Survey of Aerosol Delivery Techniques to Spontaneously Breathing Tracheostomized Children

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BACKGROUND: Therapeutic inhaled aerosols are often delivered to spontaneously breathing tracheostomized children. Although aerosol delivery can be affected by several factors, no recommendations for device/drug formulation choice are available. We hypothesized that practice modalities will vary among different institutions. METHODS: The respiratory care departments in institutions in the United States that train pediatric pulmonologists were surveyed regarding their practices of delivering aerosols to spontaneously breathing tracheostomized children. Characteristics of the institution; use of metered-dose inhalers (MDIs), nebulizers, and dry powder inhalers; use of a resuscitation bag to aid aerosol delivery (assisted); types of medication used; and factors affecting choice of delivery method were recorded. RESULTS: Of the invited institutions, 81% (38/47) participated, with 68% of them being freestanding children's hospitals. MDIs were used by 92% of the institutions surveyed, with similar use of unassisted (32%, with 83% of them using spacers), assisted (34%, with 100% of them using non-valved spacers), and both techniques (34%). Nebulizers were used by 97% of the institutions surveyed, with all using unassisted and 32% also using assisted technique. Tracheostomy aerosol mask was the most commonly used interface (89%). Assisted technique for either MDI or nebulizer was used by 68% of the institutions surveyed, with similar use of flow-inflating bag, self-inflating bag, and both devices. Types of inhaled medications utilized by surveyed institutions included aerosolized antibiotics (82%), corticosteroids (100%), short-acting β agonists (100%), combination therapy (32%), and mucolytics (84%). Dry powders were not used. Patient cooperation was the most frequent and single most important factor influencing the choice of delivery method. CONCLUSIONS: A wide variation in practice of delivering aerosols to spontaneously breathing tracheostomized children was noted. In-vivo and in-vitro studies are needed to support clinical recommendations. *Key words: tracheostomy, metered-dose inhaler, spacer, valved holding chamber, nebulizer, children, aerosol, survey.* [Respir Care 2012;57(8):1234–1241. © 2012 Daedalus Enterprises]

Introduction

Tracheostomy in children is commonly performed for either pulmonary insufficiency as a direct result of lung disease or secondary to neurologic or neuromuscular disorders, or to treat upper-airway obstruction such as subglottic or tracheal stenosis, tracheomalacia, and craniofacial anomalies.[1]

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Therapeutic inhaled aerosols are frequently used in this population.[2] Bronchodilators, inhaled corticosteroids (ICS), antibiotics, and recombinant human DNase (rhDNase) have all been reported as administered via tracheostomy tube.[3-20] Aerosol delivery devices, including the metered-dose inhaler (MDI), nebulizer, and dry powder inhaler (DPI), have been either adapted or modified for use with an artificial airway.[3-13] The most frequently prescribed medication is the bronchodilator. Short-acting bronchodilators are indicated for acute relief of bronchospasm. They are also given in conjunction with airway clearance modalities to promote secretion removal.[21-23] ICSs are used on a scheduled basis to reduce airway inflammation, while inhaled antibiotics are typically administered intermittently to treat infection. The use of rhDNase has been reported in those with a tracheostomy for the treatment of mucus plugs and atelectasis.[20]

Although a consensus statement regarding care of the child with a tracheostomy is available, there is little discussion about aerosolized medications, with no mention of delivery device recommendations.[24] According to that consensus, the use of drugs typically used in resuscitation maneuvers through an endotracheal tube (eg, naloxone, epinephrine) is considered reasonable. The consensus cautions about potential toxicity of delivering via tracheostomy drugs approved for use in children with a face mask interface. The same group suggested that pharmacokinetics of inhaled drugs through tracheostomy was an area in need of research. However, more than a decade later the state of the science has not advanced.

