

The Conversion to Metered-Dose Inhaler With Valved Holding Chamber to Administer Inhaled Albuterol: A Pediatric Hospital Experience

John W Salyer RRT-NPS MBA FAARC, Robert M DiBlasi RRT-NPS, Dave N Crotwell RRT-NPS, Charles A Cowan MD, and Edward R Carter MD

BACKGROUND: Metered-dose inhalers with valved holding chambers (MDI-VHCs) have been shown to be equivalent to small-volume nebulizers (SVNs) for the delivery of bronchodilators in children. At Seattle Children's Hospital and Regional Medical Center we sought to implement the conversion from SVN to MDI-delivered albuterol in nonintubated patients receiving intermittent treatments. **METHODS:** There were 4 distinct interventions used to plan and implement this conversion program: (1) literature review, (2) product selection, (3) policy and operational changes, and (4) staff training. Bronchodilator administration guidelines and clinical pathways for asthma and bronchiolitis were revised to recommend MDI-VHC use in lieu of SVNs. Computerized physician order sets were amended to indicate MDI-VHC as the preferred method of delivering inhaled albuterol in children with asthma and bronchiolitis. Data from administrative case mix files and computerized medication delivery systems were used to assess the impact of our program. **RESULTS:** MDI-VHC utilization increased from 25% to 77% among all non-intensive-care patients receiving albuterol, and from 10% to 79% among patients with asthma ($p < 0.001$). Duration of stay among patients with asthma was unchanged after conversion to MDI-VHC ($p = 0.53$). **CONCLUSIONS:** Our program was very successful at promoting the use of MDI-VHC for the administration of albuterol in our pediatric hospital. Duration of stay among patients with asthma did not change during or since the implementation of this program. *Key words:* aerosol, albuterol, metered-dose inhaler, holding chamber, nebulizer, neonatal, pediatric. [Respir Care 2008;53(3):338–345. © 2008 Daedalus Enterprises]

Introduction

Inhaled bronchodilators are one of the most frequently prescribed medications for children hospitalized with respiratory disorders. Historically, the most common method

of administration has been via small-volume nebulizer (SVN). The methods and effectiveness by which these medications are administered to pediatric patients has been evaluated extensively over the last decade. There is a large body of literature that indicates that the metered-dose inhaler with valved holding chamber (MDI-VHC) is at least as effective as SVN for the delivery of bronchodilators to infants, children, and adults (see literature review in the

John W Salyer RRT-NPS MBA FAARC, Robert M DiBlasi RRT-NPS, and Dave N Crotwell RRT-NPS are affiliated with the Department of Respiratory Care, Children's Hospital and Regional Medical Center, Seattle, Washington. Edward R Carter MD and Charles A Cowan MD are affiliated with the Department of Pediatrics, University of Washington, Seattle, Washington. Mr DiBlasi is also affiliated with the Center for Developmental Therapeutics, Seattle Children's Hospital Research Institute, Seattle, Washington.

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Correspondence: John W Salyer RRT-NPS MBA FAARC, Department of Respiratory Care, Children's Hospital and Regional Medical Center, 4800 Sandpoint Way NE, Seattle WA 98105. E-mail: john.salyer@seattlechildrens.org.

Results section). In the past it was thought that young children were unable to use MDIs because they could not coordinate inhalation and that these devices would not be effective in delivery of bronchodilators. However, with the use of VHCs with face masks, infants and small children can now be successfully treated via MDI. In adults, successful conversion from SVN to MDI-VHC has been reported to have reduced supply costs, labor costs, and total numbers of treatments given.¹ We hypothesized that it might be possible to realize some of these benefits at our institution if bronchodilator administration were converted from primarily SVN to MDI-VHC. Thus, we introduced educational interventions, operational policies, and management interventions that would promote the use of MDI-VHC and discourage the use of SVN for the administration of inhaled albuterol in our facility.

Methods

The initial planning and implementation of this project took place from September through November 2005. Children's Hospital and Regional Medical Center, Seattle, is a tertiary pediatric medical center. There are 254 in-patient beds and approximately 11,000 admissions per year. The hospital is not physically or administratively connected with any other hospital and has an academic affiliation with the University of Washington School of Medicine. The respiratory therapy department has 54 full-time equivalents and 61 employees. The administration of inhaled bronchodilators to patients outside the intensive care units is a shared responsibility between the nursing staff and the respiratory care department.

