

Aerosol Delivery Device Selection for Spontaneously Breathing Patients: 2012

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Using an electronic literature search for published articles indexed in PubMed between January 1990 and August 2011, the update of this clinical practice guideline is the result of reviewing 84 clinical trials, 54 reviews, 25 *in vitro* studies, and 7 evidence-based guidelines. The recommendations below are made following the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) criteria: 1: It is recommended that selection of the appropriate aerosol generator and interface be made based on the patient's age, physical and cognitive ability, cost, and the availability of the prescribed drug for use with a specific device. 2: Nebulizers and pressurized metered-dose inhalers (pMDIs) with valved holding chambers are suggested for use with children ≤ 4 years of age and adults who cannot coordinate the use of pMDI or dry-powder inhaler (DPI). 3: It is suggested that administration of aerosols with DPIs be restricted to patients ≥ 4 years of age who can demonstrate sufficient flow for the specific inhaler. 4: For patients who cannot correctly use a mouthpiece, aerosol masks are suggested as the interface of choice. 5: It is suggested that blow-by not be used for aerosol administration. 6: It is suggested that aerosol therapy be administered with a relaxed and nondistressed breathing pattern. 7: Unit dose medications are suggested to reduce the risk of infection. 8: It is suggested that nebulizer/drug combinations should be used as approved by the FDA. 9: It is recommended that healthcare providers know the correct use of aerosol generators; they should teach and periodically re-teach patients about how to use aerosol devices correctly. 10: It is suggested that intermittent positive-pressure breathing should not be used for aerosol therapy. 11: It is recommended that either nebulizer or pMDI can be used for aerosol delivery during noninvasive ventilation. *Key words:* aerosol; dry-powder inhaler; metered-dose inhaler; nebulizer; patient education; patient adherence; noninvasive ventilation; device selection. [Respir Care 2012;57(4):613–626. © 2012 Daedalus Enterprises]

ADS 1.0 DESCRIPTION

Effective administration of aerosolized medications depends on the patient's age, physical and cognitive ability,

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the delivery system, and the patient-device interface.^{1–7} Physical ability means the patient's ability to use a specific device, based on factors such as inspiratory volumes and flows, hand-breath coordination, or ability to use a mouthpiece. Cognitive ability indicates the patient's understanding of how and when to use a device and medication.^{8–10} Airway size, respiratory rate, inspiratory flow rate, and breathing pattern create substantial challenges for effective aerosol delivery.^{4,5,8–12} While most aerosol generators can be used with all age groups, special consideration should be given to young children because they cannot master the complex steps required for adequate delivery of aerosol treatments.^{8,9,13} A mouthpiece may be used for patients ≥ 3 years who are able to cooperate,^{8,10,14} while a face mask is recommended for patients who cannot use a mouthpiece.^{2,3,8,9,14–17} Face masks should be properly fitted with minimal leak, particularly avoiding aerosol deliv-

Table 1. Age Guidelines for Use of Aerosol Delivery Device Types^{3,8,9,14,39}

Aerosol Device and Interface	Age
Small-volume nebulizer with mask or hood	Infants
Small-volume nebulizer with mask	≤ 3 y
Small-volume nebulizer with mouthpiece	≥ 3 y
pMDI with valved holding chamber/spacer and mask	< 4 y
pMDI with valved holding chamber/spacer	≥ 4 y
DPI	≥ 4 y
MDI	≥ 5 y
Breath-actuated MDI (eg. Autohaler)	≥ 5 y
Breath-actuated nebulizer	≥ 5 y

pMDI = pressurized metered-dose inhaler

DPI = dry powder inhaler

ery into the eyes, to optimize inhaled dose.^{18–24} Aerosol generators are equally efficacious if they are age appropriate and used correctly.^{25–39} Regardless of age, patients need to demonstrate ability to seal the lips around the mouthpiece and ability to generate sufficient flow for the specific inhaler. Table 1 provides age guidelines for use of aerosol delivery device types.

This clinical practice guideline (CPG) addresses the selection of an aerosol delivery device for the administration of inhaled medications by small-volume nebulizer (SVN), large-volume nebulizer (LVN), pressurized metered-dose inhaler (pMDI), and dry-powder inhaler (DPI) to spontaneously breathing patients without an artificial airway. Studies on spontaneously breathing patients with tracheostomy were excluded from this CPG, due to lack of evidence in this area of research. Using an electronic literature search for published articles indexed in PubMed between January 1990 and August 2011, the update of this CPG is result of reviewing 84 clinical trials, 54 reviews, 25 *in vitro* studies, and 7 evidence-based guidelines. The search terms used in this CPG include nebulizer, dry-powder inhaler, metered-dose inhaler, aerosol, face mask, mouthpiece, hood, blow-by, valved holding chamber (VHC), spacer, patient education, patient adherence, non-invasive ventilation, and device selection.