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There are several case reports showing different ways of delivering aerosols to spontaneously breathing tracheostomized pediatric[3-5] and adult patients.[6-12] However, clinical data comparing optimal conditions for aerosol delivery are not available. In vitro data have provided some insight into the intricacies of aerosol delivery through tracheostomies. Those studies showed that interface, presence of bias flow, use of a resuscitation bag to provide larger V_T, and type of add-on device significantly affect the amount of delivered drug.[25-28] Animal data are in agreement with these findings.[29]

Patient ability is considered to be the primary factor when selecting an aerosol device for a child without an artificial airway.[30] However, both parent and physician preference, as well as availability, also influence the choice of device. Currently there are no available recommendations to aid in the choice of the delivery device used to administer inhaled aerosols via tracheostomy. Several studies have reported on the variability of other respiratory care practices among different institutions.[31-33] Additionally, research shows that freestanding children's hospitals treat more complex patients than do general acute-care hospitals.[34] We hypothesize that differences in practice might also be present for aerosol delivery to spontaneously breathing tracheostomized children. The purpose of this study was to describe current use patterns of delivering aerosols to spontaneously breathing pediatric patients with a tracheostomy.

QUICK LOOK

Current knowledge

Therapeutic inhaled aerosols are often delivered, via several techniques, to spontaneously breathing children with tracheostomy, but no recommendations for device/drug formulation choice are currently available.

What this paper contributes to our knowledge

Considerable differences in aerosol delivery techniques were found between the surveyed institutions. Several institutions reported using practices that have been reported to decrease aerosol delivery efficiency. Validated objective measurements to aid in the device selection process are lacking.

Methods

Survey

A survey tool was developed by the authors (see Appendix 1 in the supplementary materials at http://www.rcjournal.com). It addressed institution characteristics; MDI, jet nebulizer, and DPI devices and techniques; inhaled medications; factors influencing device selection; and use of objective measurements.

Institution characteristics consisted of regional location and hospital size and type. Location was described as West, Midwest, South, or Northeast, and was based on the United States Census Bureau regions map.[35] Hospitals were classified in the following size categories: $<$ 100 beds, 100–299 beds, 300–499 beds, and $\geq$ 500 beds. Hospitals were also classified as either freestanding children's hospitals or not.

Specific methods for MDI, jet nebulizer, or DPI administered to spontaneously breathing pediatric patients with a tracheostomy were included. The type of resuscitation bag used with assisted methods, such as hyperinflation or manual bagging, was reported. Hyperinflation was defined as the use of a resuscitation bag or other device in conjunction with aerosolized medications for the purpose of increasing the inhaled tidal volume (ie, manual bagging or manual ventilation).[31,32] Examples of different inhalation

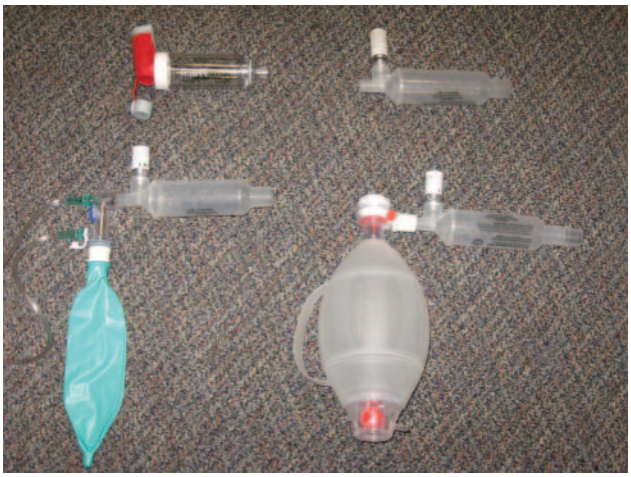

Fig. 1. Examples of devices used with metered-dose inhalers. From left upper to right lower: valved holding chamber (unassisted); spacer (unassisted); spacer with flow-inflating bag (assisted); and spacer with self-inflating bag (assisted).

techniques and devices can be seen in Figures 1 and 2. Brand and type of spacer or holding chamber used with MDI were noted, as well as brand and type of jet nebulizer.

