REVIEW

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Oxygen and aerosolized drug delivery: Matching the device to the patient

ABSTRACT

The variety of devices for administering supplemental oxygen and aerosolized drugs for hospital inpatients allows physicians to tailor the therapy to patient's needs, but presents a challenge in determining which device is best for the individual patient. We describe the selection process, appropriate use, and the advantages and disadvantages of various devices.

KEY POINTS

The nasal cannula is simple to use, inexpensive, comfortable, well tolerated, and allows the patient to speak and to eat, but flow through the cannula may dry and irritate the nasal mucous membrane and the eyes, especially at higher flow rates.

Venturi masks allow precise control of the inspired oxygen fraction, but may not provide adequate total flow for some critically ill patients.

Large-volume jet nebulizers may be unheated or heated; the latter is preferred when secretions are thick and extra humidification is desired.

The metered-dose inhaler with a spacer device should be the first choice for aerosolizing medications to the lower respiratory tract in cooperative adult patients.

WHEN PRESCRIBING supplemental oxygen or aerosolized drugs, physicians can choose from a range of delivery systems and devices, which differ in the amount of oxygen, total flow, or medication they deliver, and in comfort level. Knowing the relative advantages and disadvantages of each in specific clinical settings enables the physician to select the best therapy for each patient.

In this article, we review the appropriate use, common clinical indications, and advantages and disadvantages of various supplemental oxygen systems (FIGURE 1) and aerosolized drug delivery devices (FIGURE 2).

SUPPLEMENTAL OXYGEN THERAPY

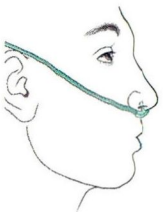
In general, supplemental oxygen is needed if the partial pressure of arterial oxygen is less than 60 mm Hg, the arterial oxygen saturation is less than 90%, or both. With each type of delivery system, increasing the oxygen flow rate will increase the patient's fraction of inspired oxygen (FIO_2) and therefore the level of arterial oxygen.

Therefore, it is essential to select a device that can deliver the desired inspired oxygen fraction, sufficient to raise the arterial saturation to at least 90%.

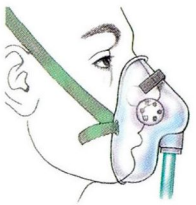
By definition, low-flow systems provide only a portion of the volume of the patient's minute ventilation (the sum of air breathed in over 1 minute). To make up the difference, these systems allow room air to enter ("entrain") continuously, or include reservoirs that hold oxygen. Therefore, the fraction of inspired oxygen delivered varies not only with the flow rate of oxygen, but also with the patient's respiratory pattern.

Supplemental oxygen delivery systems: Advantages and disadvantages

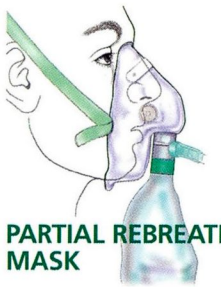
LOW-FLOW SYSTEMS



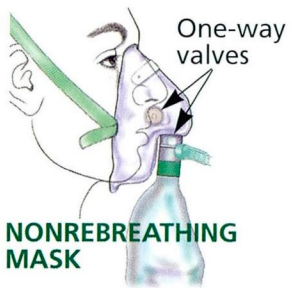
NASAL CANNULA



SIMPLE MASK



PARTIAL REBREATHING MASK



NONREBREATHING MASK

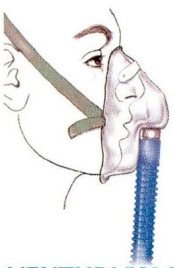
ADVANTAGES

NASAL CANNULA	SIMPLE MASK	PARTIAL REBREATHING MASK	NONREBREATHING MASK
Simple and comfortable at flow rates at or below 6 L/minute Allows speaking, eating	Provides higher inspired oxygen fraction than nasal cannula, ie, up to 50%	Provides inspired oxygen fraction 60% to 80%	Easy way to deliver as much as 100% oxygen