A team was formed to develop and implement interventions to promote the use of MDI-VHC, consisting of the medical director of respiratory care (ERC), the administrative director of respiratory care (JWS), the clinical coordinator of respiratory care (DNC), a recognized clinical expert in respiratory care practices who was also an educator and researcher (RMD), and a hospitalist for the general medical in-patient units (CAC).

This project had 4 distinct interventions: (1) literature review, (2) product selection, (3) policy and operational changes, and (4) staff training.

Our hospital already had in place specific treatment protocols for the administration of bronchodilators to patients with asthma and bronchiolitis. These protocols were based on use of a clinical scoring system to assess need for and response to bronchodilators. Patients were scored before and after treatment with albuterol, and their scores determined their progression through the pathways, including frequency and dosage of bronchodilators. This clinical scoring system that we used has been shown to have a high inter-rater reliability.² We revised these clinical pathways to indicate that MDI-VHC was the preferred method of

administration of albuterol, though clinicians could still choose to administer the drug via SVN.

The respiratory care department policy and procedure for the administration of bronchodilators was extensively revised and included the following statements:

All intermittent inhaled bronchodilator therapy should be administered via MDI with valved holding chamber. Studies have proven that MDIs with valved holding chambers are as good as or better than SVN for delivery of bronchodilators to spontaneously breathing infants and children, whether patients are cooperative or not. Parents and patients prefer MDIs when they are compared to nebulizers.

If physicians order intermittent bronchodilators via SVN, the respiratory therapist or nurse should contact the physician and attempt to get the method of administration changed to MDI with valved holding chamber.

In 2003 Children's Hospital and Regional Medical Center converted to a computerized physician order entry system. This system required all physicians to enter all orders for patient care in the computer system. The computerized physician order sets were revised to make MDI-VHC the default mode of delivering aerosolized bronchodilators in children with asthma and bronchiolitis. Physicians who wished to order SVN in lieu of MDI-VHC had to "drill" further down into the orders hierarchy.

Dosing equivalency for albuterol via SVN versus MDI-VHC was set as 2.5 mg of albuterol via SVN = 4 puffs via MDI, and 5 mg via SVN = 8 puffs via MDI. This dosing equivalency was based on a consensus of expert opinion within the hospital and included input from respiratory therapists (RTs), pharmacists, and pediatric pulmonologists. The conversion to MDI-VHC from SVN was announced in various hospital publications that were distributed within and outside the hospital in an attempt to inform the medical staff about these pending system changes. An information packet that described the reasons for the conversion, including a bibliography, was created and made available to clinicians in the community upon request. It included reprints of selected literature that supports the use of MDI-VHC.

RTs and nurses were informed of the proposed conversion via lectures, printed materials, e-mail messages, and staff meetings. MDI-VHC training was made part of mandatory nursing skills training and included didactic training on how MDI-VHC works, how effective it is, dosing equivalency, and how to use the device with an emphasis on the importance of an effective face mask seal and the effects air entrainment would have on overall medication delivery.³ In addition, members of the RT staff verified

individual nursing competency with MDI-VHC, using one-on-one instruction and return demonstration over a period of months at the onset of the program. Return demonstration consisted of a nurse doing an actual MDI treatment on a patient while being observed by an RT.

VHCs were added to the supply distribution system (Omniceil, Mountain View, California), which includes computerized supply carts on each nursing unit throughout the hospital.

Outcomes of interest included albuterol administration costs, proportions of patients who received albuterol via SVN and MDI-VHC, duration of stay among patients with asthma, and number of albuterol treatments per admission. Data sources included administrative case mix files and our electronic medication administration record, which is a computerized repository of information about all administered medications. In collaboration with the information technology staff, a customized query was developed that lists the routes of administration for all doses of albuterol given to any patient.

Our costing model was developed with our own supply costs for a multi-dose vial of albuterol (\$1.94) an albuterol MDI canister (\$2.45), a VHC with mask (\$13.65), and an SVN with mask (\$2.36). Our labor costs for the 2 methods of administration were calculated with our own relative value units for an MDI treatment (13.2 min) and an SVN treatment (20.4 min). Salary expense was calculated with an average hourly rate of \$28.00. This was multiplied by 1.3 to adjust for benefits costs (30%), and then divided by 60 to develop a salary cost per minute of \$0.61. Treatment administration costs were modeled by calculating supply and labor cost for every treatment given during the study period, with the variables described above. Assumptions of the model included 3 changes of SVN with mask, one multi-dose vial of albuterol per patient, and one MDI-VHC per patient. Total administration costs for each method of administration for each study period were then added together and divided by the total albuterol treatments during that period, yielding an average administration cost per albuterol treatment.