1.1 Small-Volume Nebulizer. SVNs are divided into 3 types: jet nebulizer, mesh nebulizer, and ultrasonic nebulizer. The jet nebulizer is powered by a compressed gas source, in the form of a compressor or hospital pressurized gas source such as piped medical gas or high pressure tanks. The medication is displaced up a capillary tube from the nebulizer's reservoir and is dispersed continuously as aerosolized particles.^{14,40–43} There are 4 types of jet nebulizer: jet nebulizer with reservoir tube, jet nebulizer with collection bag, breath-actuated jet nebulizer, and breath-

enhanced jet nebulizer. Jet nebulizer with reservoir tube is the most commonly used and generates continuous aerosol during the entire breathing cycle. Jet nebulizer with a reservoir bag collects aerosol leaving the jet nebulizer when patient is not inhaling. Thus, it increases dose efficiency by delivering aerosol in the reservoir bag with the next inspiration. While the breath-actuated jet nebulizer generates aerosol only during inspiration, which reduces loss of medication during expiration, the breath-enhanced jet nebulizer uses one-way valves to prevent the loss of aerosol to the environment and to increase aerosol delivery to the patient. Mesh nebulizer is powered by electricity to create aerosol by way of an aperture plate or an ultrasonic horn. The diameter of the mesh or aperture determines the size of the particle generated.^{14,44–46} Ultrasonic nebulizer is also powered by electricity to create high frequency vibrations in a piezo crystal, which are transferred to the surface of the solution, creating a standing wave that generates aerosol.¹⁴

The aerosolized particles are inhaled by the patient or delivered in conjunction with positive-pressure breaths such as intermittent positive-pressure breathing, noninvasive ventilation (NIV), and intrapulmonary percussive ventilation. Whereas aerosol delivery via SVN with intermittent positive-pressure breathing is less efficient than SVN alone,⁴⁷ using NIV for aerosol therapy is feasible and effective in improving bronchospasm.^{48–52} However, it should be noted that aerosol delivery with NIV is influenced by the NIV settings, the leak port position, the type of aerosol generator, and the interface used during the treatment.^{53–55} For instance, increasing the inspiratory pressure during NIV increases aerosol deposition, as opposed to increased expiratory pressure, which decreases aerosol delivery.⁵³ The efficiency of an aerosol generator is influenced by the location of the leak port. If the leak port is distal to the device, drug delivery is greater than at the proximal location, regardless of the type of aerosol generator used.^{54,55} Consequently, drug delivery via mask with a leak port is less than that without. If the leak port is in the mask, the efficiency of pMDI is better than that of nebulizer because aerosol loss with pMDI during expiration is less, compared to the nebulizer. According to a recent *in vitro* comparison, aerosol deposition with mesh nebulizer is significantly greater, compared to the jet nebulizer during NIV.⁵⁵ Also, the use of nebulization with NIV is better than nebulization alone in some patients.⁵² The intrapulmonary percussive ventilator is primarily an airway clearance device, but it is usually combined with a nebulizer, although its physiologic and clinical effects have not been studied extensively. Studies have shown that aerosol deposition with the intrapulmonary percussive ventilator is significantly lower than with a standard nebulizer alone and has large inter-individual variability.^{56,57}

1.2 Large-Volume Nebulizer. LVNs with a fill volume > 10 mL, powered by a compressed gas source, are utilized to administer continuous aerosol delivery over a prolonged period of time. Due to changes in drug concentration over time, LVNs should be emptied and refilled at 5 hours.⁵⁸ An alternative approach for continuous nebulization is small volume jet or mesh nebulizer with infusion pump. Regardless of the type of nebulizer utilized, a face mask is typically used as the interface for continuous nebulization. Previous studies reported that continuous inhaled bronchodilator administration is safe, effective, and less time consuming, when compared with intermittent nebulization in patients with severe asthma.^{59–61} Continuous bronchodilator delivery is the most common aerosol treatment for continuous nebulization.^{62,63}

1.3 Pressurized Metered-Dose Inhaler. There are 2 types of pMDI: conventional and breath-actuated. Both include a canister, propellants, drug formulary, metering valve, and actuator. Actuation of the pMDI results in the ejection of one dose of aerosolized medication.⁶⁴ The conventional pMDI has a press-and-inhale design, whereas the breath-actuated pMDI eliminates the need for hand-breath coordination. A simple spacer attached to the pMDI enhances aerosol delivery by decreasing the velocity of the particles and the number of large particles, thus reducing oropharyngeal deposition.^{65,66} A spacer without valves requires coordination between inhalation and actuation and is not suitable for patients with poor hand-breath coordination; a VHC is more desirable in this setting. Electrostatic charge can decrease aerosol delivery unless it is washed with soap and water, or, alternatively, a non-electrostatic device can be used without the need for pretreatment.^{66–69} Use of breath-actuated pMDI in children ≥ 5 years old may result in better asthma control, less hospitalization, and less use of relief medication prescription.⁷⁰

