotted blood. Emesis with liquid gastric contents behaves differently from particulate emesis. Secretions in pneumonia or pulmonary edema are different again. The likely value of device-based lens protection therefore depends on the airway phenotype. An active variceal bleed with persistent hematemesis is different from a stable intensive care patient whose lens fogs during prolonged positioning. A device intended to address both with the same settings may end up optimally tuned for neither. This is one reason why the contaminated airway should be broken down into separate use cases during research rather than handled as a single broad category.

Another clinical burden lies in cognition. Operators facing a soiled airway are often required to control the blade, interpret a rapidly changing view, coordinate one or two suction catheters, judge whether laryngoscopy should continue or be aborted, and remember the rescue sequence if the view is lost completely. That cognitive load is not a soft problem. It affects timing, hand movement, team communication, and willingness to persist with a failing view. A device that slightly improves the picture but adds an extra control, extra tubing, or a nonintuitive flow setting may offer less practical benefit than expected. In other words, contaminated airway interventions must be judged against the full burden of the scenario, not just against the isolated optical problem they were designed to solve. A usable device in this domain has to reduce uncertainty without creating new tasks that matter just as much.

3. Visualization Failure During Video Laryngoscopy

Video laryngoscopy has justifiably reshaped airway practice because it changes the alignment problem. The operator does not need a direct oral-pharyngeal-laryngeal line of sight in the same way that classic direct laryngoscopy does, and this often yields better glottic views, especially in anatomically difficult or restricted positions.[6] The DEVICE trial gave large-scale support to that pragmatic advantage in critically ill adults, with improved first-attempt success for video laryngoscopy under emergency conditions.[6] Yet the trial also highlights an im-

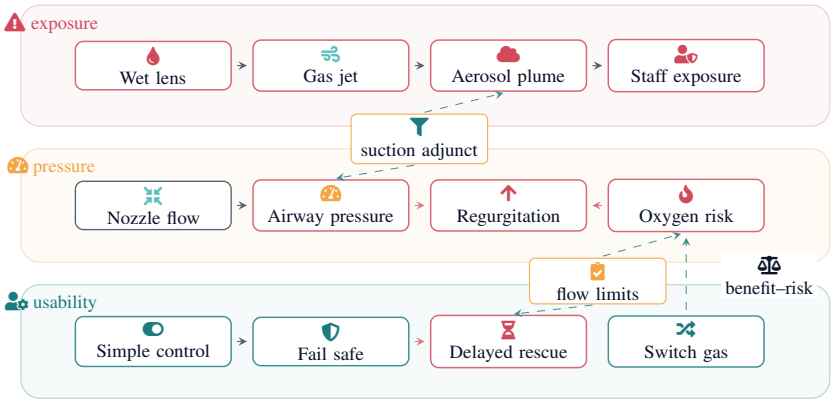

Figure 7 Safety map for gas-directed lens protection, linking aerosol formation, pressure exposure, oxygen enrichment, and human-factor failure modes to the controls needed before clinical translation.

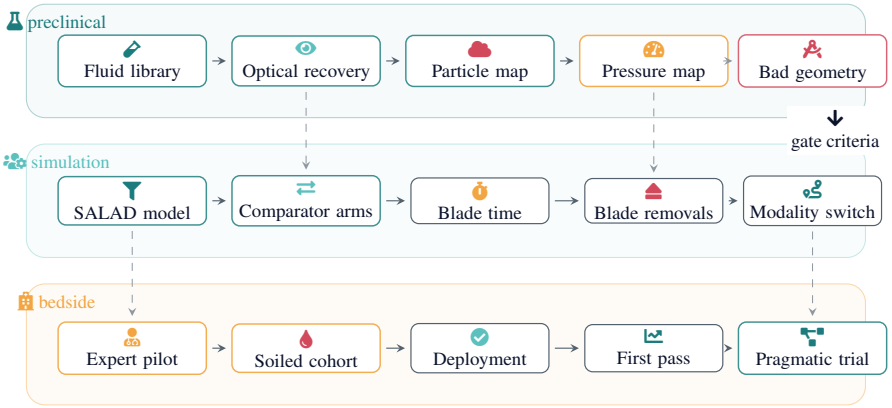

Figure 8 Translational study pathway moving from heterogeneous contaminant models and safety profiling to simulation endpoints, enriched clinical feasibility, and phenotype-specific comparative evaluation.

portant limit. A better standard approach does not erase the existence of subgroups in which the mechanism of failure differs. The contaminated airway is one of those subgroups. The information pathway in video laryngoscopy depends on a distal optical interface that can be degraded by a small amount of material placed in exactly the wrong location.