The delivery device used with different classes of inhaled medications was documented, and included antibiotics, ICS, long-acting bronchodilators, short-acting bronchodilators, combination ICS plus long-acting bronchodilator, and mucolytics.

The single most important factor used to determine device choice when more than one delivery device was available for the same medication class was posed as an open-ended question. Factors influencing device choice were rated on importance, and included convenience, cost, cooperation, family preference, insurance, medication availability for specific devices, objective measurements, patient age, physician preference, and respiratory therapist preference. Each item was ranked using a Likert scale of 1–5, with 5 considered the most important and 1 being the least important. We inquired about the single most important factor to help decide the delivery method of choice. We also inquired about the use of objective measurements to assist with device selection.

Survey Protocol

Inclusion criteria were hospitals located in the United States with an Accreditation Council for Graduate Medical Education pediatric pulmonary fellowship program. The rationale behind surveying this group was that pediatric pulmonologists take care of spontaneously breathing tracheostomized children who are prescribed inhalation therapy. The strategy of assessing practice at training/teaching institutions provided us with a more uniform picture of what is being taught to prescribers of these therapies. The use of a less focused sample could have potentially introduced more confounding variables. There were 47 institutions that met this requirement. The respiratory care department of affiliated hospitals was contacted by telephone to participate in the survey. The department director or designee was invited to share the department's practices for administering aerosols to spontaneously breathing pediatric patients with a tracheostomy. Potential participants were informed of the purpose of the survey and that responses would be reported anonymously. If a response was not received after 3 attempts to contact an institution, participation was considered declined. All surveys were administered by the same author (LDW). The protocol was submitted to the local institutional review board and was exempted from review.

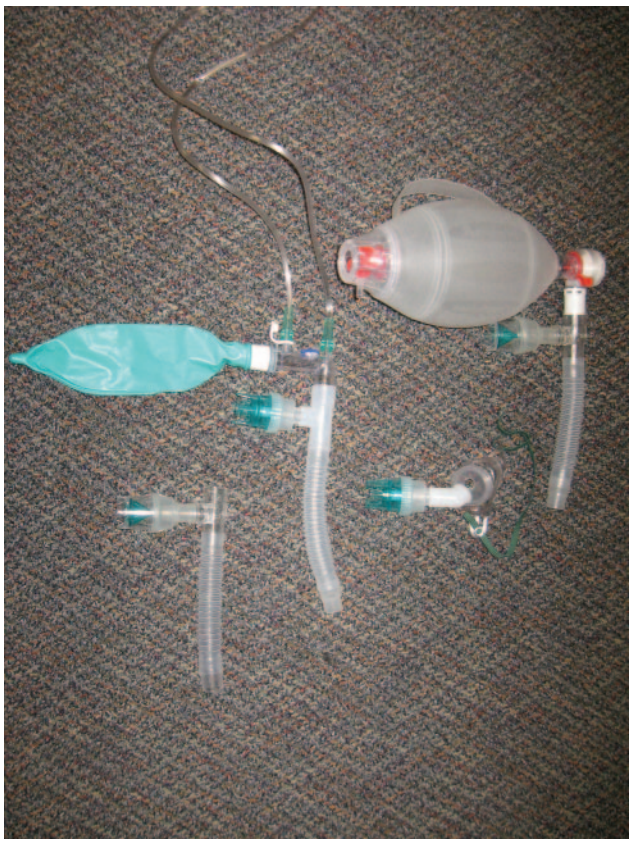

Fig. 2. Examples of nebulizer devices. From top to bottom: continuously operated jet nebulizer placed between a self-inflating resuscitation bag and a 6-inch corrugated tube (assisted); jet nebulizer with tracheostomy mask (unassisted); jet nebulizer placed between a flow-inflating resuscitation bag and a 6-inch corrugated tube (assisted); and jet nebulizer connected to a 6-inch corrugated tube (unassisted).