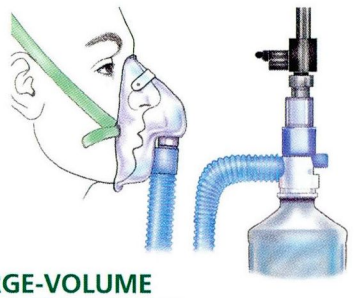
DISADVANTAGES

NASAL CANNULA	SIMPLE MASK	PARTIAL REBREATHING MASK	NONREBREATHING MASK
Oxygen flow can dry and irritate nasal mucous membrane and eyes Maximal deliverable inspired oxygen fraction is ≤ 44% Ineffective when nasopharynx is occluded (eg, trauma)	Common disadvantages for simple, partial rebreathing, and nonrebreathing masks • Less comfortable than nasal cannula • Pressure on the face and sweating within the covered area • Must be removed for eating, drinking, and airway care • Inadequate flow rate increases risk of rebreathing carbon dioxide		

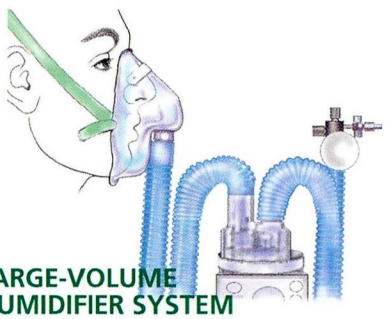
HIGH-FLOW SYSTEMS



VENTURI MASK



LARGE-VOLUME AEROSOL SYSTEM



LARGE-VOLUME HUMIDIFIER SYSTEM

ADVANTAGES

VENTURI MASK	LARGE-VOLUME AEROSOL SYSTEM	LARGE-VOLUME HUMIDIFIER SYSTEM
Delivers specific and consistent inspired oxygen fractions from 24% to 50%	Provides source of humidity System of choice following surgery or extubation May be used with mask, face tent, T-piece May be heated when extra humidification is needed (eg, thick secretions) Delivers inspired oxygen fractions of 21% to 100% (actual delivered fractions 21% to 60%)	Can deliver inspired oxygen fraction of 21% to 100% and flow rates up to 150 L/minute May be used with several interfaces (eg, mask, face tent, T-piece) Can be modified to provide continuous positive airway pressure

DISADVANTAGES

VENTURI MASK	LARGE-VOLUME AEROSOL SYSTEM	LARGE-VOLUME HUMIDIFIER SYSTEM
Same as for other masks	Oxygen delivery may be inadequate for patients with high inspiratory demands	Noisy

FIGURE 1

In contrast, high-flow systems provide a precise and consistent concentration of oxygen at a flow rate that exceeds the patient's minute ventilation by threefold to fourfold.

LOW-FLOW OXYGEN SYSTEMS

Low-flow systems include the nasal cannula, the simple mask, the partial rebreathing mask, and the nonrebreathing mask. In general, such systems are best suited to patients whose requirements for supplemental oxygen are modest.

Nasal cannula

The nasal cannula, which delivers a continuous flow of oxygen through prongs that fit in the patient's nostrils, is the most frequently used oxygen delivery system. Oxygen from the nasal cannula fills the nasopharynx and oropharynx, which act as a reservoir. Therefore, the patient need not breathe through the nose to receive oxygen, but the nasopharynx must be patent. Nasal cannulas deliver oxygen at rates of 1 to 6 L/minute and inspired oxygen fractions between 24% and 44%.[1,2] As a rule of thumb, the inspired oxygen fraction increases by 4% with each 1-L increment in the delivery rate.

Higher cannula flow rates can irritate the nasal mucosa

Advantages. The nasal cannula is simple to use, inexpensive, comfortable, well tolerated, and allows the patient to speak and to eat.

Disadvantages. The oxygen flow tends to dry and irritate the nasal mucous membrane and the eyes, especially at higher flow rates. If higher flow rates are needed, ie, 4 L/minute or more, the oxygen should be humidified.[3,4] If more than 6 L/minute are needed, another delivery device should be used. Another disadvantage is that the cannula is easily dislodged. Additionally, the inspired oxygen fraction depends not only on the flow rate, but also on the rate and depth of respiration and the peak inspiratory flow rate,[5] so that the inspired oxygen concentration can vary with the respiratory pattern.