That failure mode is easy to underestimate because the volume of material required may be small. A view can be rendered marginal or useless by a thin film, scattering droplets, or a smear across the lens surface. The operator may still see light and movement, but the discriminating features needed for airway navigation, arytenoid contours, vocal cord aperture, or tube tip orientation, become blurred or disappear. This can be more frustrating than complete darkness because it invites extra seconds of effort before the operator concedes that the view is no longer workable. In an uncontaminated airway, video laryngoscopy often simplifies the problem by producing a stable magnified image. In a soiled airway, it can instead magnify uncertainty. Small contaminant events at the lens surface become large decision problems for the clinician holding the blade.[3]

Direct laryngoscopy is not immune to contamination, but its failure pattern differs. The line of sight may be obscured by pooled blood or emesis, and suction can be equally necessary. Even so, there is no distal camera to wipe, flush, or protect. This matters because contamination can shift the relative strengths of the two modalities. Sakles and colleagues reported reduced first-pass success in soiled airways with both techniques.[3] The point is not that direct laryngoscopy becomes preferable in every contaminated airway. Rather, it means the usual advantage of video laryngoscopy cannot be assumed to survive the moment the lens is soiled. In practice, many clinicians already respond to this by treating contaminated airways as hybrid situations in which video is attempted but direct laryngoscopy remains immediately available if optics fail. That pragmatic flexibility is sensible, but it also reveals a gap: a device that preserves the video view during active contamination could allow clinicians to retain the general advantages of video laryngoscopy without abandoning them the moment blood or emesis reaches the lens.

Current mitigation strategies are mostly workarounds rather than integrated solutions. The first line is suction, especially large-bore suction used deliberately and continuously as emphasized in SALAD.[4] When the lens is obscured despite suction, clinicians often remove the blade, wipe the lens, and reinsert. Some use improvised irrigation or saline flush approaches. Commercial or simulation-based lens-clearing systems have also appeared, but the available clinical literature remains sparse.[8] The letter by Napier and Zitek is suggestive in this respect. In a simulated setting, experienced users had shorter times to in-

Table 1 Key operational features of contaminated emergency airways

Feature	Clinical Effect	Procedural Impact
Blood contamination	Obscures anatomy	Delays tube delivery
Emesis aspiration risk	Rapid desaturation	Repeat suctioning needed
Lens soiling	Loss of optical clarity	Video failure episodes
Low oxygen reserve	Faster hypoxemia	Reduced safe apnea time
Repeated attempts	Physiologic decline	Higher complication burden

Table 2 Comparison of direct and video laryngoscopy in contaminated settings

Aspect	Direct Laryngoscopy	Video Laryngoscopy
Visualization mode	Line-of-sight	Distal camera imaging
Main contamination issue	Pooled obstruction	Lens smear or droplets
View recovery	Suction repositioning	Lens clearing required
Device dependence	Minimal optics	Camera dependent
Failure transition	Gradual loss	Sudden image collapse

tubation with a lens-clearing video laryngoscope.[8] That is not enough to prove bedside value. The study was limited, the setting was controlled, and simulation outcomes can exaggerate practical ease. Still, it points toward a sensible target for further work: the moment after obscuration, when a device that restores or preserves the image may save an otherwise failing attempt.

A difficult point in this literature is that not all obscuration events are the same. Fogging, thin liquid film, repeated droplet spray, and adherent particulate contamination are separate engineering problems. A saline flush may deal reasonably with one but not another. A gas jet might shear a liquid film yet fail against thick clotted blood or chunky emesis. This means that claims about "lens clearing" are only clinically meaningful if they specify the contaminants being modeled, the lens orientation, the amount of suction in the airway, and the time required to recover a usable field. A view that returns partially after three seconds may be good enough in one patient and useless in another. Research in this area sometimes treats the lens as though it were a binary state, clean or dirty. Clinically it behaves more like a gradient, and that gradient is where a great deal of decision-making occurs.

