Physiologic Effects of Nasal Aspiration and Nasopharyngeal Suctioning on Infants With Viral Bronchiolitis

Coral N Ringer, Rebecca J Engberg, Kristen E Carlin, Craig D Smallwood,[†] and Robert M DiBlasi

BACKGROUND: There is limited evidence supporting an optimum method for removing mucus from the airways of hospitalized infants with bronchiolitis. This study was designed to evaluate short-term physiologic effects between nasal aspiration and nasopharyngeal suctioning in infants. METHODS: Sixteen infants requiring hospitalization for supportive management of bronchiolitis were instrumented with transcutaneously measured partial pressure of carbon dioxide (P_{tcCO_2}) and S_{pO_2} monitoring. Electrical impedance tomography (EIT) was used to estimate changes in inspiratory and end-expiratory lung volume loss and recovery. Subjects were suctioned with both nasal aspiration and nasopharyngeal suctioning methods in a randomized order (8 received nasal aspiration followed by nasopharyngeal suctioning, and 8 received nasophayrgeal suctioning followed by nasal aspiration). Noninvasive gas exchange and EIT measurements were obtained at baseline (pre-suction) and at 10, 20, and 30 min following each suctioning intervention. Sputum mass was obtained following suctioning, and clinical respiratory severity scores, before and after suctioning, were computed. RESULTS: There were no differences in inspiratory EIT ($P = .93$), change in end-expiratory lung impedance (ΔEELI; $P = .53$), P_{tcCO_2} ($P = .41$), S_{pO_2} ($P = .88$), heart rate ($P = .31$), or breathing frequency ($P = .15$) over the course of suctioning between nasal aspiration and nasopharyngeal suctioning. Sputum mass ($P = .14$) and clinical respiratory score differences before and after suctioning ($P = .59$) were not different between the 2 suctioning interventions. Sputum mass was not associated with ΔEELI at 30 min for nasal aspiration ($\rho = 0.11$, $P = .69$), but there was a moderate positive association for nasopharyngeal suctioning ($\rho = 0.50$, $P = .048$). CONCLUSIONS: Infants with viral bronchiolitis appeared to tolerate both suctioning techniques without adverse short-term physiologic effects, as indicated by the unchanged gas exchange and estimated lung volumes (EIT). Nasopharyngeal suctioning recovered 36% more sputum than did nasal aspiration and there was moderate correlation between sputum mass and end-expiratory lung impedance change at 30 minutes post-suction with nasopharyngeal that was not present with nasal aspiration. It is possible that a subset of patients may benefit from one type of suctioning over another. Future research focusing on important outcomes for suctioning patients with bronchiolitis with varying degrees of lung disease severity is needed. *Key words: bronchiolitis; suctioning; nasopharyngeal; olive tip; nasal suctioning; electrical impedance tomography.* [Respir Care 2020;65(7):984–993. © 2020 Daedalus Enterprises]

Introduction

Bronchiolitis is an acute respiratory illness, typically caused by a viral infection, affecting millions of children under 2 y of age worldwide. The diagnosis is based on an assessment of symptoms that include airway obstruction

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from mucus production and inflammation, cough, wheezing, and increased work of breathing. Bronchiolitis is the most common reason for hospitalization in infants nationally, accounting for nearly 100,000 admissions annually at an estimated cost of $1.73 billion.[1] The management of bronchiolitis is largely supportive and focuses on hydration, nutrition, and airway clearance. Airway clearance is especially important in infants because they may have difficulty clearing thick secretions from the airways that persist despite the patient's best cough effort.[2] Chest physiotherapy and postural drainage have traditionally been used to mobilize secretions, but a recent Cochrane Review failed to show a reduction in clinical severity of disease with these therapies, so they are not recommended as a standard practice for patients hospitalized with bronchiolitis.[3] The standard for airway clearance in bronchiolitis involves suctioning the nares and distal airway to temporarily remove secretions from the upper and lower airways, reduce airway obstruction, and improve lung mechanics and gas exchange. Benefits may include improved feeding, sleep, and work of breathing. All forms of suctioning may cause some temporary distress in the infant, upper airway inflammation or obstruction, hypoxemia, nasal trauma, discomfort or pain, sleep disruption, increased risk for secondary infection, and caregiver duress.[2] Because infants are often considered obligate nasal breathers,[4] clinicians need to carefully weigh the benefits of relieving nasal obstruction from mucus against the perceived risks associated with different suctioning techniques.