These interventions were implemented over a period of 3 months, from September through November of 2005. We then analyzed the routes of administration of albuterol in 2 groups of patients: (1) all non-intensive-care patients who received albuterol, and (2) non-intensive-care patients ≥ 2 years of age with a primary diagnosis of asthma. We selected all non-intensive-care patients who received albuterol because (1) albuterol given in the intensive care units to intubated patients is already administered with an MDI, via bagging, with a spacer,^{4,5} and (2) we were interested in the broad impact of our interventions. We also selected nonintensive-care-unit patients with asthma ≥ 2 years of age because (1) much of the research done regarding the use of VHC-MDI was done in patients with

asthma, and (2) this gave us a fairly homogenous group of patients in whom we could measure some process and outcome measures with confidence.

We analyzed the time period of January through May for each year from 2004 through 2006. January through May is historically our busiest time of the year for administering inhaled albuterol. We then determined the route of administration of all intermittently administered albuterol for both groups of patients. We excluded any continuously administered albuterol from our analysis. For the group of patients with asthma we also determined duration of stay in 2004, 2005, and 2006.

The differences in proportions of patients who received SVN versus MDI-VHC during the 3 time periods studied were compared with chi-square analysis, with significance established as a $p < 0.05$. Mean duration of stay among patients with asthma and mean number of albuterol treatments per patient were compared with the Kruskal-Wallis ranked sum test, with significance also set at $p < 0.05$.

Results

Literature Review

The literature revealed that in spontaneously breathing infants and children with moderate-to-severe asthma, bronchodilator delivery via MDI-VHC has been shown to be equivalent to SVN for the delivery of aerosolized bronchodilators in children⁶⁻¹² and adults.¹³⁻¹⁵ A meta-analysis that included data from over 1,000 children concluded that MDI-VHC was as effective as SVN and may have some advantages in emergency department duration of stay and decreased heart rate over SVN in children.¹¹ Another meta-analysis that included data from approximately 500 pediatric patients concluded, "The use of an MDI-VHC was more effective in terms of decreasing hospitalization and improving clinical score than the use of a nebulizer in the delivery of β agonists to children under 5 years of age with moderate-to-severe exacerbations of wheezing or asthma".¹⁶

Delgado et al conducted a double-blind randomized placebo-controlled trial that evaluated the efficacy of MDI-VHC versus SVN in spontaneously breathing pediatric patients with wheezing, age 2-24 months, in an emergency department.⁶ They found that albuterol (Ventolin, GlaxoSmithKline) delivered via MDI-VHC, compared to SVN, was more efficient, easier to deliver, and resulted in a lower hospital admission rate in patients with severe wheezing episodes.

Fok et al investigated radio-aerosol deposition of a bronchodilator given via SVN versus via MDI-VHC in non-ventilated infants and found that a larger lung dose of drug was delivered to the lung by 2 puffs from an MDI-attached spacer than by 5 min of nebulization via SVN.¹¹

Leversha et al compared the cost and effectiveness of albuterol delivered via MDI-VHCs versus nebulizers in young children (1–4 years old) with moderate-to-severe asthma, and found that the MDI-VHCs were as effective as SVN in improving clinical score, respiratory rate, and oxygen saturation.¹⁰ In addition, fewer children in the MDI-VHC group required hospital admissions, and the use of MDI-VHC resulted in cost savings.

Most of these studies were in wheezy infants/children with asthma and/or bronchiolitis, and they used asthma severity and clinical scoring systems that are subjective in nature. Objective measurements (eg, spirometric measurements and/or pulmonary function testing) might be more useful in determining clinical efficacy. Deerojanawong et al measured pulmonary function in infants and children before and after bronchodilator treatments via both delivery methods.¹⁷ They found that there were no significant differences in pulmonary function test results between the 2 groups.