The contaminated airway therefore creates a specific design problem for video laryngoscopy. Bulk contamination must still be managed by suction. The optical interface should recover quickly once contamination reaches it. The device should avoid requiring removal from the mouth if possible, because removal and reinsertion can consume time and alter anatomy. The method of lens protection should not significantly enlarge the blade, distort a familiar Macintosh-like technique, or add steps that matter under stress. It should also remain useful when the gas or clearing function is unavailable, because the worst moment to discover flow dependence is during a crashing airway. These design requirements are pragmatic rather than elegant, but they are the ones that determine whether an intervention moves from interesting bench concept to something that experienced emergency airway teams would actually reach for.

4. Apneic Oxygenation and Distal Oxygen Delivery During Laryngoscopy

reduce The second half of the dual-function blade concept concerns oxygen delivery during apnea. The physiological principle of apneic oxygenation is straightforward enough. Oxygen continues to move into the blood during apnea so long as there is a partial pressure gradient and some route for oxygen to reach the alveoli. In idealized settings, this can extend the time before severe desaturation. In real critically ill patients, the situation is less clean. Shunt physiology, reduced functional residual capacity, obesity, pulmonary edema, aspiration, and ongoing metabolic demand can sharply limit the effect. That is why apneic oxygenation has had a mixed reception in emergency medicine. The principle is sound, but the bedside effect is variable and not always large enough to be reliably seen across broad populations.[9, 10]

The randomized trial by Semler and colleagues illustrates that uncertainty.[9] In critically ill adults undergoing intubation, apneic oxygenation via nasal cannula did not produce a clear improvement in lowest oxygen saturation compared with usual care. That finding tempers broad claims that oxygen delivery during apnea necessarily changes meaningful outcomes in emergency intubation. Yet the negative or neutral result should not be overread. It does not mean oxygen delivery site is irrelevant, and it does not mean all approaches share the same limitations. Meta-analytic work by Pavlov and colleagues suggested a reduction in hypoxemia during emergency intubation with apneic oxygenation overall, though the pooled literature

Table 3 Integrated workflow during contaminated airway intubation

Workflow Step	Primary Objective	Supporting Method
Preoxygenation	Extend oxygen reserve	High-flow oxygen
Continuous suction	Remove bulk contaminants	SALAD technique
Lens protection	Preserve visual field	Directed gas flow
Tube advancement	Secure airway access	Stable glottic view
Rescue readiness	Reduce failed attempts	Backup airway plan

Table 4 Potential advantages of gas-directed lens protection

Function	Expected Benefit	Clinical Relevance
Distal gas sweep	Reduces droplet deposition	Better visualization
Continuous oxygen flow	Supports apneic oxygenation	Delays desaturation
No blade removal	Maintains anatomy alignment	Faster intubation
Integrated lumen	Simplifies setup	Lower task switching
Macintosh geometry	Familiar handling	Easier adoption

contained heterogeneous populations, delivery methods, and baseline practices.[10] The lesson is less about victory or failure than about context. Oxygen delivered during laryngoscopy may help, but the mechanism, timing, and patient phenotype likely determine whether the effect is clinically visible.

That context is where deeper oxygen delivery becomes interesting. Nasal oxygen supplementation is simple and familiar, but it still relies on the upper airway remaining a reasonably effective conduit during apnea. Distal or deep laryngeal oxygen insufflation moves the gas source closer to the glottic inlet, which may reduce entrainment of room air and maintain a higher local oxygen fraction during laryngoscopy. Mitterlechner and colleagues explored this principle in a simulation model using a dual-use laryngoscope, showing that oxygen insufflation into a simulated laryngeal space maintained higher oxygen concentrations in a test lung than oxygen insufflation delivered by nasal prongs.[11] That result does not prove patient benefit, but it does support a physiological rationale for laryngoscope-integrated oxygen delivery rather than assuming that all apneic oxygenation methods are interchangeable.

The pediatric randomized trial by Steiner and colleagues adds another layer.[12] In children undergoing laryngoscopy, deep laryngeal oxygen insufflation was associated with slower desaturation than conventional direct laryngoscopy without insufflation. Pediatric physiology differs from adult critical illness, and one should be careful about direct translation. Even so, the trial matters because it moves the concept beyond bench plausibility. It suggests that oxygen delivered near the laryngeal inlet during laryngoscopy can alter desaturation kinetics in a living clinical context. For adults with contaminated airways, that does not answer the whole question. The relevant patients may have pulmonary shunt, aspiration, or active bleeding, all of which reduce the likelihood of a large oxygenation effect. Still, it makes it harder to dismiss distal insufflation as merely theoretical.