There are 2 commonly used methods for suctioning secretions in this population, including nasopharyngeal or "deep" suctioning and nasal aspiration. Nasopharyngeal suctioning is achieved by inserting a small-caliber catheter into the nasopharynx to elicit a cough and removing any expectorated secretions from the distal and proximal nasal passage. Nasopharyngeal suctioning is more invasive and may introduce greater risk for gagging, vomiting, bradycardia, bleeding (ie, airway trauma), bronchospasm and edema, atelectasis, and deteroration in gas exchange and lung mechanics than nasal aspiration. Deep suctioning has been associated with prolonged hospital length of stay and is typically reserved for patients who are unresponsive to nasal aspiration and who have excessive secretions.[5] Nasal aspiration is a form of minimally invasive suctioning that is performed by placing a bulb-shaped interface over the naris while applying suction through a large-caliber tubing to remove secretions from the proximal nasal airway opening. Due to the minimally invasive nature of nasal aspiration, there may be fewer complications than with nasopharyngeal suction.

QUICK LOOK

Current knowledge

There is variability in the technique and frequency of suctioning used to manage secretions in hospitalized infants with bronchiolitis. A previous study suggested that there may be a correlation between nasopharyngeal suctioning and increased hospital stay when compared to nasal aspiration.

What this paper contributes to our knowledge

Our results indicate that nasal aspiration and nasopharyngeal suctioning were equally effective in removing mucus from airways without any difference in clinical stability, gas exchange, or indices of lung volume. Nasopharyngeal suctioning recovered 36% more sputum than did nasal aspiration, and there was moderate correlation between sputum mass and end-expiratory lung impedance change at 30 min post-nasopharyngeal suction that was not present with nasal aspiration.

Currently, there are no specific recommendations from the American Academy of Pediatrics on suctioning practices for bronchiolitis due to a lack of sufficient data.[6] As such, suctioning guidelines have been disparate and are largely based on personal preference or anecdotal experience. Assessing physiologic responses to suctioning and airway clearance using objective measurements in this patient population has been extremely challenging and is limited primarily to S_{pO_2}, heart rate, breathing frequency, clinical respiratory scores, and documented adverse events.[7,8] With newer approaches, however, such as electrical impedance tomography (EIT), it is possible to measure global and regional changes in lung impedance through the application of an electrode array placed circumferentially around the patient's chest. These noninvasive measurements are correlated with changes in inspiratory volume and end-expiratory lung volume (EELV) observed with computed tomography scans, spirometery, and functional residual capacity measurements.[9-16] EIT measurements have been used to assess lung volume loss and recovery related to different suctioning techniques in mechanically ventilated infant and adult subjects.[17,18]

† Deceased.

Mr DiBlasi has disclosed relationships with Dräger Medical, Vapotherm, Mallinckrodt Medical, and Vero Biotech. Dr Smallwood disclosed relationships with Ventec Life Systems and Capsule Technology. The other authors have disclosed no conflicts of interest.

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The aim of this study was to evaluate respiratory function and clinical response in hospitalized children with viral bronchiolitis with 2 different suctioning techniques. We hypothesized that there would be no differences in indices of lung volume (EIT measurements), noninvasive gas exchange (S_{pO_2} and transcutaneously measured partial pressure of carbon dioxide [P_{tcCO_2}]), breathing frequency, heart rate, sputum mass, and respiratory clinical score between nasal aspiration and nasopharyngeal suctioning in hospitalized infants with acute viral bronchiolitis.

Methods

Subjects

This single-cohort study with a randomized crossover design was approved by Seattle Children's Hospital Institutional Review Board. Subjects were eligible for the study upon admission to the medical unit on the bronchiolitis pathway.[19] Inclusion criteria for the clinical pathway were age < 2 y, viral upper respiratory symptoms, and lower respiratory symptoms that included increased work of breathing, cough, feeding difficulties, tachypnea, wheeze, and fever. Patients were excluded from the study if they met our institution's bronchiolitis pathway exclusion criteria: cardiac disease requiring baseline medication, anatomic airway defects, neuromuscular disease, immunodeficiency, or chronic lung disease. Patients were also excluded for the following reasons: if the EIT electrodes were not able to be positioned properly on the chest due to size or weight; if they had severe disease requiring high-flow nasal cannula therapy; if there was a lack of an English-speaking and/or legal caregiver available for consent; or if their care team felt it was not appropriate to participate due to medical, social, or emotional concerns. Figure 1 presents a CONSORT flow chart. The desired sample size of 16 was calculated to produce 91% power assuming a baseline mean EELI (measured in arbitrary units) of 732 au (SD 798), comparable to the effects found in a similar study.[18]