Recent improvements in face mask and spacer technology have provided VHCs that are constructed from materials that maximize particle deposition, decrease electrostatic charge, and have valve systems that are reportedly sensitive enough for use with patients with low inspiratory flow. Most holding chambers are produced from nonconducting materials (eg, polycarbonate or polyester), which can acquire surface electrostatic charge during manufacture and use. This electrostatic charge creates an attraction that causes an attachment of aerosol particles to the sides of the chamber, which reduces the delivered dose.^{18–20} There are now VHCs that are made of conducting material that is charge-dissipative and minimizes this effect. Rau et al²¹ and Coppolo and colleagues²² demonstrated that VHCs made of charge-dissipative materials can significantly increase drug delivery. One technique suggested for reducing electrostatic charge in chambers not made of conducting material is to rinse the inside of the chamber with detergent solution. However, Rau et al showed that, although rinsing increased total emitted mass and fine-particle mass from some chambers not made of conducting material, those still did not perform as well as chambers made of conducting material without rinsing. This did not appear to improve drug delivery, and the best way to optimize delivery was to use holding chambers made from conducting material.²¹

Most children can master the technique of using an MDI. Minai et al demonstrated that a systematic approach to teaching MDI use to children can result in sustained improvements in technique.²³ Furthermore, pediatric patients and families who had previously used SVNs to administer bronchodilators overwhelmingly preferred MDI-VHCs after using them for a short time.²⁴

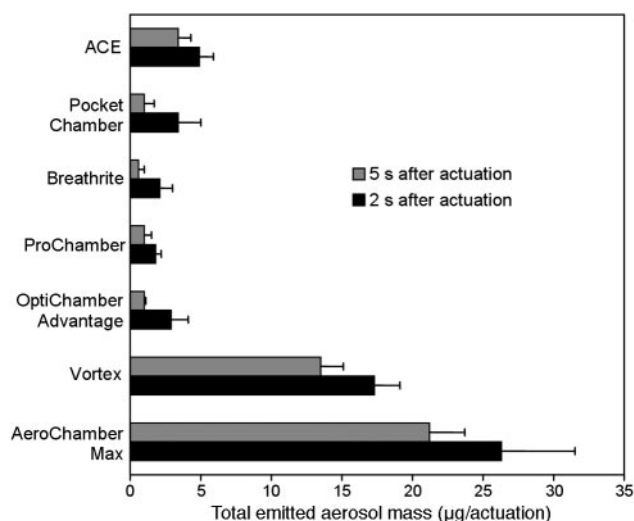


Fig. 1. Aerosol availability of various brands of metered-dose inhaler with valved holding chamber without pre-washing or rinsing. The error bars represent standard deviations. (Adapted from Reference 22.)

Product Selection

The VHC product we selected was the AeroChamber Max (Monaghan Medical, Syracuse, New York). Our reasons for choosing this VHC were (1) the valve design with baffling to improve drug delivery, (2) the visual indication of inspiration and face mask seal via the Flow-VU indicator, (3) the charge-dissipative polymer, and (4) the availability and design of various sizes of mask. We were not particularly concerned about costs, but instead wanted the best-performing device. The AeroChamber Max VHC has a low-resistance one-way “duckbill” valve that is reported to reduce the inspiratory effort required to access the aerosol in the chamber and prevents exhalation into the chamber, thus eliminating rebreathing. Visual observation of the Flow-VU indicator signals successful inhalation through the valve via the silicone face mask and confirms a good mask-to-face seal. The baffling system is designed to trap large particles, thereby reducing oral impaction and minimizing systemic adverse effects. The chamber is constructed from an electrostatic charge-dissipative polymer (nonelectrostatic) that enhances aerosol suspension in the chamber by minimizing adhesion of particles to the chamber wall. In a recent study by Rau et al, the AeroChamber Max VHC performed demonstrably better than a series of VHCs tested in an in vitro model.²¹ The AeroChamber Max had a larger total emitted mass and fine-particle mass than any other chamber tested, with or without washing the chamber (Fig. 1). The models tested included AeroChamber Max, Vortex (Pari Respiratory Equipment, Midlothian, Virginia), OptiChamber Advantage (Respiroincs HealthScan, Cedar Grove, New Jersey), ProChamber (Re-

CONVERSION TO METERED-DOSE INHALER WITH VALVED HOLDING CHAMBER

Table 1. Method of Albuterol Administration for All Nonintensive-Care Patients Who Received Albuterol*

| Method of Administration | Jan–May 2004 | Jan–May 2005 | Jan–May 2006 |
|--------------------------|--------------|--------------|--------------|
| MDI (%) | 25 | 63 | 77 |
| SVN (%) | 75 | 37 | 23 |

