Severe Intraoperative Bronchospasm Treated with a Vibrating-Mesh Nebulizer

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Bronchospasm and status asthmaticus are two of the most dreaded complications that a pediatric anesthesiologist may face. With the occurrence of severe bronchospasm and the inability to ventilate, children are particularly vulnerable to apnea and ensuing hypoxia because of their smaller airway size, smaller lung functional residual capacity, and higher oxygen consumption rates than adults. Nebulized medication delivery in intubated children is also more difficult because of smaller endotracheal tube internal diameters. This case demonstrates the potentially lifesaving use of a vibrating-mesh membrane nebulizer connected to the anesthesia circuit for treating bronchospasm.

Key Words: Asthma; Bronchospasm; Nasal intubation; Pediatric dental anesthesia; Vibrating-mesh; nebulizer.

Asthma is an episodic disease characterized by hyperreactive bronchi, chronic airway inflammation, and airflow obstruction during expiration. Bronchospasm is caused by spasmodic contraction of the bronchial smooth muscle. Status asthmaticus is bronchospasm that does not respond to standard treatments, which include intravenous (IV), inhaled, and subcutaneous (SQ) interventions. It is estimated that 9.6 million children in the USA have been diagnosed with asthma. This represents approximately 13% of the total pediatric population.^{1,2} The incidence of asthma is higher in urban areas, in children of low socioeconomic status, and in those with a history of atopy.^{3,4} The area in which our institution is located (Bronx, New York) has the highest

incidence of asthma in New York State.^{3,4} The current report presents a case of bronchospasm in a 3-year-old child that was refractory to all usual treatments. A therapy not previously reported as being used in the operating room, a vibrating-mesh membrane nebulizer (Aeroneb Professional Nebulizer [APN] System, AG-AP6000-US, Aerogen Ltd, Ireland), was used to successfully relieve this episode.

CASE DESCRIPTION

A 3-year-old, 15-kg girl presented to the ambulatory surgical unit for dental restorations under general anesthesia. Her past medical history was significant for mild intermittent asthma, for which she had never been hospitalized. Onset of asthma was at age 2.5 years, and her asthma triggers included upper respiratory infections and smoke. The father stated that he smoked but only

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Assembly of conventional anesthesia circuit with APN and size-specific connectors. A indicates the universal adapter (Intersurgical Incorporated, #1969, Liverpool, NY) with a 22-mm outer diameter (OD) and a 15-mm inner diameter (ID); B, the APN chamber; C, the straight connector (Intersurgical Incorporated, #1962, Liverpool, NY) with a 15-mm OD and 22-mm ID; and D, the APN control module, which connects to the APN chamber via a cable.

outdoors. The child's father and younger brother were also asthmatic. The patient, two brothers, and both parents lived in an apartment that had mice but no pets, curtains, carpets, dust, or mold. The patient also had a history of atopic dermatitis but tested negative for allergy to aeroallergens, peanuts, and nuts. The patient had no known drug allergies. Preoperative medications included beclomethasone (inhaled daily via an aerochamber) and infrequent use of albuterol via a metered dose inhaler (MDI).

The patient was prophylactically pretreated with 2 inhaled puffs of albuterol via an MDI 20 minutes prior to induction. In the operating room, standard monitors were placed and general anesthesia was induced by face mask inhalation with 6% sevoflurane, 50% nitrous oxide, and 50% oxygen. A 22-gauge peripheral IV line was placed in the left hand. A muscle relaxant (rocuronium, 10 mg IV) was given for tracheal intubation, and propofol (40 mg IV) was given to facilitate intubation. After the patient was deeply anesthetized, a nasotracheal intubation was successfully completed on the first attempt with an uncuffed, size 4.0 nasal RAE endotracheal tube (ETT). A leak was heard, and the throat pack was inserted. A leak was no longer audible following insertion of the throat pack. Upon auscultation of the lungs immediately after intubation, breath sounds were markedly decreased bilaterally and bag ventilation was increasingly difficult. An inspection was completed to rule out mechanical obstruction of the anesthesia circuit and the ETT. The tube was suctioned to rule out a potential mucus plug. Proper placement of the ETT was confirmed with di-

rect laryngoscopy, and the depth of anesthesia was increased by boosting the concentration of inhaled sevoflurane to 8%.

Peak airway pressures became progressively higher (at least 40 cm H₂O) over a period of 10 minutes. Medications given to relieve the bronchospasm included high-concentration sevoflurane (8%) and 100% oxygen. Albuterol (8 puffs via an MDI) was administered directly into the ETT. No improvement was noted following albuterol MDI. Thereafter, the following additional medications were given: hydrocortisone 50 mg IV, terbutaline 75 µg SQ, ketamine 30 mg IV, magnesium 375 mg IV, and epinephrine 0.15 mg SQ. Despite these interventions, the patient's oxygen saturation via pulse oximetry continued to decrease to 75%. An epinephrine infusion was started at 1.5 µg/min after a 150-µg IV bolus. There was initial improvement after the epinephrine infusion was started: the oxygen saturation increased to 85%–90%. Despite this improvement, tidal volumes remained low, at 10 mL per breath at a peak airway pressure of 30–40 cm H₂O (the patient's nominal tidal volume should be approximately 75–150 mL).