Instrumentation and Measurements

After consent, infant subjects were instrumented with noninvasive S_{pO_2} and P_{tcCO_2} probes. P_{tcCO_2} was measured with the SenTec Digital Monitor (SenTec, Fenton, Missouri), and S_{pO_2} and heart rate were obtained with the RAD 7 Monitor (Masimo, Irvine, California) with a noninvasive, disposable sensor (LNCS Inf-3 S_{pO_2}, Masimo) applied to a toe, foot, or finger. Each day prior to testing, all devices were calibrated. Continuous analog output signals of S_{pO_2} and heart rate (from the RAD 7 monitor) and P_{tcCO_2} (from the SenTec monitor) were sampled at 1,024 kHz and processed using an analog-to-digital converter (Power Lab Model #16/35, Power Lab, ADI Instruments, Colorado Springs, Colorado). All data were displayed and recorded digitally in real time with LabChart data analysis software 5.5.6 (AD Instruments, Sydney, Australia).

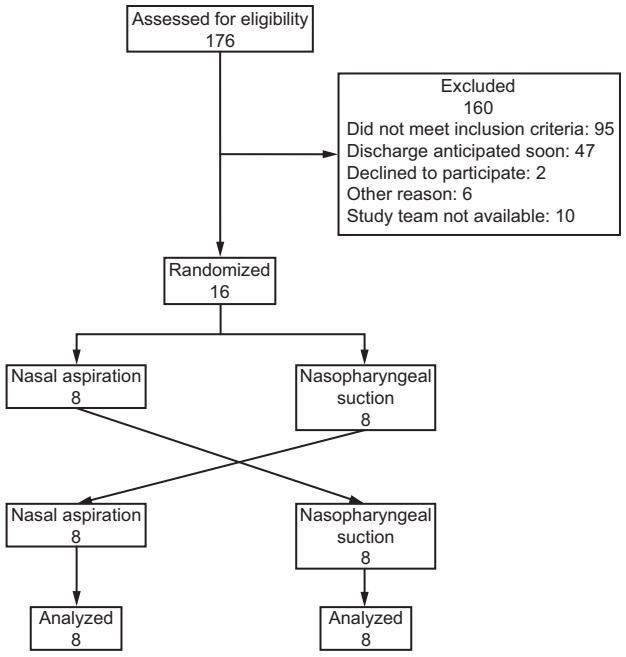

Fig. 1. Flow chart.

Global and regional inspiratory and expiratory EIT measurements were obtained with the PulmoVista 500 (Dräger, Lubeck, Germany). Our goal for measuring inspiratory and expiratory EIT was to determine: 1) whether removal of obstructive mucus from the airways resulted in improved alveolar recruitment and recovery; and/or 2) whether bronchospasm, airway edema (irritation of mucosal layer), laryngospasm, or negative pressure related to the different techniques contributed to changes in lung volumes, especially in the post-suction period. The pre-suction testing, application, and utilization of the EIT device were done according to manufacturer recommendations. To ensure adequate function and high-quality measurement, 16 ECG electrodes (Red Dot, 3M, Maplewood, Minnesota) and a reference lead were applied to each subject using a small amount of electrode gel approximately 30 min prior to recording measurements. Neonatal radiolucent ECG monitoring electrodes were placed in a straight line at the level of the fifth intercostal space, circumferentially around the chest and back, and the reference electrode was placed on the abdomen above the navel and attached to the PulmoVista.

Subjects remained supine either in a crib or in a caregiver's arms and were maintained in this position throughout the study. The PulmoVista 500 was then turned on, and device monitoring settings (filters) were configured based on

the subject's breathing frequency and heart rate. Data were acquired according to manufacturer recommendations: a frame rate of 30 Hz, operating frequency of 90 kHz, and a low pass filter to eliminate cardiac artifact.

Study Design

A crossover design was used, and each subject served as their own control. A randomized crossover design was chosen because the within-patient variation is less than the between-patient variation and thus required fewer subjects.[20] Given that the study interventions lasted only a couple hours, the investigators anticipated low dropout rate or variation in clinical condition within subjects. Eligible subjects were randomized in a 1:1 allocation to one of two treatment sequences: nasal aspiration followed by nasopharyngeal suction, or nasal pharyngeal suction followed by nasal aspiration. There was a 60-min wash-out period between each intervention. The order of the 2 suctioning techniques was randomized to allow an equal number of subjects in each intervention group. A biostatistician used created a permuted-blocks randomization scheme for equal allocation of the 2 treatments. Following consent, subjects were assigned to an intervention group. Study investigators, bedside nurses, and caregivers were not blinded to subject allocation due to the nature of the interventions.