*p < 0.001 via chi-square test
MDI = metered-dose inhaler
SVN = small-volume nebulizer

Table 2. Method of Albuterol Administration Among Nonintensive-Care Patients With Asthma Only*

| Method of Administration | Jan–May 2004 | Jan–May 2005 | Jan–May 2006 |
|--------------------------|--------------|--------------|--------------|
| MDI (%) | 9 | 67 | 79 |
| SVN (%) | 91 | 33 | 21 |

*p < 0.001 via chi-square test
MDI = metered-dose inhaler
SVN = small-volume nebulizer

spironics HealthScan, Cedar Grove, New Jersey), Breathrite (Ventlab, Mocksville, North Carolina), PocketChamber (Ferraris Respiratory, Orchard Park, New York), and ACE (DHD Healthcare, Wampsville, New York). The model used a 2-second delay between MDI actuation and the beginning of inspiratory flow, to mimic an uncoordinated patient effort, which we think gives the study additional credibility for us, since uncoordinated patient effort is common in pediatric patients.

Data

Before implementing our conversion program in late 2005, 75% of all intermittent albuterol treatments outside the intensive care unit were administered via SVN (Table 1), and 90% of intermittent albuterol treatments for children with asthma were delivered via SVN (Table 2). By May 2006 the proportion of albuterol delivered via MDI had increased to 77% among all nonintensive-care patients and 79% among nonintensive-care patients with asthma. These changes were statistically significant (chi-square p < 0.001).

The duration of stay among nonintensive-care patients with asthma \geq 2 years of age was not statistically or clinically different before and after the MDI implementation project (Table 3, Kruskal-Wallis p = 0.53).

Our cost model (Table 4) indicated a 21% decrease in total albuterol administration costs from 2004 to 2006 (January through May). The difference in the mean number of albuterol treatments during the 3 study periods was neither

Table 3. Descriptive Statistics on Duration of Stay Among Patients With Asthma*

| | 2004 | 2005 | 2006 |
|------------------------------------|---------------|---------------|---------------|
| Duration of Stay (mean \pm SD d) | 1.4 \pm 0.8 | 1.4 \pm 1.0 | 1.5 \pm 1.0 |
| Count | 471 | 426 | 315 |
| Minimum stay (d) | 1 | 1 | 1 |
| Maximum stay (d) | 5 | 9 | 8 |

*p < 0.53 via Kruskal-Wallis test
Inclusion criteria: $>$ 2 y old, discharge diagnosis of asthma
Exclusion criteria: Any patient who had part of their hospitalization in the intensive care unit

statistically significant nor clinically important (Kruskal-Wallis p = 0.21).

Discussion

There has clearly been a large and sustained change in the way albuterol is administered at our facility. We believe the key factors in the success of this conversion include strong medical leadership, the multidisciplinary nature of this approach, the training of RTs and nurses, and the computerized physician order entry system. The design of our study did not enable us to determine with any certainty which, if any, of these factors was most contributory. Our view is that the largest contributor was the change in the computerized physician order entry system to default to MDI-VHC as the method for albuterol administration. We also believe the extensive training and communications that we did were also important factors.

We had a number of medicine and nursing “champions” who helped to support this transition and worked with members of the medical staff who were reluctant to embrace this change. Not all physicians and nurses agreed with our protocol, but most were very supportive. When we set out to implement this practice change we acknowledged that there would be some physicians, RTs, and nurses who would have difficulty embracing this change. We knew it would be unrealistic to introduce a protocol that did not allow for some degree of individual practice variation in selecting devices. A common concern among hospitals and departments considering implementing change through practice protocols is the inability to get *everyone* to agree to the practice change. We liken this to the concept of sacrificing the good for the perfect. It is unlikely that everyone will agree to any practice guidelines. But our experience implementing this and other protocols has shown us that the overwhelming majority of clinicians respond positively to well-crafted, evidence-based guidelines. Occasionally, a physician would contact the respiratory care department and ask why we were implementing such a change. In anticipation of this, we had prepared