1.4 Dry-Powder Inhaler. A DPI is a breath-actuated device that requires sufficient inspiratory flow to inhale the medication from the device. The patient's inspiratory flow disperses the dry particles and draws them from the device into the lower airways. Patients unable to demonstrate sufficient inspiratory flow for the inhaler, particularly those in respiratory distress or children < 4 years of age, may not reliably use DPIs.^{3,11,12,14,26,71,72} At 4 years of age and above, patients may be able to use the DPI if they are shown how to use it effectively and to generate sufficient inspiratory flow required by the device.^{73,74} Current DPIs are available in 3 categories: single-dose, multiple single-dose, and multiple-dose. Like the pMDI,

and unlike nebulizers, the DPI is always provided as a drug/device combination.¹⁴

1.5 Interfaces Used with Aerosol Generators. Mouthpieces, masks, hoods, and spacers are the most common interfaces used between the aerosol generator and the patient. Evidence is lacking for better clinical response with one or another interface (eg, mask vs mouthpiece). Selection of interface is dependent on age, ability to use a mouthpiece, and patient preference. When a nebulizer is used, a mouthpiece is preferred, but a mask can be used if the patient cannot effectively hold the mouthpiece between the lips. Also, a face mask should be avoided in the delivery of corticosteroids, due to the side effects of steroid administration to the facial skin and eyes. A VHC is preferred when a pMDI is used in a patient with poor hand-breath coordination, and it can be used with a mask in patients unable to use a mouthpiece effectively. For a VHC with mask, a larger dead volume reduces aerosol delivery to infants.^{75,76} The lack of mask seal leads to a substantial decrease in aerosol delivery,^{21,75–78} and aerosolized medications delivered with a mask may inadvertently deposit in the eyes.^{23,24,76,79} Aerosolized drug delivery to children < 3 years old should be through a mask or hood. For an infant, a hood is as efficient as a mask, its use results in better therapeutic index with minimal deposition at the infant's eyes, and it is preferred by parents for aerosol drug administration.^{80–83}

ADS 2.0 PATIENT PREPARATION

- 2.1 Identify patient and assess the need for inhaled medication.
- 2.2 Describe the procedure to be performed, how it will be performed, what the patient is expected to do, and how frequently it will be performed.
- 2.3 Utilize age-appropriate strategies.
- 2.4 Clear the airways as needed.
- 2.5 Position the patient appropriately.

ADS 3.0 PROCEDURE

It is recommended that techniques for using aerosol delivery devices follow the procedural steps from *A Guide to Aerosol Delivery Devices for Respiratory Therapists*.¹⁴ In some cases, the FDA has approved a drug-device combination with specific nebulizers identified on the drug label. Table 2 shows approved nebulizers for specific drug formulations.¹⁴ The use of specified nebulizers is recommended.

Table 2. Approved Devices for Specific Drug Formulations

Drug Formulation	Approved Aerosol Device
Bronchodilator	Nebulizer type not specified
Acetylcysteine	Nebulizer type not specified
Budesonide (Pulmicort respules)	Should not be used with ultrasonic nebulizer
Tobramycin (TOBI)	Pari LC
Dornase alfa (Pulmozyme)	Hudson T Up-draft II, Marquest Acorn II, Pari LC, Durable Sidestream, Pari Baby
Pentamidine (NebuPent)	Marquest Respigard II
Ribavirin (Virazole)	Small Particle Aerosol Generator (SPAG)
Iloprost (Ventavis)	I-neb Adaptive Aerosol Delivery (AAD) System
Aztreonam (Cayston)	Altera nebulizer system
Treprostinil (Tyvaso)	Tyvaso inhalation system

ADS 4.0 FOLLOW-UP CARE

- 4.1 Monitor the patient for adverse response.
- 4.2 Assess whether or not the patient is using the device correctly.
- 4.3 Assess response to therapy and document findings.

ADS 5.0 SETTING

Aerosolized medications can be administered by properly trained healthcare providers in a number of settings that include (but are not limited to):

- 5.1 Hospital
- 5.2 Extended care facility
- 5.3 Out-patient clinic
- 5.4 Physician's office
- 5.5 Transport vehicle
- 5.6 Home

ADS 6.0 INDICATIONS

- 6.1 SVN
 - 6.1.1 Delivery of aerosolized medications available as a solution^{64,84,85}
 - 6.1.2 Need to modify drug concentration or combine compatible nebulized solutions¹⁴
 - 6.1.3 Device of choice for patients who are unable to operate, coordinate, cooperate, or perform the necessary inspiratory maneuvers required for the use of other devices (eg, infants, small children, and the elderly)
- 6.2 SVN With Mouthpiece
 - 6.2.1 Delivery of aerosolized medications to patients who are able to utilize a mouthpiece correctly (> 3 years of age)^{2,3,8,9,14,84}

6.2.2 Breath-actuated nebulizers are indicated in patients ≥ 5 years if they are able to demonstrate their ability to open the valve.

