Optimizing Prehospital Nebulization with the O-Two Mesh Nebulizer

Abstract

Nebulized bronchodilators are commonly used for acute bronchospasm in prehospital care, including asthma and chronic obstructive pulmonary disease (COPD) exacerbations and pediatric acute wheeze. The effectiveness of nebulized therapy in prehospital settings significantly depends on delivery efficiency, which is influenced by the proportion of the nominal dose converted into a respirable aerosol (1 to 5 µm), the rate of pulmonary deposition, and the ability to administer the therapy without interrupting high-fraction oxygenation, non-invasive positive-pressure ventilation (NIV/CPAP), or mechanical transport ventilation. Moreover, prehospital aerosol delivery faces challenges due to limited portable oxygen cylinder capacity, confined patient compartments, and narrow timeframes for therapeutic reassessment.

Pneumatic jet nebulizers use compressed gas to generate aerosol and may retain a clinically relevant volume of medication after treatment. Reported residual volumes vary by device, fill volume, and operating conditions; conventional jet systems have been reported to retain approximately 0.8 to 2.0 mL, with a substantial portion of the nominal dose remaining in the reservoir in some configurations (Dailey & Shockley, 2021).

Vibrating mesh nebulizers (VMNs) generate aerosol electronically through a perforated mesh and do not require compressed gas for aerosol generation (Ari, 2014). Studies in clinical emergency departments, pediatrics, non-invasive ventilation (NIV), and in vitro simulation have shown that VMN technology is associated with significantly higher delivered doses, improved pulmonary deposition, minimal residual volumes, and faster drug delivery rates under various conditions (Galindo-Filho et al., 2019).

Introduction:

EMS crews often begin bronchodilator therapy before the diagnostic picture is complete. A patient may be sitting upright in a hallway, stairwell, vehicle, residence, workplace, roadside location, or moving ambulance. The patient may be tachypneic, anxious, hypoxemic, hypercapnic, fatigued, or unable to maintain a mask seal. In those conditions, aerosol delivery is not a simple device function; it is a clinical process shaped by interface fit, breathing pattern, oxygen titration, medication preparation, transport time, and rapid reassessment.

Inhaled bronchodilators are routinely used in asthma and COPD exacerbations because they deliver medication to the airways while generally limiting systemic exposure compared with non-inhaled routes (Dailey & Shockley, 2021).

In EMS, effective nebulized therapy is not defined by visible mist alone. Clinically meaningful performance depends on respirable aerosol generation, inhaled dose, pulmonary deposition, residual medication volume, nebulization time, patient-interface stability, patient tolerance, and the ability to maintain oxygenation or ventilatory support during treatment.

Device selection is one component of respiratory-care quality. Aerosol delivery varies with device type, particle characteristics, medication formulation, respiratory pattern, patient technique, interface fit, and the delivery system used during treatment. These factors are relevant in prehospital care, where therapy may occur during supplemental oxygen, CPAP/NIV, or transport ventilation (De Vries et al., 2023).

Why Jet Nebulizer Limitations Matter in Prehospital Care

Pneumatic jet nebulizers use compressed gas to draw liquid medication through a capillary and generate aerosol against an internal baffle (Ari, 2014). Their operation requires a specified driving flow. In EMS, oxygen is commonly used for this purpose and is drawn from the same portable supply needed for patient oxygenation and ventilation.

This additional gas demand reduces available cylinder duration during long transports, offload delays, repeated treatments, and multi-patient respiratory incidents. Oxygen consumption increases with the selected driving flow and treatment duration, placing an additional demand on finite prehospital oxygen resources.

Conventional jet nebulizers also retain medication in the reservoir after treatment. Dailey and Shockley (2021) reported typical residual volumes of 0.8 to 2.0 mL for conventional systems. In simulated adult and pediatric testing, the jet nebulizer retained more medication than the mesh nebulizer (Ari et al., 2015).