CONVERSION TO METERED-DOSE INHALER WITH VALVED HOLDING CHAMBER

Table 4. Cost Model for Comparison of SVN and MDI-VHC Costs

| | Jan–May 2004 | | Jan–May 2005 | | Jan–May 2006 | |
|---|----------------------------|--------------------------|----------------------------|--------------------------|----------------------------|--------------------------|
| | Treatments (<i>n</i>) | Patients (<i>n</i>) | Treatments (<i>n</i>) | Patients (<i>n</i>) | Treatments (<i>n</i>) | Patients (<i>n</i>) |
| Method of Administration | | | | | | |
| MDI-VHC | 2,474 | 197 | 5,080 | 390 | 6,178 | 401 |
| SVN | 7,441 | 714 | 2,966 | 404 | 1,843 | 295 |
| Device Costs (\$) | | | | | | |
| SVN with mask \$2.36 each × 3 daily SVN changes = \$7.08 × number of patients | 5,055 | | 2,860 | | 2,089 | |
| Albuterol multi-dose vial \$1.94 each × number of patients | 1,385 | | 784 | | 572 | |
| MDI albuterol canister \$2.45 each × number of patients | 483 | | 956 | | 982 | |
| Valved holding chamber \$13.65 each × number of patients | 2,689 | | 5,324 | | 5,474 | |
| Labor Costs (\$) | | | | | | |
| MDI-VHC = 13.2 × \$0.61 = \$8.05 × number of treatments | 19,916 | | 40,894 | | 49,733 | |
| SVN = 20.4 × \$0.61 = \$12.44 × number of treatments | 92,566 | | 36,897 | | 22,927 | |
| Total Costs, Treatments, and Change in Cost Per Treatment | | | | | | |
| Total albuterol treatment costs (supplies + labor) (\$) | 122,094 | | 87,714 | | 81,777 | |
| Total number of treatments | 9,915 | | 8,046 | | 8,021 | |
| Total cost per treatment (\$) | 12.31 | | 10.90 | | 10.20 | |
| Percent reduction in cost per treatment, compared to Jan–May 2004 | NA | | 13 | | 21 | |

MDI = metered-dose inhaler
VHC = valved holding chamber
SVN = small-volume nebulizer
NA = not applicable

educational information in the form of a brief overview of the program and selected scientific literature, which we would provide.

The duration of stay of our nonintensive-care patients with asthma was very low (1.4 d) before the implementation of this program and remained low after the conversion (1.5 d). If the MDI-VHC was a less effective way of administering albuterol to in-patient pediatric patients, we anticipate that we may have seen an increase in duration of stay, because it might have taken longer for albuterol-mediated asthma symptoms to be relieved sufficiently to warrant discharge. Admittedly, the duration of stay has many contributing factors, and no association between albuterol delivery device and duration of stay can be determined from this study design. At the very least we can say that duration of stay has not changed, despite the introduction of this new method of albuterol delivery.

Our cost model was based on some assumptions that may not be true for all hospitals. We used the model of 3 daily changes of the SVN for several reasons. Mean du-

Table 5. Descriptive Statistics for Number of Albuterol Treatments Per Patient From January Through May of Each Year During Our Study

| | 2004 | 2005 | 2006 |
|--|------|------|------|
| Albuterol treatments per patient (mean)* | 13.6 | 14.6 | 16.1 |
| Trimmed mean (10%) | 9.4 | 9.4 | 9.7 |
| Median | 8 | 7 | 8 |
| Standard deviation | 20.5 | 26.4 | 35.9 |
| Minimum treatments (<i>n</i>) | 1 | 1 | 1 |
| Maximum treatments (<i>n</i>) | 173 | 341 | 587 |

**p* = 0.21 via Kruskal-Wallis test

ration of stay for our acute care population is approximately 5 days, whereas it is < 2 days among patients with asthma. However, as our data show in Table 5, there is tremendous variability in the total numbers of albuterol treatments per patient and, by inference, the duration of

stay. Some patients are in the hospital for months receiving albuterol. We believe every-24-hour SVN change is the most common practice in pediatric hospitals and is congruent with published guidelines.²⁵ Thus, we picked 3 daily changes on the assumption that this probably was a reasonable mid-point between the short-stay and long-stay patients. Even had we modeled 1 or 5 SVN changes per admission, the total albuterol administration costs would still have been less after conversion to MDI-VHC, because labor is by far the largest component of the administration costs of albuterol.