Masks

Masks used in supplemental oxygen therapy all share several drawbacks. They are less comfortable than the nasal cannula. They exert pressure on the face, and the patient may experience sweating within the covered area. Masks must be removed during eating, drinking, and airway care. In addition, failure to flush exhaled carbon dioxide from the mask system can allow rebreathing of carbon dioxide; therefore, adequate oxygen delivery flow rates (eg, > 5 L/minute) must be assured.

A simple face mask has an oxygen entry port and multiple exhalation ports. Simple masks can deliver only moderate inspired oxygen fraction levels, usually between 35% and 50% at flow rates of 5 to 10 L/minute.[1,2] A minimum flow of 5 L/minute is required to flush out the mask between respirations and, thus, to prevent the patient from rebreathing exhaled carbon dioxide, because different masks hold from 100 to 200 mL.[1,2,6] Because the mask reservoir is relatively small and because peak inspiratory flow rates exceed the flow capacity of the mask, oxygen flow rates higher than 10 L/minute generally cannot raise the inspired oxygen fraction further.[7]

Partial rebreathing and nonrebreathing masks provide higher inspired oxygen fractions than nasal cannulas or simple masks. A partial rebreathing mask is a simple oxygen mask with a 1-L reservoir bag attached. It delivers an inspired oxygen fraction of 60% to 80%, depending on the patient's ventilatory pattern.

Partial rebreathing masks, unlike nonrebreathing masks, have no one-way valves between the mask and the reservoir bag, nor at the exhalation ports of the mask. During exhalation, approximately the first third of the tidal volume (ie, the anatomic dead space gas) enters the reservoir bag, and the remainder leaves the mask via the exhalation ports. During inspiration, the patient draws oxygen from the mask, the reservoir bag, and the gas entering the system. Room air may be entrained through the mask ports. No carbon dioxide should accumulate in the reservoir bag if the oxygen flow rate to the system is adequate to prevent the bag from collapsing more than halfway during inspiration. To achieve this, a flow rate of 8 L/minute or higher is recommended.

Nonrebreathing masks, in contrast, have one-way valves between the mask and the reservoir bag and side ports on the mask itself. On exhalation, the valves prevent the exhaled gas from entering the reservoir bag

and allow it to leave the mask. Adequate oxygen flow flushes carbon dioxide from the mask. During inspiration, the patient draws oxygen from the mask, the reservoir bag, and from the flow entering the system. Oxygen flow rates higher than 10 L/minute, and occasionally higher than 15 L/minute, are required to deliver inspired oxygen fractions between 80% and 100%. As a practical point, the oxygen flow should be sufficient to prevent the bag from collapsing during inspiration.

HIGH-FLOW OXYGEN SYSTEMS

High-flow oxygen systems provide a patient's entire inspired volume. Examples of these systems are air entrainment or Venturi masks, large-volume aerosol systems, and large-volume humidifier systems. As a general rule, sicker patients whose oxygen demands are higher or more precise or both will require such systems.

Venturi masks

Venturi masks deliver a specific, consistent inspired oxygen fraction by entraining a specific volume of room air with every liter of oxygen that flows through the mask (FIGURE 1). With this system, oxygen is forced through a small jet, thus accelerating the flow. The accelerated flow creates a negative pressure (the Venturi effect) that entrains room air through a small side port. Varying the size of the jet orifice changes the velocity of the oxygen, thereby affecting the amount of room air entrained and the inspired oxygen fraction. Jets that deliver 24%, 28%, 31%, 35%, 40%, and 50% inspired oxygen fractions are available.