Statistics

Descriptive statistics were used to analyze the collected data. Nominal variables were compared with the Fisher

Table 1. Spacers and Valved Holding Chambers Used by Surveyed Institutions

	Manufacturer	No.
Spacers		
Unknown brand	Unknown	10
AeroChamber MV	Monaghan Medical, Plattsburgh, New York	10
MiniSpacer	Thayer Medical, Tuscon, Arizona	3
Ace	Smiths Medical, Dublin, Ohio	1
Valved Holding Chambers		
AeroTrach*	Monaghan Medical, Plattsburgh, New York	17
Optichamber	Philips Respironics, Murrysville, Pennsylvania	2
Vortex*	Pari Respiratory Equipment, Midlothian, Virginia	1

* One institution used both Vortex and AeroTrach.

exact test (2×2 contingency tables) and chi-square statistics ($n \times n$ contingency tables) to explore differences among regions and between freestanding children's hospitals and others. The Kruskal-Wallis test was utilized to compare differences in factors determining the choice of the delivery device among regions and between freestanding children's hospitals and others. The Dunn test was used when multiple comparison analysis was required. A P value $< .05$ was considered statistically significant.

Results

Characterization of the Participating Institutions

The response rate was 81%, with 38/47 hospitals participating. The geographic distribution of the institutions was balanced, with 8 located in the West, 9 located in the South, 11 located in the Midwest, and 10 located in the Northeast. The majority were freestanding children's hospitals (68%). The median size was 100–299 range of beds, with 2 hospitals having $<$ 100 beds, 21 with 100–299 beds, 8 with 300–499 beds, and 4 hospitals having $\geq$ 500 beds.

Metered-Dose Inhalers

Use of MDI for spontaneously breathing pediatric patients with a tracheostomy was reported by 35/38 (92%) of participating hospitals, with 11/35 (32%) utilizing unassisted method only, 12/35 (34%) using assisted method only, and 12/35 (34%) using both methods. Of those utilizing unassisted methods, a valved holding chamber and a non-valved spacer were used by 19/23 (83%) and 4/23 (17%), respectively. All of those reporting assisted methods used non-valved spacers. Specific brands of valved holding chambers and non-valved spacers are listed in Table 1.

Nebulizers

Almost all the institutions reported using nebulizers (37/38, 97%). Most hospitals utilized unassisted delivery methods (25/37, 68%), while some used both unassisted and assisted techniques (12/37, 32%). However, none of the institutions used assisted delivery only.

The tracheostomy mask was the most common interface used for unassisted method 33/37 (89%), with one institution also using a T-piece as a second interface. Three other institutions used a T-piece, each with different configurations (unspecified, 6-inch corrugated tubing and capped T-piece, uncapped T-piece and 6-inch corrugated tubing with a 1-way valve). One institution reported jet nebulizer administration in-line of the circuit of a heated tracheostomy collar.

Five institutions used 2 different brands of nebulizer, with 3 institutions using 2 different types of nebulizer. The following types of nebulizers were reported: breath-actuated jet nebulizer (4, all operated in continuous mode), breath-enhanced jet nebulizer (2, but one had the inspiratory valve removed), continuously operated jet nebulizer (34), and vibrating mesh nebulizer (1). Specific brands are listed in Table 2.

Dry Powder Inhalers

No DPI use for children with a tracheostomy was reported by any institution.

Assisted Delivery

Sixty-eight percent (26/38) of the institutions used hyperinflation for assisted technique with either MDI or jet nebulizer. Of those using hyperinflation, 10 institutions (10/26, 38%) used flow-inflating bag only (including one institution that used 2 different techniques), 8/26 (31%) institutions used self-inflating bags only (including one institution that used 2 different techniques), and 8/26 (31%) institutions used both. Use of a manometer was more frequent for flow-inflating bags (17/19, 89%) than for self-inflating bags (8/17, 47% $P = .01$).