More recent technical simulation work points in the same direction while also emphasizing geometry. Herff and colleagues compared an oxygenation laryngoscope with nasal standard flow and nasal high-flow oxygenation in apneic simulation and found better maintenance of oxygen concentration in the test lung with the blade-based system.[13] Wetsch and colleagues later showed that oxygen delivery position along modified Macintosh blades mattered, with more distal delivery maintaining oxygenation more effectively than more proximal configurations in a bench model.[14] Those findings are easy to connect to a contaminated-airway device concept. If oxygen is going to be delivered through a laryngoscope blade at all, where it exits and how it is directed are not secondary questions. They determine whether the gas mostly benefits the airway, mostly dissipates into the mouth, or does some mixture of both.

At the same time, there is a real tension between the requirements for oxygenation and the requirements for lens protection. A quiet, continuous flow may support local oxygen enrichment and reduce fogging, but a high-velocity jet is more likely to shear liquid off the lens. The optimal settings for one effect may not be optimal for the other. A lumen that aims tangentially across the camera window may preserve the image but direct less oxygen toward the glottic inlet than a more distal or central exit would. Conversely, an outlet optimized for oxygen delivery into the laryngeal space may have weak lens-sweeping performance. A serious research program should therefore avoid assuming that a single geometry will naturally perform both functions well. The dual-use claim is plausible, but it is still a claim that requires optimization rather than a property guaranteed by combining two ideas in one device.

A more realistic clinical framing is to treat oxygen delivery as a secondary but still relevant effect. In a contaminated airway, the primary task remains securing the tube. A device that

Table 5 Major risks associated with gas-assisted airway devices

Risk Factor	Potential Consequence	Mitigation Strategy
Aerosol generation	Staff exposure	Concurrent suction
High airway pressure	Gastric insufflation	Controlled flow limits
Oxygen enrichment	Fire hazard	Air-mode fallback
Extra tubing	Cognitive overload	Simplified controls
Delayed abandonment	Prolonged apnea	Defined rescue thresholds

Table 6 Clinical situations with high contamination burden

Scenario	Typical Contaminant	Procedural Challenge
Upper GI bleeding	Hematemesis	Persistent obscuration
Facial trauma	Active bleeding	Distorted anatomy
Cardiac arrest	Passive regurgitation	Continuous contamination
Pulmonary edema	Frothy secretions	Repeated suctioning
Peri-arrest shock	Mixed secretions	Rapid desaturation

keeps the camera usable may matter most because it reduces interruptions and rescues a view that would otherwise be lost. Distal oxygen delivery through the same pathway may then offer incremental help by slowing desaturation during the extra seconds required for suctioning or tube placement. That kind of effect is modest by design, not dramatic. It would probably matter most in patients at high risk of rapid hypoxemia, and least in those with severe shunt physiology or heavy particulate contamination. This narrower expectation is useful because it keeps the research question tied to the actual bedside problem. The goal is not to replace preoxygenation, noninvasive ventilation, or other preparation strategies. It is to see whether a blade-based oxygen stream can slightly widen the margin for success while simultaneously protecting the optical field that video laryngoscopy depends on.[9, 10, 11, 12, 13, 14]

5. Safety Risks and Human Factors

Any device that directs gas into a contaminated airway raises safety questions that are serious enough to be central rather than peripheral. The most immediate is aerosol generation. A gas jet crossing a wet lens and then entering an airway containing blood, saliva, or vomitus may break liquid films into smaller particles or alter the direction of emitted droplets. In some circumstances the flow may even push contaminated material upward or laterally in ways not obvious to the operator. The mere fact that the jet is small or targeted does not settle the issue. Aerosol behavior depends on contaminant properties, jet speed, nozzle orientation, mouth opening, concurrent suction, and the position of the laryngoscope in the oropharynx. This is one of the stronger arguments for avoiding premature clinical use. If the price of better lens visibility is greater operator contamination, the trade would be difficult to justify except perhaps in very narrow scenarios.