Minimum recommended oxygen flow rates for each of the different jets (24% to 50%) are presented in TABLE 1. Of note, at the minimum recommended oxygen flow rate, the total flow delivered by a Venturi mask with an inspired oxygen fraction greater than 40% is less than 40 L/minute, which may be inadequate for a critically ill patient. Instead, patients with high inspiratory flow demands often benefit from large-volume humidifier systems which can deliver flow rates in excess of 100 L/minute. A Venturi system relies on humidity contained in the entrained room air. Patients requiring humidified gas will benefit from a large-volume aerosol system or a large-volume humidifier system.

TABLE 1

Entrainment ratios and outputs of specific Venturi masks

OXYGEN/AIR ENTRAINMENT RATIO	MINIMAL OXYGEN FLOW (L/MINUTE)	TOTAL FLOW (L/MINUTE)	INSPIRED OXYGEN FRACTION*
1:25	4	104	24
1:10	4	44	28
1:7	6	48	31
1:5	8	48	35
1:3	8	32	40
1:1.7	12	32	50
1:1	12	24	60
1:0.6	12	19	70

*Variations in the inspired oxygen fraction delivered may occur because systems are disposable; for the system to be classified as high-flow, at least 40 L/minute must be provided

Large-volume aerosol systems

Large-volume aerosol systems provide a source of moisture to humidify inspired gases and a relatively high gas flow to the patient. They offer several advantages:

- They are the oxygen delivery systems of choice following surgery or extubation, since they provide cool, moist gas which is soothing to an irritated airway, decreasing mucosal edema.
- They can be used with several interfaces, such as a mask, face tent, or T-piece
- They can be heated when extra humidification is needed, such as when secretions are thick.

However, as discussed below, oxygen delivery may be inadequate for patients with high inspiratory demands.

The most common type of aerosol system uses a large-volume jet nebulizer, consisting of a reservoir for solution, a jet, a capillary tube, and a baffle. Most large-volume nebulizers have solution volumes of 0.5 to 1.5 L. This volume, usually sterile water, allows the nebulizer to operate continually for 4 to 6 hours before it must be refilled.

The jet nebulizer creates an aerosol by the Bernoulli principle of lowering the later-

High-flow oxygen systems provide all of a patient's inspired oxygen

al pressure of gas around the jet to draw solution up the capillary tube, from which it is blasted into particles by the gas jet. The particles then strike a baffle, which causes larger particles to drop out or to fragment into smaller ones.

Most nondisposable aerosol systems offer fixed inspired oxygen fractions (eg, 40%, 60%, and 100%), whereas most disposable units provide a spectrum (21% to 100%) by varying the size of the entrainment port. As a collar is turned, the size of the entrainment port is decreased and the inspired oxygen fraction is increased.

Although it was once common practice to use two aerosol units in tandem when high flow and an inspired oxygen fraction greater than 60% were needed, work by Faust et al[8] has demonstrated that this method delivers lower flow rates than expected. Thus, the currently recommended method of delivering an inspired oxygen fraction of 60% or greater is to use a high-flow, large-volume humidifier rather than an aerosol system.

A jet nebulizer is similar to the Venturi mask in that as the set inspired oxygen fraction is increased (by decreasing the size of the entrainment port), the amount of room air drawn into the mask is decreased—and so the total amount of gas delivered to the patient also decreases.

Use a T-piece to deliver aerosol to patients with an artificial airway

Therefore, a patient's inspiratory demand may exceed the flow available from the aerosol unit, and the patient may breathe in so hard that room air may leak underneath the aerosol mask or tent. Thus, as noted above, for patients who require high flow and a high inspired oxygen fraction, a large-volume, high-flow humidifier system is more effective than an aerosol system.

The aerosol reaches the patient by one of several interfaces.

The **aerosol mask**, made of vinyl, has a 22-mm connector to attach the large-bore corrugated tubing from the nebulizer. There are two holes in the mask for exhalation and escape of excess flow. The face mask may be used for a spontaneously breathing patient without an artificial airway.