A jet nebulizer filled with albuterol (2.5 mg in a 3-mL solution) and ipratropium bromide (250 µg) was connected to the anesthesia circuit driven by 100% oxygen by hand bag ventilation, with no improvement. A pediatric intensive care physician was consulted and brought the APN to the operating room. This membrane nebulizer was filled with the same dose of albuterol and ipratropium bromide and placed on the anesthesia circuit using special connectors (Figure). The result was a rapid improvement of tidal volume to 100–150 mL at reduced peak airway pressures of 20 cm H₂O over a period of approximately 5 minutes. The oxygen saturation via pulse oximetry increased to 98%–100% over this period of time.

The procedure was cancelled and the patient was transferred to the pediatric intensive care unit while still intubated. The duration of the episode in the operating room was 3.5 hours. A chest radiograph was taken, confirming correct positioning of the ETT and no cardiopulmonary findings. The patient continued to improve, was extubated after 3 hours in the pediatric intensive care unit, and was discharged home on day 2.

DISCUSSION

Intraoperative bronchospasm is commonly treated with MDI nebulizers, which deliver aerosolized medications.^{5,6} Conventional aerosol therapy for intubated patients outside of the operating room consists of small-volume jet nebulizers (SVN) driven by air or ox-

xygen. Studies have shown that continuous aerosolized delivery of medication is more effective than intermittent pump administration.^{6,7} In this case, we described the use of an electronic vibrating mesh nebulizer (APN) connected to the anesthesia circuit to successfully relieve severe bronchospasm in a pediatric patient.

In comparison to conventional continuous aerosol modalities such as SVN, the APN can deliver medication more effectively and overcomes many limitations of traditional nebulizers in the intubated pediatric patient. The mechanism by which different nebulizers generate aerosols affects their efficacy in mechanically ventilated patients. SVN forms a mist by drawing liquids from the nebulizer reservoir and passing high-velocity gases through a venturi nozzle.⁸ APN implements a vibrating mesh to produce aerosols. Uniformly sized droplets form as the liquid is drawn through the vibrating apertures, thus acting as a micropump.⁹ Jet nebulizers require their own flow to produce aerosols. The aerosol may be diluted and reduces drug delivery, whereas an APN does not add any flow. The high flow rates required by SVN are problematic for babies and children, as the delivered tidal volumes may be dramatically increased and the delivered anesthetic gas concentrations decreased.

In the present patient, the delivery of aerosolized medications through a small-diameter nasal RAE ETT presented challenges that are quite different from those encountered in adult-sized patients. The acute bend in the nasal RAE ETT prevents the aerosols from effectively reaching the lungs. The lower lung volumes, long length of the ETT relative to patient size, the small inner diameter of the ETT, and the mechanical ventilator settings used in pediatric patients decrease the total drug delivered to the lungs.^{10–12}

An additional problem we faced was that conventional anesthesia circuits cannot be disconnected before the wye piece at the inspiratory limb (Figure). Therefore, it was necessary to connect the APN after the wye at the ETT. To connect the APN to the circuit, size-specific connectors were placed proximally between the nebulizer and the wye and distally between the nebulizer and the ETT.

The APN was able to effectively deliver albuterol and ipratropium to the lungs and relieve bronchospasm in this patient. It was previously reported that APN more efficiently delivers aerosolized medications than SVN with respect to several factors, including enhanced droplet stability and increased aerosolization.^{6,7,12}

According to Elhissi et al, the droplets formed by the APN had consistently higher entrapment or retention of drugs compared to droplets produced using an SVN.⁷ The APN has been shown to be less disruptive to droplet formation, while the droplets formed by SVN are more prone to destabilization, fusion, and aggregation, which will decrease delivery.

An animal model of neonatal ventilation studied by Dubus et al showed improvement in drug deposition using APN. APN deposited 25 times more radioactive markers than SVN in intubated macaque monkeys. The APN also deposited 4 times more aerosol volume versus the SVN.¹²

APN has been shown to be more effective than SVN in its volume requirements and output rate. APN requires 0.5 mL, whereas an SVN requires a 3.0-mL fill volume to produce equal volumes of aerosol.¹² The volume of aerosol produced by APN in 30 seconds will be produced by the SVN in 10 minutes.¹² The higher efficiency is extremely valuable in severe bronchospasm situations, when time to onset is crucial.

CONCLUSION

A vibrating mesh membrane nebulizer was used to deliver and break a severe bronchospasm in a nasally intubated 3-year-old girl after MDI, jet nebulizers, and other pharmacologic interventions failed. In this case, several advantages of the APN helped to quickly deliver adequate quantities of drug to the lungs through a nasal RAE ETT to relieve bronchospasm when SVN failed. Unlike APN, SVN has several disadvantages, such as a requirement for its own flow to aerosolize the drug and droplet instability, which can lead to droplet aggregation or disruption. APN can produce uniformly sized droplets with enhanced droplet stability. APN produces a larger total volume of aerosol in a shorter time period for a given amount of drug in comparison to an SVN. The smaller particles produced by APN result in less aerosol loss in the circuit and airways, which is especially helpful with a small nasal RAE ETT. We propose that future research comparing MDI, SVN, and APN using a test lung setup with anesthesia ventilators similar to the research accomplished using ICU ventilators can further demonstrate the efficacy of inhaled drug delivery in intubated patients using inhalers and nebulizers.

We believe that anesthesiologists should be aware of this treatment modality. It may be easily deployed and useful in severe bronchospasm especially in babies and children. Because of this experience, the Aeroneb nebulizer and its associated connectors are now stocked in our operating rooms. This case is especially important because of the high incidence of asthma in many urban communities.

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