It might be argued that these modeled savings were not actually realized, since you would still have these RTs in the hospital being paid, but doing something else (or nothing) in the time saved by using MDI-VHC. "Folk wisdom" says that if there is no reduction in force, there is no savings. This might be true if respiratory therapy staffing was static. But our staffing is volume-adjusted such that when there are more patients and more scheduled work, we have more RTs in the building. Our staffing is adjusted shift-by-shift, based on scheduled demand for service. During peak times of demand we often have one or more RTs working overtime (at a higher hourly rate), which makes their worked hours more expensive. If peak demand for the number of RTs needed could be reduced by making each of them able to give more treatments in the same amount of time, then the overall cost structure of the department might improve through a reduction in overtime hours.

We have evidence that our total direct operating costs have decreased in the period spanning the conversion to MDI-VHC. Our inflation-adjusted total direct expense per relative value unit has dropped 16.5% between 2004 and 2006. This improvement could have contributed to our reduction in cost per relative value unit by reducing overtime utilization. Total respiratory therapy overtime hours have dropped 47%, and overtime hours as a percent of total paid clinical hours dropped 33% from 2004 through 2006. Certainly, many factors contribute to the overall operating expense of a respiratory care department of our type and size, including supplies, equipment, medical gases, and labor. However, we speculate that part of this decrease in operating expense may have been the result of our MDI conversion program, although we cannot prove this at this time.

Albuterol is the most widely used bronchodilator in our hospital. Our current information technology does not allow us to search medication administration records for a particular class of drugs such as bronchodilators. We estimate that albuterol constitutes at least 90% of all the inhaled medication treatments that are administered.

Reasons frequently reported to us for why MDI-VHC were not used on patients were: (1) patient, family, and/or physician preference, (2) aversion to the face mask, and

(3) alleged ineffectiveness of MDI-VHC, based on subjective assessment by an RT, nurse, or physician, after the initial treatment. The consensus from our clinical staff is that the program has been very successful, and the MDI-VHC is well liked by nurses, patients, and families.

Other potential benefits of MDI-VHC over SVN have been promoted. Our experience during this transition supports the view of some researchers that, overall, patients prefer MDI over SVN.²⁴ For patients who need to go home on albuterol therapy, MDI-VHC is a much more convenient option than SVN with a portable compressor. It may also be less expensive, although this remains to be studied carefully. We speculate that this convenience could translate into better compliance with albuterol treatment schedules among patients at home.

Conclusions

Methods of delivery of albuterol have substantially changed in our facility since implantation of our program. MDI-VHC is now used in the overwhelming majority of patients treated with intermittent albuterol, especially among patients with asthma. There have been no changes in asthma duration of stay since the implementation of this program. Our albuterol administration costs have also decreased. We acknowledge the multidisciplinary nature of this program and the contributions of the respiratory care, nursing, and medical staffs to its success.

REFERENCES

1. Tenholder MF, Bryson MJ, Whitlock WL. A model for conversion from small volume nebulizer to metered dose inhaler aerosol therapy. *Chest* 1992;101(3):634-637.
2. Liu LL, Gallaher MM, Davis RL, Rutter CM, Lewis TC, Marcuse EK. Use of a respiratory clinical score among different providers. *Pediatr Pulmonol* 2004;37(3):243-248.
3. Amirav I, Newhouse MT. Aerosol therapy with valved holding chambers in young children: importance of the facemask seal. *Pediatrics* 2001;108(2):389-394.
4. Lugo RA, Kenney JK, Keenan J, Salyer JW, Ballard J, Ward RM. Albuterol delivery in a neonatal ventilated lung model: Nebulization versus chlorofluorocarbon- and hydrofluoroalkane-pressurized metered dose inhalers. *Pediatr Pulmonol* 2001;31(3):247-254.
5. Lugo RA, Keenan J, Salyer JW. Accumulation of CO₂ in reservoir devices during simulated neonatal mechanical ventilation. *Pediatr Pulmonol* 2000;30(6):470-475.
6. Delgado A, Chou KJ, Silver EJ, Crain EF. Nebulizers vs. metered-dose inhalers with spacers for bronchodilator therapy to treat wheezing in children aged 2 to 24 months in a pediatric emergency department. *Arch Pediatr Adolesc Med* 2003;157(1):76-80.
7. Osmond M, Diner B. Evidence-based emergency medicine. Nebulizers versus inhalers with spacers for acute asthma in pediatrics. *Ann Emerg Med* 2004;43(3):413-415
8. Ploin D, Chapuis FR, Stamm D, Robert J, David L, Chatelain PG, et al. High-dose albuterol by meter-dose inhaler plus a spacer device versus nebulization in preschool children with recurrent wheezing: a double blind, randomized equivalence trial. *Pediatrics* 2000;106(2 Pt 1):311-317.