A **face tent** may be used instead of a full-face aerosol mask for patients who are uncomfortable having both their mouth and nose covered. The face tent fits under the chin and is open above the nose. It is also made of vinyl and has a 22-mm connector for aerosol tubing. When using an aerosol mask or face tent, the actual concentration of oxygen delivered to the hypopharynx may be far lower than that leaving the end of the aerosol tube.[9–11]

A **T-piece** is commonly used to deliver aerosol to patients with an artificial airway such as an oral or nasal endotracheal tube or a tracheostomy tube. A reservoir tube between 6 and 18 inches in length may be added; an adequate aerosol flow rate should be maintained so that a continuous stream of aerosol is observed exiting from the reservoir during inspiration, thereby assuring that the patient is not rebreathing carbon dioxide and is receiving the entire inhaled volume from the aerosol. If carbon dioxide retention does occur, the reservoir should be shortened or removed. A disadvantage of the T-piece is that it connects directly to the tracheostomy tube and may pull, causing irritation and decannulation.

Tracheostomy collar or mask. If a patient with a tracheostomy can tolerate small variations in inspired oxygen fraction, a tracheostomy collar or mask is preferred. The tracheostomy mask is made of vinyl and has a swiveled 22-mm adapter for aerosol tubing. Whereas the T-piece connects directly to the tracheostomy tube and may cause irritation or decannulation, the tracheostomy mask fits over the tracheostomy tube but may not contact it. Though the tracheostomy mask decreases torque on the tracheostomy tube, it is easily displaced from the neck site.

Large-volume jet nebulizers may be unheated or heated; the latter is preferred when secretions are thick and extra humidification is desired. The aerosol output of unheated nebulizers ranges from 5.6 to 7.0 L/minute, and the output of heated nebulizers is greater. The heaters generally slip over the neck of the nebulizer and heat only a small portion of the solution just before nebulization. These units are generally left unheated when used with a face mask or tent because patients often do not tolerate inspiring warm, moist air. However, some patients with artificial airways require higher humidity because the upper airway has been bypassed.

Large-volume humidifier systems

High-flow humidifier systems can provide a spectrum of inspired oxygen fraction values (21% to 100%) at flow rates up to 150 L/minute, much higher than the large-volume aerosol system. They can deliver gas that is cool or heated via a face mask, artificial airway, or T-piece.

The oxygen or air-oxygen mixture is generated by dual air and oxygen flow meters, an air-oxygen blender, or an adjustable flow generator. The gas mixture then passes through a large-volume humidifier and on to the patient via large-bore tubing. When attached to an artificial airway, a 10- to 15-inch reservoir tube is normally used to ensure that room air is not entrained through the open port of the T-piece. Such a system is the most accurate and precise method of delivering an inspired oxygen fraction of 60% or greater. It is the preferred system for patients requiring a high inspired oxygen fraction and high flow, and is capable of delivering 100% oxygen at flow rates approaching 150 L/minute.[8]

High-flow humidifier systems can be modified to deliver continuous positive airway pressure (CPAP) via mask or artificial airway.

The main drawback to such systems is the excessive noise created as gas flows through them at 80 to 100 L/minute. For these reasons, patient tolerance and compliance with high-flow systems is often low.

AEROSOLIZED DRUG DELIVERY DEVICES

Three types of delivery devices are used most often to deliver medications to the lower respiratory tract in adults:

- Small-volume nebulizers.
- Metered-dose inhalers.
- Dry powder inhalers.

All these devices generate particles with a median diameter of 2 to 5 μm.[12–14] **FIGURE 2** lists the advantages and disadvantages of each of the aerosol drug delivery devices.

Small-volume nebulizers

A small-volume nebulizer is a jet nebulizer powered by a compressed gas source and produces an aerosol much like the large-volume aerosol system previously described. Small-volume nebulizers, sometimes called hand-held nebulizers, all have basically the same features: a 5- to 30-mL medication cup, a jet, a capillary tube, a baffle, and a gas delivery tube.

The most common interface is the mouthpiece, with a 4- to 6-inch length of reservoir tubing placed distal to the nebulizer to increase the volume of aerosol available with each inhalation. An aerosol mask may also be used, but the patient should be instructed to breathe through an open mouth to minimize deposition of the drug in the nose and nasopharynx. For patients with an artificial airway, a T-piece or tracheostomy mask may be used.