Table 2. Nebulizer Operating Principles and Brands Used by Surveyed Institutions

	Manufacturer	No.
Continuously Operated Jet Nebulizer		
MistyMax	Cardinal Health, Dublin, Ohio	13
Salter	Salter Labs, Arvin, California	6
Acorn	Vital Signs, Totowa, New Jersey	6
Hudson	Hudson RCI, Temecula California	4
Unknown brand	Unknown	4
VixOne	Westmed, Tucson, Arizona	2
Breath Enhanced Jet Nebulizer		
Pari	Pari Respiratory Equipment, Midlothian, Virginia	2
Breath Actuated Jet Nebulizer		
AeroEclipse BAN	Monaghan Medical Corporation, Plattsburgh, New York	4
Vibrating Mesh Nebulizer		
Aeroneb	Aerogen, Mountain View, California	1

Table 3. Importance of Different Factors That Influence Delivery Device Selection

	Most Important				Least Important	Mean ± SD
Likert scale	5	4	3	2	1	
Convenience	8	15	11	2	2	3.7 ± 1.0
Cost	9	11	13	2	3	3.6 ± 1.2
Cooperation	22	6	7	1	2	4.2 ± 1.2
Family preference	6	17	9	3	3	3.5 ± 1.1
Insurance	9	8	8	3	10	3.1 ± 1.5
Medication device availability	19	10	7	0	2	4.2 ± 1.1
Objective measurement	7	17	9	5	0	3.5 ± 0.9
Patient age	8	10	9	6	5	3.3 ± 1.3
Physician preference	11	11	10	3	3	3.6 ± 1.2
Respiratory therapist preference	7	16	8	4	3	3.5 ± 1.2

Medication/Delivery Device

The use of inhaled antibiotics via jet nebulizer was reported by 31/38 (82%) of the institutions surveyed. ICSs were utilized by all the institutions, with 4/38 (11%) using MDI only, 6/38 (16%) jet nebulizer only, and 28/38 (73%) employing both devices. Only 24% (9/38) used long-acting bronchodilators via jet nebulizer. Short-acting β agonists were used by all the institutions, with 3/38 (8%) reporting MDI only, 4/38 (11%) jet nebulizer only, and 31/38 (81%) using both. Combination therapy (long-acting bronchodilator plus ICS) was utilized by 32% (12/38) of the institutions, with 10/12 (83%) using MDI only, none using jet nebulizer only, and 2/12 (17%) using both devices. Mucolytics via jet nebulizer were used by 84% (32/38) of the institutions.

Factors Affecting Choice of Delivery Device

When more than one delivery device was available for the same medication, device preference by the respiratory therapist was more frequently stated than other reasons ($P < .02$), except for physician preference ($P = .53$ between device and physician preference). Institutions identified the following as having an impact on selection of a device: device preference (15/38, 39%), physician preference (8/38, 21%), patient factors (5/38, 13%), home regimen (5/38, 13%), convenience/time (4/38, 11%), and medication (1/38, 3%).

The most important factors used to select a device were patient cooperation and medication availability for specific devices (mean of 4.2). Ratings for all factors can be seen in Table 3. Cooperation was deemed the single most important factor in choosing a device by 11/38 (29%) of all institutions. Others chose physician preference (8/38, 21%), objective measurements (7/38, 18%), medication availability (6/38, 16%), family preference (3/38, 8%), convenience (2/38, 5%), and cost (1/38, 3%). No hospital chose insurance, patient age, or respiratory therapist preference.

Objective measurements were used by several institutions to aid the selection of delivery device, and included peak flow, resting tidal volume, assessment of breath sounds, respiratory rate, pulse oximetry, transcutaneous CO_2, response to treatment, evaluation of cough effort/secretion clearance, and assessment scoring.