Suction complicates that picture in both helpful and unhelpful ways. On the one hand, effective suction removes bulk fluid and may reduce the material available for aerosolization. On the other hand, a poorly coordinated combination of suction and directed gas flow could create recirculating turbulence in the airway, especially in pharyngeal spaces where structures are irregular and moving. SALAD teaches that suction is indispensable in the massively contaminated airway.[4] A lens-protection strategy should therefore be evaluated as an adjunct to suction rather than in isolation. The safety question is not whether a gas jet alone aerosolizes fluid in a bench setup. It is whether it changes aerosol burden, contaminant directionality, or field contamination compared with a realistic suction-assisted airway approach. Those are different experiments, and only the latter has much relevance to real emergency practice.

Pressure effects are a second concern. Gas delivered through a blade lumen may increase pharyngeal or supraglottic pressure, potentially affecting gastric insufflation, regurgitation, or the distal displacement of contaminants. The available literature does not directly answer what a lens-clearing jet would do in this exact context. Bouvet and colleagues studied gastric insufflation during facemask pressure-controlled ventilation and identified pressure thresholds relevant to insufflation detection.[15] That is not the same as a localized blade-based jet, but it provides a useful reminder that apparently modest upper-airway pressures can have downstream physiological consequences. A dual-function blade should therefore not inherit safety assumptions from either nasal oxygen or positive-pressure ventilation without measurement. Local nozzle pressure, net pharyngeal pressure, jet duration, and patient anatomy would all shape the actual exposure.

A third issue is that oxygen is not a neutral gas in all environments. Directing oxygen through the blade raises local oxidizer concentration. In many emergency department intu-

Table 7 Evaluation stages for contaminated-airway devices

Study Phase	Primary Endpoint	Typical Environment
Bench testing	Optical recovery	Controlled models
Phantom simulation	Tube placement time	Soiled mannequins
Team simulation	Workflow usability	Crisis scenarios
Cadaver evaluation	Anatomical feasibility	Human anatomy models
Clinical feasibility	First-pass success	Emergency settings

Table 8 Factors influencing apneic oxygenation effectiveness

Factor	Physiologic Effect	Clinical Limitation
Obesity	Reduced reserve volume	Faster desaturation
Pulmonary edema	Increased shunt fraction	Lower oxygen transfer
High metabolic demand	Accelerated oxygen use	Short apnea window
Distal oxygen delivery	Higher local oxygen fraction	Device complexity
Poor preoxygenation	Limited baseline reserve	Earlier instability

bations, this may be of limited consequence because ignition sources are sparse during the immediate intubation attempt. In other settings, especially operating-room workflows or any sequence that involves electrocautery, laser use, or delayed airway instrumentation after intubation, oxygen enrichment becomes more consequential. One practical implication is that a device pathway that can accept either oxygen or medical air may be safer and more flexible than one committed exclusively to oxygen. Yet switching gases also changes the expected oxygenation benefit. This is another example of why dual-function designs often look simpler on paper than in use. The clinically preferred gas may depend on whether the operator is trying to preserve the lens, delay desaturation, or minimize combustion risk.

Human factors are just as important. A contaminated airway occurs under time pressure, often with a crowded bedside, active suction tubing, monitor alarms, and a team attempting parallel tasks. If the lens-protection mechanism requires extra assembly, separate priming, or a control that is not obvious by touch, adoption will be poor and errors will follow. A useful design would need to fail safely, meaning the blade still functions as a standard video blade when gas flow is absent or disconnected. It would also need to minimize added cognitive steps. A device that forces the operator to think about flow settings while also holding suction and advancing a tube may be less safe than a simpler blade that occasionally requires wiping. This is not an argument against device innovation. It is an argument for treating usability as a core outcome equal to image quality.