The small-volume nebulizer should be operated at gas flows of 6 to 8 L/minute and with a total solution volume of about 4 mL to optimize the volume of drug delivered.[15,16] The sides of the nebulizer should be periodically tapped until no aerosol is produced; this minimizes the dead volume, ie, the volume of solution that remains in the nebulizer.

The patient should inhale slowly (0.5 L/second) at normal tidal volume, and occasionally take a deep inspiration and hold it for 4 to 10 seconds.[17] However, even with optimal technique, only about 9% to 12% of the drug placed in the nebulizer is actually delivered to the lower respiratory tract.[14,18,19]

Patients using a nebulizer should occasionally take a deep breath and hold it

Advantages of small-volume nebulizers include:

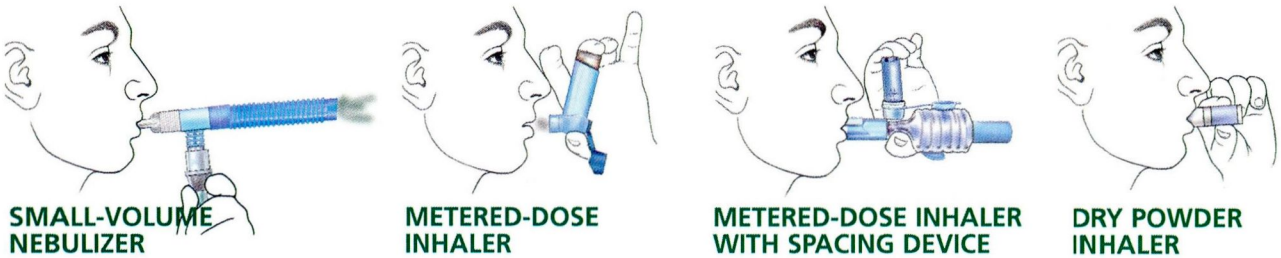
- Ease of administration. Once the device is set up, aerosolized medications can be delivered for prolonged periods with tidal breathing.
- Capability to aerosolize large volumes: 15 to 20 mL/hour for jet nebulizers.
- Ability to deliver medications not available in metered-dose inhaler or dry powder inhaler form.[20]

Disadvantages, as noted above, include low deposition of the medication in the lung with tidal breathing, the consequent need for higher doses and longer administration times, and the associated costs. In addition, there is a risk of bacterial contamination[20] if the reservoir is not adequately cleared.

Metered-dose inhalers

Metered-dose inhalers are often preferred as a cost-saving alternative to small-volume nebu-

Aerosolized drug delivery systems: Advantages and disadvantages



	SMALL-VOLUME NEBULIZER	METERED-DOSE INHALER	METERED-DOSE INHALER WITH SPACING DEVICE	DRY POWDER INHALER
ADVANTAGES	Less patient coordination required High doses possible (even continuous doses) No chlorofluorocarbon release	Convenient Inexpensive	Less patient coordination required	Less patient coordination required Breath-holding not required No chlorofluorocarbon release
DISADVANTAGES	Expensive Wasteful Contamination is possible if not carefully cleaned Pressurized gas source required More time required for medication delivery	Patient coordination required Patient activation required Results in pharyngeal deposition Potential for abuse Difficult to deliver high doses Not all medications available	Releases chlorofluorocarbons Less portable than the simple metered-dose inhaler	Requires high inspiratory flow Most units are single-dose Can result in pharyngeal deposition Not all medications available Difficult to deliver high doses

FIGURE 2

lizers.[21] A metered-dose inhaler is a pressurized canister that contains a medication and propellant. Actuation of the metered-dose inhaler releases a prescribed quantity of medication in a volume of inert gas. Average deposition in the lungs is 10% to 25% of the total dose.[22,23]

Proper technique for using a metered-dose inhaler is essential to ensure drug delivery and requires both ample instruction by the caregiver and a return demonstration by the patient, to confirm that he or she can use the device correctly.[24,25]

The device should be held before an open mouth and actuated near the beginning of a complete slow inspiration from functional residual capacity. Such slow inspiration helps to maintain a more laminar flow and, therefore, deeper particle deposition. Ideally, the inspiration should be held approximately 4 to 10 seconds to aid particle deposition.