Residual medication reduces the proportion of the loaded dose available for inhalation. This is especially relevant when prescribed volumes are small, repeated treatments are required, or treatment time is limited (Ari et al., 2015; Dailey & Shockley, 2021).

Vibrating mesh nebulizers generate aerosol electronically without compressed driving gas. This allows supplemental oxygen flow to be selected according to the patient's clinical requirements rather than the mechanical requirements of aerosol generation. By separating aerosol generation from the oxygen supply, VMN technology supports efficient

medication delivery while preserving portable oxygen resources for patient oxygenation and ventilation (Ari, 2014; De Vries et al., 2023).

Vibrating Mesh Nebulization Technology

Vibrating mesh nebulizers (VMNs) use electronic energy to vibrate a mesh that contains microscopic holes, creating a highly consistent aerosol of fine particles without the need for compressed gas to generate the aerosol (Ari, 2014; Salameh et al., 2025). The design relies on this vibrating mesh, where the tiny openings interact directly with the liquid medication to produce a fine aerosol cloud (Ari, 2014; Salameh et al., 2025).

The American Association for Respiratory Care (AARC) clinical consensus guidelines describe vibrating mesh nebulizers as highly efficient, portable, and battery-operated devices (De Vries et al., 2023). Because VMNs produce a fine, respirable mist directly through the mesh apertures, they do not require an internal baffling system to recycle large droplets and have a minimal residual dead volume (De Vries et al., 2023). This low residual volume ensures that nearly all of the prepared medication is nebulized, which contrasts significantly with the high drug retention observed in standard pneumatic jet nebulizers (Ari et al., 2015; Dailey & Shockley, 2021; De Vries et al., 2023).

For prehospital emergency medical services (EMS), this gas-independent electronic design offers immediate clinical and operational benefits. Conventional pneumatic jet nebulizers require a constant flow of pressurized medical oxygen—usually between 6 to 10 L/min—just to generate the aerosol. This requirement can deplete portable gas cylinders and dilute the inhaled drug mass (Ari, 2014; Dailey & Shockley, 2021). In contrast, VMN technology completely separates aerosol generation from the flow of carrier gas (Ari, 2014).

This gas independence enables prehospital clinicians to select and adjust the patient's supplemental oxygen or positive-pressure ventilation based solely on physiological needs rather than the mechanical requirements of the nebulizer (De Vries et al., 2023). Additionally, the minimal residual volume allows for more complete utilization of the prepared nominal dose, ensuring reliable drug delivery within the short transport times typical of EMS operations (Ari et al., 2015; De Vries et al., 2023).

Delivery Efficiency and Lung Deposition

The primary clinical parameter that determines the efficacy of aerosol therapy is total pulmonary deposition. A bronchodilator can only have a therapeutic effect if a significant respirable fraction is successfully delivered to the lower airways within a short treatment window (Ari, 2014; Dailey & Shockley, 2021). To quantify deposition rates, Dugernier et al. (2017) conducted a randomized crossover study involving six healthy male participants. They utilized single-photon emission computed tomography combined with a low-dose CT scan (SPECT-CT) to compare a representative active vibrating mesh nebulizer (VMN) system paired with a specific valved holding chamber against a conventional continuous-output jet nebulizer connected to a standard corrugated tube. The study found that total pulmonary aerosol deposition was six times greater with the VMN-chamber configuration than with the jet nebulizer, achieving a mean lung dose of 34.1% ± 6.0% of the nominal dose compared to just 5.2% ± 1.1% with the jet nebulizer (Dugernier et al., 2017).