The final safety question is one of indication. No lens-clearing system should be expected to solve all forms of contamination. Highly viscous particulate emesis, thick clot burden, or large tissue fragments may overwhelm any lens-sweeping effect. In those cases the right response may still be aggressive suction, rapid conversion of technique, or a surgical airway if oxygenation and access are collapsing. This matters because devices can create a subtle trap. When a mechanism works intermittently, operators may persist longer than they otherwise would, trusting that another burst of flow will restore the image. A safety-conscious research program should therefore examine not only whether the device sometimes clears the view, but also whether it changes operator behavior in ways that delay necessary rescue actions. In emergency airway management, delayed abandonment of a failing approach is itself a meaningful hazard.[2, 1]

6. Translational Evaluation and Study Design

A credible evaluation pathway for a dual-function blade has to begin with bench work, but not with simplistic bench work. The contaminated-airway problem is heterogeneous, so benchtop testing should deliberately vary the type and behavior of the contaminant. Thin blood analogs, more viscous blood surrogates, opaque fluid mixtures resembling gastric contents, and particulate suspensions should all be represented. The outcome should not be whether the lens looks cleaner after gas is applied. It should include a quantified recovery of usable visualization. Metrics might include time to restoration of a predefined image contrast threshold, percentage of the field of view obscured over time, persistence of recontamination under continued fluid introduction, and the amount of gas flow required to maintain a minimally interpretable image. Because the nozzle geometry may trade oxygenation against lens shearing, multiple outlet angles and lumen diameters should be tested rather than fixing those parameters too early.[13, 14]

Optical testing alone would be incomplete. Aerosol generation should be studied in the same models using realistic mouth opening, blade position, and concurrent suction. This could be approached with fluorescent tracer particles, high-speed videography, particle counting at operator head height, and contamina-

Table 9 Operational recommendations for selective deployment

Operational Area	Recommended Practice	Intended Outcome
Airway preparation	Dual suction setup	Faster decontamination
Device selection	Use in predicted soiling	Targeted deployment
Simulation training	Contaminated-airway drills	Better team response
Backup planning	Early modality switch	Reduced persistence failure
Gas management	Adjustable flow settings	Improved safety control

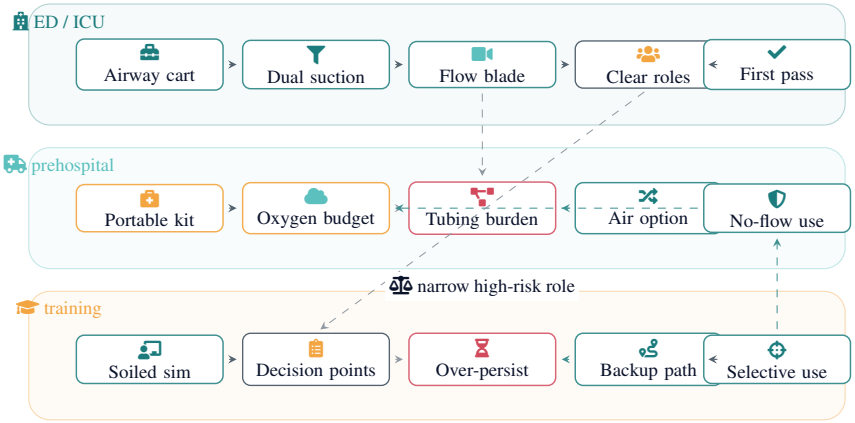

Figure 9 Operational integration of a dual-function blade into emergency airway systems, emphasizing suction-first use, flexible gas configuration, simulation-based decision training, and selective deployment in anticipated contaminated airways.

tion mapping on simulated personal protective equipment. Such experiments would not yield a single universal "safe" flow rate, but they could narrow the design space and identify geometries that are clearly unfavorable. Pressure measurements are also needed. Local exit pressure, oropharyngeal pressure, and any evidence of distal insufflation should be captured across the full range of candidate flows. Bouvet's work on gastric insufflation thresholds during pressure-controlled ventilation is not directly transferable, but it offers a practical reminder that upper-airway pressure effects are measurable and clinically relevant.[15] A device intended for use during apnea should not enter simulation without already having a mapped pressure profile.

High-fidelity simulation would then be the next step, but it needs proper outcomes. Standardized soiled-airway scenarios based on SALAD methods are an obvious platform because they allow repeated contaminant challenges while keeping operator training conditions relatively consistent.[4] Comparators should include standard video laryngoscopy, standard video laryngoscopy with whatever lens-cleaning workaround is locally typical, and direct laryngoscopy when appropriate. Endpoints should extend beyond total intubation time. More informative measures would include time to best view, time from first obscuration to view recovery, number of blade removals, need for modality conversion, success on first insertion of the blade, and effective apneic interval under simulation. Video review would be especially useful because it could separate a lens problem from a tube-delivery problem. Without that distinction, there is a risk of concluding that a device failed when the true issue was unrelated hand mechanics or poor use of suction.