The bronchodilatation that follows the initial actuation can augment the effect of later actuations. Ideally, an interval of 3 to 10 minutes should separate successive actuations, but a 1-minute interval is generally more practical.[26–28]

One limitation of the metered-dose inhaler is the difficulty patients—particularly children—have in achieving the hand-breath coordination required for ideal technique. Also, the high velocity with which the particles exit the metered-dose inhaler cause impaction on the mouth and oropharynx, predisposing to thrush when corticosteroids are delivered.

Spacer devices. A spacer device for use with metered-dose inhalers is a holding cham-

ber with a one-way valve designed to optimize drug delivery. Many different types of commercial spacers are available. Deposition of the aerosolized medication via the metered-dose inhaler into the spacer allows large particles to impact and evaporate, thereby reducing particle size, enhancing delivery to the lower airway, and lessening pharyngeal impaction. For this reason, spacers are recommended for use with metered-dose inhaler delivery of corticosteroids. The spacer also eliminates the need for the patient to coordinate actuation and inhalation.[24] The mouthpiece should be placed in the mouth with the lips tightly sealed around it. Then the patient exhales fully into the spacer. The inhaler may then be activated any time before the patient begins a slow, deep inspiration.

Advantages of metered-dose inhalers include shorter treatment times, lower cost, and greater convenience compared with small-volume nebulizers.

Disadvantages include patient difficulty coordinating taking a deep breath while activating the inhaler when not using the spacer device, and the use of chlorofluorocarbons as propellants, though manufacturers are gradually adopting propellants free of chlorofluorocarbons.

Dry powder inhalers

Dry powder inhalers are breath-actuated devices that use a gelatin capsule containing a single dose of medication and a carrier substance to assist dispersion of the drug. The capsule is inserted into the device and punctured. The patient then places the inhaler in the mouth and inhales rapidly (at a rate faster than 60 L/minute) through the device, which disperses the dry particles and draws them into the lower airways. Inhalation is repeated until the capsule is empty.

Advantages. No breath-holding is necessary. Because the dry powder inhaler is breath-actuated, no hand-breath coordination is needed. Also, unlike metered-dose inhalers, dry powder inhalers do not require chlorofluorocarbon propellants.

Disadvantages. As with metered-dose inhalers, dry powder inhalers allow substantial oropharyngeal impaction. One additional issue with dry powder inhaler devices is the need to insert the gelatin capsule, which can pose difficulty for patients with poor dexterity, such as those with arthritis. Also, airway irritation from the dry powder and reactions to lactose or glucose carriers have been described.[22,29] Currently, only cromolyn sodium and albuterol are available as dry powder inhalers in the United States.

In recommending aerosolized drug delivery devices, the clinician must choose the device that best meets the patient's needs. In general, however, the metered-dose inhaler with a spacer device should be the first choice for aerosolizing medications in cooperative adult patients on the grounds of convenience, cost, and effectiveness.