6.3 SVN With Mask

6.3.1 Delivery of aerosolized medications to patients unable to utilize a mouthpiece (≤ 3 years of age)^{2,3,8,9,16,86}

6.4 SVN With Hood

6.4.1 Delivery of aerosolized drugs to young children who cannot tolerate face mask⁸⁰⁻⁸²

6.5 LVN

6.5.1 Delivery of continuous aerosolized bronchodilator^{62,87}

6.6 pMDI: General Indications

6.6.1 Delivery of medications that are available in pMDI form⁸⁶

6.6.2 Convenience of being small and portable

6.7 Breath-actuated pMDI

6.7.1 Delivery of inhaled bronchodilator for patients with poor hand-breath coordination who can use a mouthpiece

6.8 pMDI with VHC and mouthpiece

6.8.1 Patients who are able to hold the mouthpiece during treatment

6.9 pMDI with VHC and mask

6.9.1 Small children, elderly, and others unable to use a mouthpiece^{2,86}

6.9.2 Reduces need for actuation and inspiratory maneuver coordination

6.9.3 Reduces oropharyngeal impaction, particularly with the delivery of corticosteroids⁸⁸

6.10 pMDI with spacer (non-valved pMDI accessory device)

6.10.1 Patients who can coordinate inspiration and actuation

6.10.2 Reduces oropharyngeal impaction, particularly with the delivery of corticosteroids⁸⁸

6.11 DPI

6.11.1 Delivery of aerosolized medications available as DPI⁸⁹

6.11.2 Patients who are able to generate sufficient inspiratory flow for the specific inhaler^{35,36,90}

ADS 7.0 ASSESSMENT OF OUTCOME

Appropriate selection of an aerosol generator is reflected by the following evidence:

- 7.1 A positive clinical outcome after aerosol therapy:
 - 7.1.1 Desired medication effect is observed, as indicated by an improvement in subjective (eg, physical examination) and objective (eg, spirometry) assessments, in short time frame if bronchodilators are used, and over longer time frame for

other drugs such as antibiotics or corticosteroids.^{91,92}

7.2 Use of proper technique in applying aerosol delivery systems:

7.2.1 Healthcare providers must demonstrate competency with proper technique and patient instruction of aerosol delivery systems.^{15,93–96}

7.2.2 Patients and family members must demonstrate proper technique with use of prescribed aerosol delivery systems.^{93–96}

7.3 Patient adherence with application of aerosol delivery systems:

7.3.1 Patients and family members demonstrate adherence with the use of aerosol delivery systems with initiation of therapy and periodic follow-up visits.^{94–96}

ADS 8.0 CONTRAINDICATIONS

8.1 No contraindications exist to the administration of aerosols by inhalation. Aerosol therapy is contraindicated when there is a known hypersensitivity or history of an allergic reaction to a specific pharmacologic agent, its preservatives, and/or its excipients.⁹⁷

8.2 Contraindications associated with specific medications being delivered may exist. Pharmaceutical information in the package insert should be consulted for relative contraindications.

8.3 Aerosol generators should not be used for patients with known allergies to medication preservatives and other excipients.

8.4 A pMDI or DPI should not be used for patients unable to perform the respiratory maneuver required to deliver the drug.

ADS 9.0 HAZARDS/COMPLICATIONS

9.1 Aerosol Delivery

9.1.1 When aerosol generators are contaminated with bacteria, they increase the risk of infection in patients with respiratory diseases.^{98–105}

9.1.2 Care providers and bystanders have the risk of infection due to the inhalation of pathogens and second hand aerosols during aerosol therapy.¹⁰⁶ If indicated, negative pressure rooms and personal protective equipment should be used.^{107–109}

9.1.3 Workplace exposure to aerosol may increase the risk of asthma-like symptoms and cause occupational asthma.^{14,110–112}

9.1.4 Malfunction of device and/or improper technique may result in underdosing or overdosing.^{41–43,96,113–116}

9.1.5 Specific pharmacologic agents can produce adverse side effects such as headache, insomnia, tachycardia, tremor, and nervousness with adrenergic agents; local topical effects with anticholinergics; airway reactivity with antibiotics, hypertonic saline, inhaled corticosteroids, and bronchodilators; systemic/local effects with corticosteroids; and bad taste with mucolytics and hypertonic saline.^{14,117}

9.1.6 Bronchospasm may be induced due to a cold and high-density aerosol administration in patients with pulmonary diseases.^{117–119}

9.1.7 The prescription of aerosol delivery devices for use in the home can lead to misuse if the user has not been properly trained.^{95,96,120}

9.2 SVN

9.2.1 There may be an increase in the drug concentration in the nebulizer cup at the end of the treatment when jet and ultrasonic nebulizers are used.^{43,121–123}

9.2.2 The nebulizer may become contaminated and can be a source of infection.¹²⁴

9.3 LVN

9.3.1 There may be an increase in the drug concentration in the nebulizer cup when jet and ultrasonic nebulizers are used.