This superior delivery efficiency is particularly valuable during positive-pressure ventilatory support, where gas flows can dilute and disrupt aerosol pathways. Galindo-Filho et al. (2019) conducted a randomized crossover single-dose trial involving nine stable subjects with moderate to severe COPD undergoing non-invasive ventilation (NIV). The trial compared a representative VMN positioned proximal to the mask elbow against a standard jet nebulizer operated with oxygen at 8 L/min. Both the inhaled and actual lung doses were significantly higher with the VMN (22.78% ± 3.38% and 12.05% ± 2.96%, respectively) than with the jet nebulizer (12.51% ± 6.31% and 3.14% ± 1.71%, respectively). This equated to nearly a four-fold increase in pulmonary drug delivery (Galindo-Filho et al., 2019). Additionally, the VMN significantly reduced the residual dead volume in the nebulizer reservoir to 3.08% ± 1.30% compared to 46.44% ± 5.83% with the jet nebulizer, virtually eliminating medication waste in the circuit (Galindo-Filho et al., 2019).

These delivery advantages are consistently seen across pediatric cohorts, where narrow airways and low tidal volumes limit aerosol penetration. MacLoughlin et al. (2026) used anatomically correct upper airway models of a 9-month-old infant connected to a pediatric breathing simulator and demonstrated that VMN technology delivers a superior drug mass compared to continuous-output jet nebulization. During spontaneous pediatric breathing via a face mask, the VMN delivered a significantly greater albuterol mass (762.75 ± 187.32 μg) than the jet nebulizer (388.24 ± 35.66 μg), representing nearly a two-fold increase in delivered dose (MacLoughlin et al., 2026). Under simulated pediatric mechanical ventilation, the VMN provided a greater than three-fold increase in drug mass (950.00 ± 63.83 μg compared to 307.84 ± 80.35 μg), delivered at a significantly faster rate (281.71 ± 0.64 μg/min versus 116.34 ± 36.05 μg/min) and reduced residual dead volume to 2.41% ± 1.08% compared to 75.18% ± 6.97% with the jet nebulizer (MacLoughlin et al., 2026).

To systematically evaluate these comparative outcomes in adults with obstructive airways, Feng et al. (2024) conducted a systematic review and meta-analysis of ten trials involving 314 stable and exacerbated COPD patients (157 receiving VMN and 157 receiving jet nebulizers). The meta-analysis found that VMN was significantly superior to jet nebulizers for drug delivery and utilization, indicating highly significant differences in both 30-minute urinary salbutamol excretion and cumulative 24-hour urinary salbutamol excretion, which serve as key in vivo markers of pulmonary deposition and systemic absorption (Feng et al., 2024). The VMN also showed a statistically significant increase in total emitted aerosol mass compared to jet nebulizers (Feng et al., 2024). While the meta-analysis found no differences between the devices in terms of immediate changes in lung function (FEV1 and FVC) due to the underlying pathophysiology of advanced COPD, VMN technology represents a far more consistent and efficient drug delivery platform for managing acute obstructive airway disease (Feng et al., 2024).

Clinical Relevance for Asthma and COPD

Asthma and COPD exacerbations are time-sensitive obstructive-airway emergencies. In EMS, aerosolized bronchodilator therapy is often delivered while clinicians are reassessing air entry, wheeze, respiratory rate, work of breathing, oxygenation, ventilation, fatigue, response to CPAP or NIV, and the need for escalation. The nebulizer should support dependable bronchodilator delivery during this decision window, especially when the patient is dyspneic, tachypneic, anxious, poorly cooperative, or already receiving respiratory support.

In severe asthma, improvement in air flow helps guide the next treatment decision. Chweich et al. (2024) compared vibrating mesh nebulization with jet nebulization in adults presenting to the emergency department with severe asthma exacerbation. Air-flow outcomes favoured VMN across repeated assessments, with greater improvement trends in PEF% and FEV1%. FEV1% improvement at disposition reached statistical significance with VMN, supporting its clinical relevance during severe asthma exacerbations, where bronchodilator response guides ongoing treatment and escalation decisions.