Regional and Freestanding Hospitals Versus Other Comparison

No differences were found between freestanding children's hospitals and others for any of the surveyed questions. The only regional difference found was a higher use of hyperinflation technique in the Midwest than in the Northeast ($P = .025$).

Discussion

Spontaneously breathing children with a tracheostomy are often prescribed inhaled medications. However, specific recommendations regarding aerosol devices and techniques are not available. We surveyed the respiratory care departments of United States hospitals that sponsor Accreditation Council for Graduate Medical Education accredited pediatric pulmonology fellowship programs about their practices regarding aerosol delivery to spontaneously breathing children with a tracheostomy. Considerable differences in practice were noted among institutions. However, little regional variation or differences between freestanding children's hospitals and other institutions were observed. Several institutions reported practices that had previously been reported to decrease drug delivery efficiency[25-29] Cooperation and device preference/availability were both considered very important factors in the device selection process.

Metered-Dose Inhalers

The vast majority of institutions surveyed used MDIs. The proportion of hospitals reporting unassisted, assisted, and both methods were similar. Of those using unassisted technique, a valved holding chamber was most commonly utilized. All institutions using assisted methods administered MDI with a non-valved spacer. As previously noted, differences in practice could result in variation of the amount of delivered albuterol.[25-29] Recent in vitro studies with a spontaneously breathing tracheostomy model reported that manual bagging resulted in a significant decrease in the amount of albuterol available at the carina.[26,27] These findings are in agreement with a previously reported animal study.[29] Chavez et al also found that a non-electrostatic valved holding chamber, the AeroTrach, was the most efficient delivery device.[26] Most of the case reports on aerosol delivery in spontaneously breathing individuals with artificial airways utilized MDI and spacer/valved holding chamber.[3-12] Several factors, such as device material and volume, delay between actuation and inhalation, and others, have been reported to affect albuterol delivery.[36] Picuitto et al compared albuterol delivery through a tracheostomy tube in a spontaneously breathing adult model.[25] They reported that a jet nebulizer with T-piece was more effective than the tracheostomy mask (up to 2-fold difference), and the addition of bias flow significantly decreased albuterol output (almost 4-fold difference). They also noted that an MDI used with a valved type spacer was more efficient

Nebulizers

Nebulizers were frequently used, with the majority of institutions administering unassisted methods almost exclusively. The most commonly used interface was the tracheostomy mask. Another unassisted technique reported was the T-piece, with different configurations. Piccuito et al, in an adult model, compared the use of T-piece and tracheostomy mask and found that the former was better at delivering albuterol.[25] Another in vitro study, using a pediatric model, from our institution, confirmed their findings.[28] One institution placed the nebulizer in-line with a heated tracheostomy collar. Although no in vivo data are available, in vitro studies have shown that the use of additional continuous flow and heated humidity results in a decrease of delivered medication.[25] Different nebulizer types were used, including continuous jet, breath-enhanced, and breath-actuated. Breath-enhanced nebulizers are known to have a higher drug output than continuously operated nebulizers.[37] Breath-actuated nebulizers have the advantage of delivering medication only during inhalation, thus avoiding waste of aerosol.[38] It was interesting to note that breath-enhanced and breath-actuated nebulizers were used in such a way that negates the advantages of these technologies. By operating the nebulizers in this manner they are converted into expensive, continuously operated nebulizers. In our in vitro study, the breath-enhanced nebulizer had the best performance when tested with a larger tidal volume (310 mL), and the breath-actuated nebulizer was inefficient at low tidal volumes (80 mL).[28]

Dry Powder Inhalers

No institution reported DPI administration via tracheostomy. We speculate that DPIs are not used in this population due to inability to generate enough flow and risk of clogging the artificial airway with powder. However, no hard data are available to support this. Two groups reported successful use of DPI in tracheostomized adult patients.[10,13]