9.3.2 Side effects may occur at any time during continuous nebulization, and frequent assessment is required.^{62,87,125}

9.3.3 The nebulizer may become contaminated and can be a source of infection.

9.3.4 Drug concentration increases over time, and the solution might need to be changed after 5 hours of operation.⁵⁸

9.4 pMDI

9.4.1 Inappropriate patient use may result in underdosing or overdosing.^{7,66,95,126}

9.4.2 Reaction to propellants and other additives such as coughing and wheezing may occur.^{64,117,126}

9.4.3 Oropharyngeal impaction of corticosteroid may result in local side effects such as candidiasis.^{64,126}

9.4.4 Immersion of the canister in water may result in valve blockage.¹²⁷

9.5 DPI

9.5.1 Airway irritation and dysphonia from dry powder may occur.^{64,126}

9.5.2 Reaction to lactose or glucose carriers may occur.⁶⁴

9.5.3 Oropharyngeal impaction of corticosteroid may result in local side effects.

ADS 10.0 LIMITATIONS OF METHOD**10.1 SVN**

10.1.1 Deposition of medication into the lungs ranges from 1–15% of the dose^{128–133} and may vary from brand to brand of SVN, and unit to unit of the same brand.^{65,115,128,134}

10.1.1.1 Drug delivery varies with different nebulizer types.^{42,65,115,134} If specified, only the nebulizer cited on the drug label should be used.

10.1.1.2 Examples of drugs that require approved nebulizers include budesonide, tobramycin, dornase alfa, pentamidine, iloprost, treprostinil, and aztreonam (see Table 2).

10.1.2 Patients with smaller tidal volumes and rapid respiratory rates, particularly neonates^{130,135} and dyspneic patients with shallow breathing, may inhale less of the aerosolized agent and receive less of the dose when nebulization is continuous.^{40,130}

10.1.3 Patients with airways of smaller diameter may receive a smaller fraction of the total particles produced.^{10,130,136}

10.1.4 Crying children receive virtually no aerosol drug to the lungs.^{137,138}

10.1.4.1 Most of the inhaled dose deposits in the upper airways and is then swallowed.

10.1.4.2 Inhaled drugs should be given to infants when they are breathing quietly.¹³⁹

10.1.5 Fill volume in the SVN affects output.¹³⁴ Since filling volumes may be different, it is suggested to follow the drug label or device manufacturer's product insert to cover those devices that are not labeled for specific use with a particular medication.

10.1.6 Approximately 25–50% of the initial solution volume remains on the internal walls and reservoir of the jet nebulizer after aerosol therapy is completed.^{41,43,129}

10.1.6.1 Concentration of the solution increases during nebulization, resulting in retention of much of the dose in the jet nebulizer.^{43,84,129}

10.1.7 Aerosol is lost during the expiratory phase of breathing unless a breath-actuated design or a design with a reservoir bag is used.^{41,43,126}

10.1.8 Duration of treatment is variable and may be prolonged. A prolonged treatment time may be associated with reduced patient adherence to prescribed therapy.

10.1.9 Use is labor-intensive and costly.^{140–142}

10.1.10 The need for a power source makes the SVN less portable, particularly in the ambulatory setting, outside of the home.^{11,14,64,84}

10.1.11 SVNs require preparation and cleaning.^{14,64}

10.2 SVN and LVN With Face Mask

10.2.1 Cold, wet mist may be irritating to children and may limit the time that the treatment is tolerated.^{15,85}

10.2.2 Aerosol deposition is reduced because of upper airway impaction.¹³⁶

10.2.3 Use of LVN for bronchodilator delivery is limited to use in a critical care setting and not appropriate for home use.