Emergency department data also support the practical value of VMN in obstructive-airway care. Dunne and Shortt (2018) evaluated bronchodilator administration before and after VMN deployment in 1,594 emergency department records. VMN use was associated with lower hospital admission rates, lower total albuterol dose, and a 37-minute reduction in the median emergency department length of stay compared with jet nebulization. Device type was also reported as a predictor of discharge, disposition, and amount of drug used. For EMS and emergency care systems, these findings are important because they connect nebulizer selection with bronchodilator dose requirement, patient disposition, and acute care throughput.

In COPD, VMN is especially relevant when bronchodilator therapy must be delivered during NIV. Avdeev et al. (2021) compared bronchodilator administration with VMN and conventional jet nebulization during NIV in patients with acute COPD exacerbation. VMN produced greater improvements in FEV1 and FVC, greater reduction in respiratory rate and Borg dyspnea score, and greater improvement in $PaCO_2$ compared with conventional jet nebulization. The authors concluded that bronchodilator administration during NIV with VMN resulted in clinically significant improvements in FVC and Borg dyspnea score.

The broader COPD literature supports the same delivery advantage. Feng et al. (2024) reviewed studies comparing VMN with jet nebulization in COPD and reported stronger drug delivery and utilization outcome measures with VMN, including urinary salbutamol and aerosol emitted. These findings reinforce the clinical value of vibrating mesh nebulization: more efficient aerosol generation and patient uptake compared with conventional jet nebulization.

For EMS practice, the clinical message is direct. When aerosolized bronchodilator therapy is indicated for asthma or COPD, VMN provides a more efficient and practical delivery platform than conventional jet nebulization. Its value is greatest when treatment time is limited, repeated bronchodilator treatments are required, oxygen supply must be preserved, the patient is receiving CPAP or NIV, or the interface should remain stable during reassessment. The evidence supports VMN as a strong aerosol-delivery method for acute obstructive airway care, with supportive data in severe asthma, emergency department bronchodilator administration, COPD drug delivery, and COPD exacerbation.

Pediatric Respiratory Distress

Pediatric aerosol delivery is often limited by short cooperation windows, tachypnea, distress, mask tolerance, and difficulty maintaining a consistent mask seal. In EMS, this matters because a child with acute wheeze may need bronchodilator therapy quickly, but may not tolerate a prolonged treatment. The delivery system should help the provider deliver aerosolized medication through the interface most commonly tolerated in this population: a face mask.

Moody et al. (2020) conducted a single-blinded randomized clinical trial of 217 children, 2 to 18 years of age, presenting to the emergency department with moderate to severe asthma exacerbation. Children treated with vibrating mesh nebulization required significantly fewer bronchodilator treatments and less time to achieve a mild asthma score compared with children treated with jet nebulization. In subjects treated through a mask interface, VMN significantly reduced the probability of admission compared with jet nebulization. This is directly relevant to EMS because

pediatric respiratory patients often require mask-based aerosol delivery.

Ari (2019) showed in simulated spontaneously breathing pediatric and infant lung models that aerosol drug delivery is affected by nebulizer type, delivery interface, and flow rate. Mesh nebulizers delivered more drug than jet nebulizers across key pediatric interface conditions, including face mask use. For EMS providers, the practical message is clear: device type, mask interface, and flow settings all influence pediatric aerosol delivery.

Crumm et al. (2025) evaluated VMN implementation in a pediatric emergency department and included 605 children aged 1 to 17 years who received nebulized albuterol for a respiratory indication. After VMN introduction, the adjusted total albuterol dose per patient was lower, and the adjusted time to disposition was shorter. These findings support VMN as a practical pediatric emergency care when the goal is to deliver bronchodilator therapy efficiently and reduce treatment burden.

Dastoori et al. (2026) compared standard jet nebulizer use with VMN use in a pediatric emergency-department population presenting with acute wheeze. VMN use was associated with reductions in emergency department length of stay, nebulizer requirement, and respiratory rate. This supports the same clinical direction seen in other pediatric and emergency care studies: VMN can improve the efficiency of bronchodilator administration in children who need aerosolized therapy.