Prescribe a spacer device with metered-dose inhaled corticosteroids

REFERENCES

1. **Fulmer JD, Snider GL.** ACCP-NHLBI National Conference on Oxygen Therapy, Chest 1984; 86:234–247. (Concurrent publication in Respir Care 1984; 29:919–935).
2. **AARC Clinical Practice Guidelines:** Oxygen therapy and the acute care hospital. Respir Care 1991; 36:1410–1413.
3. **Estey W.** Subjective effects dry versus humidified low-flow oxygen. Respir Care 1980; 25:1143–1144.
4. **Campbell E. Baker D, Crites-Silver P.** Subjective effects of oxygen for delivery by nasal cannula: A prospective study. Chest 1988: 86:241–247.
5. **Meredith RL, Stoller JK.** Oxygen therapy. In: Parsons P, Heffner JE, editors. Pulmonary and Respiratory Therapy Secrets. Philadelphia: Hanley & Belfus, Inc. 1996; 108.
6. **Jensen AG, Johnson A, Sandstedt S.** Rebreathing during oxygen treatment with face mask. The effect of oxygen flow rates on ventilation. Acta Anaesthesiol Scand 1991; 35:289–292.
7. **Kacmarek RM.** Supplemental oxygen and other medical gas therapy. In: Pierson DJ, Kacmarek RM, editors. Foundations of Respiratory Care. New York: Churchill Livingstone, 1992: 859–889.
8. **Foust GN, Potter WA, Wilson MD, et al.** Shortcomings of using two jet nebulizers in tandem with an aerosol face mask for optimal aerosol therapy. Chest 1991: 99:1346–1351.
9. **Monast RL, Kaye W.** Problems in delivering desired oxygen concentration from jet nebulizers to patients via face tents. Respir Care 1984; 29:994–1000.
10. **Gibson RL, Comer PB, Beckman RW, et al.** Actual tracheal oxygen concentrations with commonly used oxygen equipment. Anesthesiology 1976; 44:71–73.
11. **Goldstein RS, Young JH, Robuck AS.** Effect of breathing pattern on oxygen concentration received from standard face masks. Lancet 1982; 2:1188–1190.
12. **Dolovich M.** Clinical aspects of aerosol physics. Respir Care 1991; 36:931–938.
13. **Dolovich M.** Physical principles underlying aerosol therapy. J Aerosol Med 1989; 2:171–186.
14. **AARC Clinical Practice Guidelines:** Selection of aerosol delivery device. Respir Care 1992; 37:891–897.
15. **Hess D, Horney D, Snyder T.** Evaluation of hand held function. Respir Care 1989; 34:717–723.
16. **Xu JB, Yu CP.** The effects of age on deposition of inhaled aerosols in the human lung. Aerosol Sci Technol 1986; 5:349–357.

17. **Vidgren M.** Factors influencing lung deposition of inhaled aerosols. Eur Respir J 1994; 4:68–70.
18. **Newman SP.** Aerosol deposition considerations in inhalation therapy. Chest 1985; 88:152S–162S.
19. **Lewis RA, Fleming JS.** Fractional deposition from a jet nebulizer: How it differs from a metered-dose inhaler. Respir Med 1985; 79:361–367.
20. AARC Aerosol Consensus Statement—1991. Respir Care 1991; 36:916–921
21. **Orens DK, Kester L, Fergus LC, Stoller JK.** Cost impact of metered-dose inhalers vs small volume nebulizers in hospital patients: The Cleveland Clinic experience. Respir Care 1991; 36:1099–1104.
22. **AARC Clinical Practice Guidelines:** Selection of an aerosol delivery device for neonatal and pediatric patients. Respir Care 1995; 40(12):1325–1335.
23. **Newman SP.** Aerosol generators and delivery systems. Respir Care 1991; 36:939–951.
24. **Kacmarek RM, Hess D.** The interface between patient and aerosol generator. Respir Care 1991; 36:952–976.
25. **Cleveland Clinic Department of Pulmonary and Critical Care Medicine, Section of Respiratory Therapy.** Metered-dose inhaler instructions (patient education material). 1996.
26. **Kacmarek RM.** Humidity and aerosol therapy. In Pierson DJ, Kacmarek RM, editors. Foundations of Respiratory Care. New York: Churchill Livingstone, 1992: 793–824.
27. **Heimer D, Shim C, Williams H.** The effects of sequential inhalations of metaproterenol aerosol in asthma. J Allergy Clin Immunol 1980; 66:75–77.
28. **Pederson S.** The importance of a pause between the inhalations of two puffs of terbutaline from a pressurized aerosol with a tube spacer. J Allergy Clin Immunol 1986; 77:505–509.
29. **Crompton GK.** Clinical use of dry powder systems. Eur J Respir Dis 1982; 122 (Suppl):96s–99s.

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