9. Kerem E, Levison H, Schuh S, O'Brodovich H, Reisman J, Bentur L, Canny GJ. Efficacy of albuterol administered by nebulizer versus spacer device in children with acute asthma. *J Pediatr* 1993;123(2):313–317.
10. Leversha AM, Campanella SG, Aickin RP, Asher IA. Cost and effectiveness of spacer versus nebulizer in young children with moderate to severe acute asthma. *Pediatrics* 2000;136(4):497–502.
11. Fok TF, Monkman S, Dolovich M, Gray S, Coates G, Paes B, et al. Efficiency of aerosol medication delivery from a metered dose inhaler versus jet nebulizer in infants with bronchopulmonary dysplasia. *Pediatr Pulmonol* 1996;21(5):301–309.
12. Lin YZ, Hsieh KH. Metered dose inhaler and nebuliser in acute asthma. *Arch Dis Child* 1995;72(3):214–218.
13. Bailey R, Weingarten S, Lewis M, Mohsenifar Z. Impact of clinical pathways and practice guidelines on the management of acute exacerbations of bronchial asthma. *Chest* 1998;113(1):28–33.
14. Newman, KB, Milne S, Hamilton C, Hall, K. A comparison of albuterol administered by metered-dose inhaler and spacer with albuterol by nebulizer in adults presenting to an urban emergency department with acute asthma. *Chest* 2002;121(4):1036–1041.
15. Cates C, Bara A, Crilly J, Rowe B. Holding chambers versus nebulisers for beta-agonist treatment of acute asthma. *Cochrane Database Syst Rev* 2003;3:CD000052.
16. Castro-Rodriguez JA, Rodrigo GJ. Beta-agonists through metered dose inhaler with valved holding chamber versus nebulizer for acute exacerbation of wheezing or asthma in children under 5 years of age: a systematic review with meta-analysis. *J Pediatr* 2004;145(2):172–177.
17. Deerojanawong J, Manuyakorn W, Prapphal N, Harnruthakorn C, Sritippayawan S, Samransamruajkit R. Randomized controlled trial of salbutamol aerosol therapy via metered dose inhaler-spacer vs. jet nebulizer in young children with wheezing. *Pediatr Pulmonol* 2005;39(5):466–472.
18. Bisgaard H, Anhøj J, Wildhaber JH. Spacer devices. In: Bisgaard H, O'Callaghan C, Smaldone GC, editors. *Drug delivery to the lung*. New York: Marcel Dekker; 2002:389–420.
19. Wildhaber JH, Devadason SG, Hayden MJ, James R, Dufty AP, Fox RA, et al. Electrostatic charge on a plastic spacer device influences the delivery of salbutamol. *Eur Respir J* 1996;9(9):1943–1946.
20. Wildhaber JH, Devadason SG, Eber E, Hayden MJ, Everard ML, Summers QA, LeSouëf PN. Effect of electrostatic charge, flow, delay and multiple actuations on the in vitro delivery of salbutamol from different small volume spacers for infants. *Thorax* 1996;51(10):985–988.
21. Rau JL, Coppolo DP, Nagel MW, Avvakoumova VI, Doyle CC, Wiersema KF, Mitchell JP. The importance of nonelectrostatic materials in holding chambers for delivery of hydrofluoroalkane albuterol. *Respir Care* 2006;51(5):503–510.
22. Coppolo DP, Mitchell JP, Nagel MW. Levalbuterol aerosol delivery with a nonelectrostatic versus a nonconducting valved holding chamber. *Respir Care* 2006;51(5):511–514.
23. Minai BA, Martin JE, Cohn RC. Results of a physician and respiratory therapist collaborative effort to improve long-term metered-dose inhaler technique in a pediatric asthma clinic. *Respir Care* 2004;49(6):600–605.
24. Cotterell EM, Gazarian M, Henry RL, O'Meara MW, Wales SR. Child and parent satisfaction with the use of spacer devices in acute asthma. *J Paediatr Child Health* 2002;38(6):604–607.
25. American Association for Respiratory Care. AARC clinical practice guideline: selection of aerosol delivery device. *Respir Care* 1992;37(8):891–897.