10.2.4 Leak between the mask and the face decreases the amount of aerosol inhaled by the patient.^{17,18}

10.3 pMDI

10.3.1 Patients who cannot perform hand-breath coordination or proper inhalation technique should not use a pMDI.^{7,10,35,36,126,143,144}

10.3.2 Failure to shake a pMDI before each use can interfere with correct drug release.^{7,66,95,126,144}

10.3.3 Failure to prime a pMDI can also affect correct drug release.^{7,66,126}

10.3.4 Use of a pMDI without a spacer device results in greater oropharyngeal impaction and a reduction in airway deposition.^{64,84,126}

10.3.5 Inadequate or inaccurate instruction and technique may result in misuse and reduced aerosol deposition.^{10,85,126}

10.3.6 Propellants, excipients, and drugs may cause bronchospasm in some patients with hyper-reactive airway diseases.

10.3.6.1 The breath-actuated pMDI (Autohaler) uses chlorofluorocarbon (CFC) as a propellant.

10.3.7 Average aerosol deposition in the lungs ranges from 1% to 40% of the total dose, depending on size, age, device and interface.^{4,67,68,145–147}

10.3.8 Lack of Built-In Dose Counter.

10.3.8.1 Dose counters are available for some brands, but add to the cost of the pMDI alone.^{6,7,14}

10.4 DPI

10.4.1 The efficiency of DPI is dependent upon patient's inspiratory flow. In clinical situations where inspiratory flow is < 40–60 L/min, such as respiratory disease exacerbations or children < 4 years old,^{72,85} use of DPI is associated with reduced lung deposition.^{64,72,130}

10.4.2 Vulnerable to ambient humidity or exhaled humidity.^{10,64,84,85}

10.4.3 High oropharyngeal impaction.^{85,130}

10.4.3.1 Average deposition in the lungs is 10–25% of the total dose.^{84,85}

10.4.4 If a single-dose DPI is used, additional time is needed to load the dose, and the patient must be capable of loading the dose before using the DPI.

10.4.5 Patients are less aware of delivered dose unless the DPI has a built-in dose counter.

10.4.6 Limited range of drugs.^{7,90,126}

10.4.7 Wide range of designs with different ways to load the dose may lead to incorrect use. This can be best resolved by proper patient and caregiver education and return demonstration.

10.5 Device Interface

10.5.1 Face Mask

10.5.1.1 Face masks with larger dead space volume reduce aerosol delivery to infants and children.^{75,148}

10.5.1.2 Leaks between the mask and the face decrease the amount of aerosol inhaled by the patient.^{18,22,23,75,77,78,149–154}

10.5.1.2.1 In infants and small children, a small leak decreases drug inhaled by > 50%.

10.5.1.3 Aerosolized medications delivered with a face mask may inadvertently deposit in the eyes, resulting in eye irritation.^{23,76,79}

10.5.2 Blow-by. Blow-by significantly decreases aerosol delivery as the distance from the device and the patient's face is increased. It is ineffective and should be discouraged.^{133,155,156}

10.5.3 Mouthpiece

10.5.3.1 Inappropriate patient use may result in underdosing.

10.5.4 Spacer/VHC

10.5.4.1 Using the spacer/VHC with the pMDI increases cost.

10.5.4.2 Assembly is necessary.

10.5.4.3 All spacers do not eliminate coordination problems.

10.5.4.3.1 Open tube spacer/accessory devices (non-valved) require coordination.

10.5.4.3.2 A spacer/accessory device with one-way valve (ie, VHC) eliminates coordination problems.

10.5.4.4 Dose delivery can be affected in some spacer designs if the device does not fit the pMDI properly.^{6,14,126}

10.5.4.5 Electrostatic charge decreases aerosol delivery.¹⁴⁸

10.5.4.6 The spacer/VHC is larger and more cumbersome than the pMDI alone.^{10,126}

10.5.4.6.1 VHCs with large volume are disadvantageous for infants and small children, as it is difficult to empty larger VHCs with fewer inhalations.¹⁴⁸

10.5.4.7 All spacer/VHCs may not fit all pMDIs.

10.5.4.8 Improper use of VHC results in inconsistent aerosol delivery.¹⁴⁸

10.5.4.9 Possible contamination with inadequate cleaning.

10.5.4.10 Valve malfunction in the VHC may decrease drug delivery.

10.5.4.11 The inspiratory flow and the number of inhalations required by children < 3 years to effectively use VHC with mask is not completely understood.^{2,10,85,135}

10.6 Drug pharmacokinetics and pharmacodynamics are markedly altered in neonates and may require dose adjustments.^{15,93,130,147}

ADS 11.0 RESOURCES

11.1 Equipment

11.1.1 Power source such as electricity, hospital compressed oxygen or air, portable oxygen or air cylinder, or domiciliary air compressor capable of producing a flow of 6–8 L/min.^{64,84}

11.1.2 Aerosol Generators

11.1.2.1 SVN capable of producing a high drug output, short nebulization time, aerosol particles with a mass median aerodynamic diameter (MMAD) of 1–5 μm , and with a low residual volume.^{11,12,41,129,157} Characteristics of nebulizers may vary among brands, and among units of the same brand.^{115,128,134,158}