Hyperinflation

Most institutions used hyperinflation with a manual resuscitation bag, but with different techniques. A pressure manometer was used more frequently with flow-inflating bags than with self-inflating. While manometers are available for use with self-inflating bags, they can be cumbersome. Additionally, self-inflating bags have a pressure-relief valve to prevent over-distention. As previously

discussed, the use of assisted bagging with MDI/spacer could lead to decreased drug output.[26,29] In a recent in vitro study using the same model as Chavez et al,[26,27] we found that bagging nebulized aerosol increased albuterol delivery to the carina when a T-piece was used as the interface.[28]

Medication/Delivery Device Used

Both ICS and short-acting bronchodilators were used by all institutions. A high percentage of institutions also used inhaled antibiotics. Most used both MDI and jet nebulizer for delivering short-acting β agonists. A relatively large number of institutions used long-acting bronchodilators, either alone or in combination with ICS. Considerable use of mucolytic agents was also noted. The documentation of current practices is important, considering that clinical trials for the use of certain inhaled medications in this patient population may not be available in the future.

Factors Affecting Choice of Device

The available literature suggests patient ability as the primary consideration for device selection in children.[30] For tracheostomized children, the institutions we surveyed regarded cooperation a vital factor as well, but medication/device availability and physician preference were also deemed important. Several institutions reported the use of different objective measurements to determine device selection. However, none have been validated in either in vitro or in vivo models. These results highlight the need for new and/or outcome validated measurements for children with a tracheostomy.

Regional and Freestanding Hospitals Versus Other Comparison

Because freestanding children's hospitals tend to care for more complex patients, we expected to find differences in current practice; however, none were found. We also evaluated regional differences in practice, and the only detected distinction was the higher use of hyperinflation in the Midwest compared to the Northeast. The importance of this does not appear to be evident.

The results of this survey should help practitioners become aware of institutional differences in regard to delivering aerosols to spontaneously breathing tracheostomized children. Practitioners should also be aware that some practices can be detrimental to efficiency of the devices/interfaces used. Finally, these findings should stimulate practitioners to develop research projects with the aim of finding the most efficient way to deliver aerosols to this population.

It is difficult to assess the impact of the variability noted in practice. One of the limitations is that there are no clear outcomes used to measure the efficiency of these devices. It is possible that the use of large medication doses may overcome the inefficiency of some systems, but the question is, at what cost? The financial implications might be minimal with albuterol but substantial with other compounds. Using more efficient devices might result in lower treatment times, lower drug doses, and more cost-efficient drug utilization. This variability in practice could be reduced through the development of specific guidelines.

Best practice guidelines are not available, and the in vivo/in vitro data are limited. However, several recommendations can be made regarding the best way to deliver aerosols with each specific device to tracheostomized spontaneously breathing children. When using nebulizers the practitioner should keep in mind that:

- A T-piece interface is preferred to a tracheostomy mask.
- The use of additional flow (ie, in-line of a tracheostomy collar) leads to a decrease in delivery efficiency.
- Breath-actuated nebulizers might not be triggered at low tidal volumes.
- The use of a resuscitation bag can enhance drug delivery.[25,28]

When using MDIs the practitioner should keep in mind that:

- A valved spacer is preferred to a non-valved spacer.
- The use of a resuscitation bag can decrease drug delivery.[25-27,29]

The use of DPIs is not recommended.

Conclusions

Considerable differences in practice were noted among institutions. However, little regional variation or differences between freestanding children's hospitals and other institutions were observed. Several institutions reported practices that had previously been reported to decrease drug delivery efficiency. Validated objective measurements to aid in the device selection process are lacking. In vitro and in vivo studies comparing the effect of different devices, different patient interfaces, and different drug formulations on drug delivery are needed. These studies will provide the scientific background that will assist in the development of specific recommendations for the administration of inhaled aerosols to spontaneously breathing tracheostomized children.

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