A pilot clinical feasibility study would need to be narrow and cautious. One poor design choice would be to begin with all emergency department intubations. The vast majority of those airways would not stress the lens-protection mechanism enough to reveal whether it matters. A more rational feasibility cohort would enrich for cases in which contamination is expected or already present, for example active hematemesis, severe oropharyngeal bleeding, or high-risk cardiac arrest airways. Experienced operators should dominate the early phases because feasibility questions are otherwise confounded by baseline airway inexperience. Feasibility endpoints should include successful deployment, ability to maintain standard laryngoscopy technique, lowest oxygen saturation, number of device removals, incidents of operator contamination, and frequency with which the gas feature was activated but did not appear to help. These are the measurements that determine whether a future effectiveness trial is even worth planning.

If feasibility is acceptable, the next step would be a comparative study designed around the specific contaminated-airway phenotype rather than generic difficult airways. A pragmatic randomized design could be considered, but operator preference and low event frequency make conventional patient-level randomization difficult. Cluster randomization by shift, stepped introduction, or carefully monitored registry-based comparison might be more realistic. The primary outcome should still likely be first-pass success because that is the point where mechanical, optical, and physiological gains intersect.[1, 2] Yet secondary

outcomes should carry equal interpretive weight: lowest oxygen saturation, incidence of severe hypoxemia, need for rescue device conversion, aspiration events, interruption for lens cleaning, and operator-rated usability. A device that improves first-pass success only by prolonging laryngoscopy or increasing exposure risk would present a mixed result that should not be simplified.

The final translational point is that the target population should remain selective even in mature trials. It is entirely plausible that a dual-function blade would add little in routine airways where contamination is absent and first-pass success with standard equipment is already high. The highest-yield question is whether it changes outcomes in the small but dangerous subgroup where video laryngoscopy loses its image or where a few extra seconds of oxygen delivery might avert severe desaturation. This matters economically as well as clinically. A device built for a narrow, high-risk problem can still be worthwhile, but its value should be judged on those terms rather than by expecting universal benefit across all emergency intubations. Good study design in this field means resisting the temptation to broaden the indication before the hard cases have actually been studied.

7. Operational Implications for Emergency Airway Practice

Even if a dual-function blade proves technically sound, its place in practice would depend on how well it fits existing airway systems. Contaminated-airway management already revolves around rapid suction deployment, preoxygenation when possible, clear team roles, and low tolerance for repeated failed attempts.[4, 1] A blade that protects the lens should sit within that structure rather than replace it. The key operational point is that suction remains primary for bulk contamination. Lens protection addresses a downstream problem, namely the loss of the optical image after contaminants reach the distal camera. Clinicians are unlikely to accept a device framed as an alternative to suction because the bedside reality does not support that framing. The more workable model is an adjunctive one in which suction clears volume and the blade mechanism helps preserve information.

The clinical setting would also shape value. In the emergency department or intensive care unit, a wall oxygen source is usually available and multiple suction setups can be arranged quickly. In prehospital care, portability, oxygen conservation, and cold-start simplicity matter more. A gas-dependent blade that is easy to use in a resuscitation bay may be awkward in an ambulance or helicopter if extra tubing tangles with other equipment or if oxygen flow is already committed to preoxygenation and post-intubation support. For that reason, a device that can operate with either oxygen or medical air, and that still functions normally without flow, appears more practical than one tied to a single configuration. Operational flexibility is not a luxury in emergency medicine. It often determines whether a device leaves the airway cart or stays in storage.

Training considerations are equally practical. The contaminated airway is relatively infrequent for any one operator compared with routine emergency intubations, which means competency with a dual-function blade cannot rely on repeated spontaneous exposure. Simulation would almost certainly be required for onboarding and maintenance. That training should not focus only on activating the gas feature. It should include decision points: when to continue with the device, when to escalate suction, when to switch to direct laryngoscopy, and when a failing contaminated-airway attempt should give way to a rescue plan. In other words, the device would need to be integrated into airway judgment rather than taught as a gadget that automatically improves performance. The literature on first-pass success and repeated-attempt harm makes that emphasis sensible.[1, 2] Devices are most useful when they simplify choices, not when they create new reasons to delay the right backup plan.