11.1.2.2 LVN capable of producing aerosol particles with an MMAD of 1–5 μm , with face mask

11.1.2.3 pMDI, which includes the medication canister and actuator, with appropriate accessories for the patient's ability and circumstances

11.1.2.4 DPI with accompanying medication capsule/blister and dispenser

11.1.3 Interface

11.1.3.1 Face mask for small children unable to utilize a mouthpiece.^{2,16,86}

11.1.3.2 Mouthpiece, with or without extension reservoir, depending on the type of nebulizer used.⁸⁴

11.1.3.3 VHC or spacer with mouthpiece or mask, depending on the patient's age and physical and cognitive ability⁵

Table 3. Approximate Costs of Nebulizers in 2011

Aerosol Generator	United States Dollars
Jet nebulizer with reservoir	1–3
Jet nebulizer with collection bag	4–5
Breath-enhanced nebulizer	4–20
Breath-actuated nebulizer	4–6
Ultrasonic nebulizer medication chamber	1–5
Ultrasonic handset replacement	100–250
Vibrating mesh nebulizer	40–150

11.1.3.4 Hood, depending on the patient’s age and tolerance as well as parents’ preference^{81–83}

11.1.4 Medication and Diluent

11.1.4.1 Selection of an aerosol generator is limited by drug availability for a specific device or type of aerosol generator.

11.1.5 Cost

11.1.5.1 Selecting the least expensive aerosol generator for the patient is essential. The cost of an aerosol generator depends upon the type of aerosol device, its brand, drug formulation, and dosage. While jet nebulizers are low-cost, newer and more efficient aerosol generators are more expensive.¹⁴ Table 3 shows the cost of nebulizers.

11.1.5.2 Since aerosol treatment with pMDI reduces the treatment time at the bedside and increases the productivity of respiratory therapists, it is considered an economical alternative to nebulizer for aerosol delivery to patients with pulmonary diseases.^{140,141,159–164} Previous studies reported success in substituting a pMDI for a nebulizer by documenting a 30–50% reduction in the annual cost of aerosol therapy.^{140,142,165,166} However, success in this substitution depends on proper planning, careful implementation, and comprehensive education programs that were directed to physicians, respiratory therapists, and other healthcare professionals. Also, it must be noted that some medications are not available in the form of pMDI, and some patients are not capable of using pMDI correctly, due to their age and physical and cognitive abilities.

11.2 Most healthcare providers do not know how to use aerosol generators correctly.^{167–171} Healthcare providers responsible for delivery of aerosolized medications should have demonstrated and documented knowledge and skills related to:

11.2.1.1 Aerosol delivery devices and their limitations^{94,95,114}

11.2.1.2 Assembly, care, and use of aerosol delivery devices^{94,95,114}

11.2.1.3 Provision of comprehensive patient and lay caregiver instruction^{86,172,173}

11.2.1.4 Medications being delivered, including contraindications, potential side effects, and desired response

11.2.1.5 Incompatibility of drugs if combined in the nebulizer cup^{174–176}

11.2.1.6 Recognition and response to adverse reactions during medication delivery, and modification of treatment accordingly

11.2.1.7 Performance of the necessary subjective and objective assessments in order to determine medication efficacy and the patient’s ability to properly utilize aerosol delivery devices^{94,95,177}

11.2.2 Healthcare providers should train and re-train patients about how to use aerosol generators correctly.^{94,95,178}

11.2.3 Most patients do not use their inhalers well enough to benefit from their prescribed medication.^{120,179–181} Patients and/or family members or lay caregivers should:

11.2.3.1 Demonstrate proper use and understanding of the aerosol delivery device and delivery technique.^{94,95,113,173,177,182–184}

11.2.3.2 Demonstrate proper assembly, cleaning, and care of the aerosol delivery device, and aseptic medication preparation.^{95,113}

11.2.3.3 Demonstrate an understanding of medication purpose, dosage, indications, and side effects, be able to alter medication as needed, and know when to report to physician or surrogate.⁹⁵

ADS 12.0 MONITORING

12.1 Observe delivery technique of spontaneously breathing patients who are able to self-administer aerosolized medications.

12.1.1 A periodic slow deep inhalation with an inspiratory pause/hold is performed during SVN treatments.¹⁵⁷ Hyperventilation should be avoided, and the patient should be observed to ensure that aerosol mist is being inhaled.

12.1.2 pMDI actuation occurs at the beginning of inhalation, followed by a slow inspiration and breath-hold for up to 10 seconds.¹⁵⁷

12.1.3 Patient is able to produce a rapid inhalation in order to fully activate and discharge DPI.

12.2 Observe patient and/or patient's family member following instructions and demonstration.^{94,95}

12.2.1 Proper understanding and return-demonstration of delivery device and accompanying equipment is observed.

12.2.2 Proper understanding and preparation of medication is observed.

12.3 Observe response to medication by performing subjective (eg, physical examination) and objective (eg, pulmonary function measurements) assessments and other diagnostic techniques that are appropriate for the specific medication being delivered.