For EMS, the pediatric value of VMN is straightforward. Children with acute wheeze often need fast bronchodilator delivery through a mask interface. Compared with jet nebulization, VMN provides a more efficient pediatric aerosol delivery option, with supportive evidence for fewer treatments, faster improvement in mild asthma score, improved mask-interface performance, lower albuterol dose, shorter time to disposition, and reduced nebulizer requirement in emergency care settings.

Use During CPAP, NIV, and Transport Ventilation

A major EMS advantage of vibrating mesh nebulization is its ability to support aerosol delivery during respiratory support. Patients who require aerosolized bronchodilator therapy may also require CPAP, BiPAP, or invasive transport ventilation. In these situations, aerosol therapy should be delivered without unnecessary interruption to the mask interface, pressure support, PEEP, oxygenation, ventilation, or patient tolerance.

Conventional jet nebulizers require a compressor or pressurized gas source to operate and may leave a higher residual drug volume at the end of the dose. Mesh nebulizers are electronically operated and do not require gas flow to generate aerosol, with greater delivery efficiency and low residual drug volume reported in aerosol-delivery literature (Ari et al., 2015). For EMS providers, this distinction matters because oxygen supply, gas flow, mask fit, and respiratory support are managed together during acute respiratory care.

During NIV in COPD, direct comparative evidence favours VMN over jet nebulization. Galindo-Filho et al. (2019) evaluated radiolabeled bronchodilator delivery during NIV in subjects with moderate to severe COPD using an oronasal face mask. VMN produced higher inhaled dose and lung dose than jet nebulization, with markedly lower residual drug volume. The authors concluded that VMN deposited more than threefold greater radioaerosol into the lungs than jet nebulization during NIV. Hassan et al. (2017) compared aerosol devices during bilevel NIV in COPD patients, with the aerosol generator positioned proximal to the facial mask. Salbutamol delivery was assessed using in vitro, in vivo, and ex vivo measures. The vibrating mesh nebulizer produced better aerosol delivery than the Sidestream jet nebulizer during bilevel NIV (Hassan et al., 2017).

Clinical response data are consistent with the delivery findings. Avdeev et al. (2021) compared bronchodilator administration with VMN and conventional jet nebulization during NIV in patients with acute COPD exacerbation. VMN produced greater improvement in FEV1 and FVC, greater reduction in respiratory rate and Borg dyspnea score, and greater improvement in $PaCO_2$ compared with conventional jet nebulization. The authors concluded that bronchodilator administration during NIV with VMN resulted in clinically significant improvements in FVC and Borg dyspnea score.

Respiratory support settings also affect aerosol delivery. Boules et al. (2022) showed that BiPAP pressure settings and HFNC configuration changed pulmonary, systemic, and ex vivo salbutamol delivery in COPD patients receiving VMN therapy, with low-pressure BiPAP producing the highest delivery measures. Fernández Fernández et al. (2021) showed that delivered aerosol dose varied across escalation-of-care conditions, including low-flow oxygen, high-flow oxygen, NIV, and invasive mechanical ventilation. These findings reinforce an important field point: aerosol delivery is influenced by the device, interface, pressure, and flow used during respiratory support.

For EMS practice, VMN is most useful when bronchodilator therapy must be delivered while respiratory support continues. Compared with jet nebulization, VMN does not require gas flow to generate aerosol and has demonstrated higher aerosol delivery than jet nebulization during NIV. This supports a practical respiratory-care workflow: maintain the interface, continue ventilatory support, deliver aerosolized bronchodilator therapy, and reassess air entry, respiratory rate, work of breathing, oxygenation, ventilation, and patient tolerance.