There are also questions of manufacturing and cost that should be handled soberly. If the lumen can be incorporated into a disposable blade geometry using processes close to those already used for video laryngoscope blades, incremental cost might be manageable. If, however, reliable nozzle geometry, additional connectors, or anti-clog features materially complicate manufacturing, the price could rise enough to change adoption decisions. That issue becomes more important because the likely target population is not every intubation. Hospitals may hesitate to stock a more expensive blade for a low-frequency scenario unless the benefit is clear, especially when alternative strategies such as direct laryngoscopy backup and improved suction training already exist. Economic arguments should therefore wait until the clinical effect size is known. A device that prevents one rare but catastrophic failure mode may still be worthwhile, but its value cannot be assumed from engineering elegance alone.

The most plausible operational role for a dual-function blade is therefore selective. It may fit best in anticipated contaminated airways where the operator would otherwise want the advantages of video laryngoscopy but worries that the lens will fail under active blood or emesis. It is less likely to matter in uncomplicated routine airways, and it may be least helpful in extreme particulate contamination where no reasonable gas jet can maintain a lens. This kind of selective framing is not a weakness. Emergency airway tools often have narrow roles for good reasons. Bougies, hyperangulated blades, rigid suction devices, and supraglottic airways all have situations in which they are particularly useful and others in which they add little. A lens-protective oxygenating video blade should probably be judged in the same way: as a potentially useful addition to a contaminated-airway toolkit, not as a new universal standard for every emergency intubation.

8. Conclusion

The contaminated emergency airway remains difficult because several separate problems arrive together. Visualization degrades, suction competes for space, aspiration risk increases, oxygen reserve drops, and the penalty for interruption grows. Standard airway concepts still apply, but they apply under harsher timing and poorer information. That is why the contaminated airway behaves differently from an ordinary difficult laryngoscopy. The clinician is not simply seeking a better view.

The clinician is trying to secure a moving target before physiology worsens further.

A dual-function video laryngoscope blade that preserves the distal image while also delivering oxygen during laryngoscopy is a plausible response to that problem, but plausibility should not be confused with established value. The physiological case for distal oxygen delivery is credible, especially in light of simulation studies and pediatric trial data showing that laryngeal insufflation can influence oxygenation dynamics. The clinical case for protecting the video image is also credible because contaminated airways reduce first-pass success and repeated attempts are consistently associated with harm. Even so, the combined device claim remains unproven until the image-preservation function, oxygenation effect, safety profile, and usability are measured together rather than inferred from component ideas.

The most important caution is that a contaminated-airway device must help where contaminated airways actually fail. Suction will remain essential for bulk fluid and particulate material. A lens-protection mechanism is only relevant after suction has done what it can and the optical advantage of video laryngoscopy is still threatened by film, droplets, or rapid recontamination. That means the device will probably have a narrower indication than routine video laryngoscopy itself. It may matter most in active hematemesis, severe oropharyngeal bleeding, and regurgitating arrest airways, and much less in ordinary intensive care intubations where contamination is absent or minor.

For that reason, the right research pathway is staged and selective. Bench work should define performance under realistic contaminants, not idealized clean conditions. Safety testing should address aerosol generation, pressure effects, and failure modes before broad clinical use. Simulation should compare the device with ordinary practice under standardized contaminated-airway conditions. Early clinical studies should focus on feasibility and enriched high-risk populations rather than routine all-comers. Only after those steps would a comparative effectiveness trial make sense, and even then the most meaningful outcomes would remain practical ones such as first-pass success, severe hypoxemia, interruption for lens cleaning, and rescue-strategy use.

If the concept eventually proves useful, its benefit will probably not come from a dramatic redesign of airway practice. More likely, it would provide a small but meaningful procedural advantage in a narrow group of unstable cases where a preserved image and a few more seconds of oxygen delivery change whether the first attempt succeeds. That is enough to justify careful study, but not enough to justify assumption. In emergency airway management, modest gains matter most when they are real, reproducible, and obtained without introducing new hazards. The contaminated airway is a setting where that standard should remain high.

Acknowledgments

We would like to thank the reviewers of this research for their helpful comments and suggestions.

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