12.3.1 Ensure that medication volume is nebulized over desired amount of time when using LVN.

12.4 Documentation

12.4.1 Successful training of patients and/or patient's family member is documented in the patient's medical record.⁹⁵

12.4.2 Treatments administered in a clinical setting are documented in the patient's medical record. Information on medication dose, frequency, response, and adverse reactions are included.

ADS 13.0 FREQUENCY

Aerosol delivery devices are used according to the frequency of the prescribed medication.

ADS 14.0 INFECTION CONTROL

14.1 Standard precautions and measures to limit the transmission of airborne pathogens must be adhered to at all times.^{103,124}

14.2 SVN

14.2.1 Jet nebulizers are for single patient use and should be changed every 24 hours, or at a frequency determined in collaboration with infection control, based on local data, when used in the hospital.^{37,124,185-187}

14.2.2 Jet nebulizers should be cleaned, rinsed with sterile water, and air-dried between treatments on the same patient.^{14,124,186}

14.2.3 At home, parts of aerosol generators should be washed with soap and hot water after each treatment, with care not to damage any parts of the aerosol generator.¹⁰³

14.2.4 Mesh and ultrasonic nebulizers should be cleaned and disinfected based on the manufacturer's recommendations. The mesh should not be touched during the cleaning of mesh nebulizers, in order to prevent the damage of the unit.¹⁴

14.3 LVN

14.3.1 LVNs are for single patient use.

14.4 pMDI

14.4.1 The plastic boot of pMDIs should be cleaned according to the manufacturer recommendation.

14.4.2 When a spacer is used with a pMDI, it should be cleaned before first use, and then periodically cleaned based on the manufacturer's suggestions.

14.5 DPI

14.5.1 DPI and accessories are for single patient use only. Clean or replace when they appear dirty.

14.5.2 DPIs should not be submerged in water. Also, they should be kept dry, as moisture will decrease drug delivery.¹⁴

14.5.3 Although there is no clear evidence about the cleaning practice for DPI, each manufacturer has recommendations for periodic cleaning and suggests wiping the mouthpiece of the DPI with a clean dry cloth.¹⁴

14.6 Aerosol Solutions

14.6.1 Use only sterile fluids, and dispense them aseptically.¹²⁴

14.6.2 Unit dose medications are recommended, when possible.^{102,124}

14.6.2.1 Multi-dose drug containers have been associated with contaminated nebulizers and are a potential source of spreading nosocomial infections.^{100-102,188}

14.6.3 If medications from multidose vials have to be used, they should be handled, dispensed, and stored according to manufacturer's instructions.

14.7 Patients should be instructed to rinse the mouth with water following each administration of inhaled steroids.

ADS 15.0 RECOMMENDATIONS

The recommendations below are made following the Grading of Recommendations Assessment, Development, and Evaluation (GRADE)^{189,190} criteria.

15.1 It is recommended that selection of the appropriate aerosol generator and interface be made based on the patient's age, physical and cognitive ability, cost, and the availability of the prescribed drug for use with a specific device. (1B)

15.2 Nebulizers and pMDIs with VHCs are suggested for use with children ≤ 4 years of age and adults who cannot coordinate the use of pMDI or DPI. (2B)

15.3 It is suggested that administration of aerosols with DPIs be restricted to patients ≥ 4 years of age who can demonstrate sufficient flow for the specific inhaler. (2B)

15.4 For patients who cannot correctly use a mouth-piece, aerosol masks are suggested as the interface of choice. (2B)

15.5 It is suggested that blow-by not be used for aerosol administration. (2B)

15.6 It is suggested that aerosol therapy be administered with a relaxed and nondistressed breathing pattern. (2B)

15.7 Unit dose medications are suggested to reduce the risk of infection. (2C)

15.8 It is suggested that nebulizer/drug combinations should be used as approved by the FDA. (2A)

15.9 It is recommended that healthcare providers know the correct use of aerosol generators; they should teach and periodically re-teach patients about how to use aerosol devices correctly. (1A)

15.10 It is suggested that intermittent positive-pressure breathing should not be used for aerosol therapy. (2B)

15.11 It is recommended that either nebulizer or pMDI can be used for aerosol delivery during NIV. (1B)

16.0 ADS CPG IDENTIFYING INFORMATION

16.1 Adaptation

Original Publication: *Respir Care* 1995;40(12):1325-1335

16.2 Guideline Developers

American Association for Respiratory Care Clinical Practice Guidelines Steering Committee.

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