Oxygen Conservation and Resource Utilization

Oxygen is part of the treatment plan in EMS. It may be needed for hypoxemia or clinical deterioration during transport. It is also a limited resource. Cylinder volume, transport time, rural distance, aircraft use, standby coverage, and high call demand all affect how much oxygen is available for the patient. Pneumatic jet nebulizers use pressurized gas to operate. Ari (2014) describes jet nebulizers as requiring 2 to 10 L/min of pressurized gas to draw medication from the reservoir and generate aerosol through a jet and baffle system. In EMS, the driving gas is oxygen. When oxygen is used to run the nebulizer, oxygen is being consumed for device operation, not only for patient support.

Vibrating mesh technology generates aerosol without compressed driving gas. De Vries et al. (2023) describe vibrating mesh nebulizers as portable, battery-operated, highly efficient devices that generate a fine aerosol through a mesh with minimal residual medication volume. For EMS use, the point is direct: oxygen can be titrated to the patient's clinical need, while aerosol generation is powered by the nebulizer. This does not mean oxygen is withheld. Oxygen should still be applied when indicated for oxygenation or patient deterioration. The difference is that the nebulizer does not create an additional oxygen-flow requirement simply to function. That matters during repeat bronchodilator treatments, long transports, rural calls, standby coverage, aircraft response, and high-demand events. A gas-independent nebulizer helps preserve cylinder oxygen for oxygenation and ventilation support instead of using it to power aerosol generation.

Pneumatic Jet Nebulization Vs Vibrating Mesh Nebulization

Factors	Pneumatic Jet Nebulization	Vibrating Mesh Nebulization
Aerosol Generation	Uses pressurized gas to draw medication from the nebulizer reservoir and generate aerosol through a jet and baffle system	Uses an electronically driven mesh. Compressed gas is not required for aerosol generation.
Oxygen Use	Requires compressed air, oxygen, or a compressor to operate. Jet nebulizers have been described as requiring 2 to 10 L/min of pressurized gas.	Does not use oxygen to power aerosol generation. Supplemental oxygen remains based on clinical need.
Residual Medication	Medication may remain in the reservoir at the end of treatment, leaving part of the loaded dose unused.	Often associated with minimal residual medication volume and higher delivery efficiency.
Delivered Dose	Aerosol delivery is affected by gas flow, fill volume, nebulizer design, interface, humidity, circuit setup, and breathing pattern.	The clinical rationale is supported by VMN evidence showing higher delivered dose, inhaled dose, lung dose, or pulmonary deposition in studied conditions compared with jet nebulization.
Pediatric Respiratory Distress	Mask delivery may be limited by distress, tachypnea, poor tolerance, inconsistent seal, and prolonged treatment time.	Mask-based VMN delivery is clinically relevant for pediatric wheeze and asthma exacerbation. Pediatric VMN evidence reports fewer bronchodilator treatments, less time to achieve a mild asthma score, and reduced probability of admission in the mask-interface subgroup compared with jet nebulization.

Conclusion

VMN technology offers practical advantages for EMS, including aerosol generation without compressed driving gas, generally low residual volume, portability, and the ability to integrate with selected respiratory-support circuits. Comparative evidence often shows higher delivered or lung doses than specific jet-nebulizer configurations. Current evidence indicates that vibrating mesh nebulization (VMN) is a more effective delivery method than traditional oxygen-driven jet nebulization for EMS respiratory care. VMN offers a higher delivered dose and better pulmonary deposition, a lower residual medication volume, and the ability to generate aerosol without relying on compressed gas. It also integrates well with respiratory support workflows and is compatible with adult, pediatric, COPD, NIV, and emergency care protocols. The O-Two Mesh Nebulizer equips EMS providers with a practical vibrating mesh solution for delivering established aerosolized therapies in the field. Its clinical value is not that it replaces assessment or protocol-based care but in providing a delivery method better suited to real prehospital conditions. This includes short treatment windows, severe dyspnea, limited oxygen supply, CPAP/NIV, transport ventilation, pediatric tolerance, confined ambulance environments, and the need for consistent care across crews and shifts.

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