After device calibration and instrumentation, S_{pO_2}, P_{tcCO_2}, breathing frequency, heart rate, and EIT measurements were obtained for 2 min to record the subject's baseline values. These measurements were repeated at 10, 20, and 30 min following each suctioning event. The bedside nurse observed and reported the respiratory clinical score prior to and after suctioning. This scoring tool allocates points for breathing frequency, wheezing, retractions, and dyspnea. It has been reported to have good interobserver agreement among clinicians caring for patients with respiratory distress and is commonly used to evaluate response to airway-clearance interventions.[21] Suctioning devices included BBG Nasal aspirator (Philips, Andover, Massachusetts) and either a 5/6 Fr or 8 Fr AirLife Tri-Flo catheter (Vyaire, Yorba Linda, California) catheter for nasal aspiration and nasopharyngeal suctioning, respectively.

To quantify the mucus removed during suctioning, a specimen trap (Centurion, Williamstem, Michigan) was attached to the end of the suction device. Each specimen trap and suctioning apparatus was weighed prior to and following suctioning. Sputum mass (μg) was calculated based on the difference in pre/post weights of catheters and specimen traps. Investigators recorded the number of saline drops used to lubricate the airways with suctioning; however, the amount of saline used was negligible (data not shown). As such, sputum weights were not adjusted based on the number of saline drops used. Subjects were suctioned according to a hospital-wide job aid (see online supplement) that was reviewed with the bedside clinical nurses prior to each suctioning intervention. Investigators recorded all adverse events around the time of suctioning, including bradycardia (heart rate < 60 beats/min), hypoxemia ($S_{pO_2} < 80\%$ for > 10 s), bleeding, and vomiting. Study data and demographics were collected and managed using REDCap electronic data capture tools hosted at Institute of Translational Health Sciences, University of Washington Seattle Children's Hospital.[22]

Data Analysis

Changes in global and regional EIT data were analyzed offline to assess changes in lung volume related to mucus removal, alveolar re-recruitment (recovery), or destabilization in lung volumes (deterioration) from suctioning using the EIT Data Analysis Tool (Dräger). Investigators reviewed the raw data for each condition (2 min) and calculated mean ± SD values for global changes in the inspiratory and EELI waveform by selecting a stable period that included a minimum of 10 spontaneous breaths. Global tidal variation was used as a surrogate for inspiratory volume changes within a given transverse slice of the lung. Tidal variation was calculated as the difference between the tidal (peak-to-trough) change or ΔZ in the global inspiratory EIT waveform (measured in arbitrary units) and was normalized to body weight (au/kg).

The EELI is representative of EELV based on previously established linear relationships between impedance and functional residual capacity change within the lungs.[13,15] The EELI was calculated as the trough value in the global impedance waveform (measured in arbitrary units) for 10 spontaneous breaths for the same period and normalized to body weight (au/kg). The relative change in EELI (ΔEELI) was calculated as the difference between the baseline (pre-suction) EELI and measurements made at 10, 20, and 30 min following suctioning.

Regional distribution of ventilation was evaluated by assessing the tidal variation and EELI as a proportion of the global EIT between 4 cross-sectional horizontal regions of interest: dorsal, mid-dorsal, ventral, and mid-ventral. Because bronchiolitis is considered a heterogeneous lung disease, regional assessment of lung impedance may provide descriptive analysis on the effects of suctioning in dependent lung regions where gravitational effects are more likely to promote sedimentation and inspissation of sputum when subjects are supine. Global and regional tidal variation and EELI were analyzed offline with a separate MatLab Toolkit to observe values pre-suction (baseline) and at 10, 20, and 30 min following suction.

The mean ± SD values for S_{pO_2}, TcO_2, breathing frequency and heart rate were calculated over two minute

periods at the end of baseline (pre-suction) and at 10, 20 and 30 minutes following each suction condition offline using Lab Chart Data Analysis Software (v5.5.6).

Statistical Analyses

Descriptive statistics were calculated for all demographic and physiologic parameters. Prior to modeling, spaghetti plots were used to visualize individual subject trends over time in weight-adjusted tidal variance and ΔEELI, heart rate, S_{pO_2}, P_{tcCO_2}, and breathing frequency. Linear mixed-effects models, an extension of linear regression that accounts for repeated measurements, were used to assess differences in lung impedance values, heart rate, S_{pO_2}, P_{tcCO_2}, and breathing frequency. Within each model, a compound symmetry covariance structure, which assumes equal correlation between each repeated measurement, was used. To account for baseline differences, all models, except for the model including ΔEELI, were adjusted for pre-suctioning measures. Linear mixed-effects models use all available data, so if a subject was missing one or two measurements, they were still accounted for in the model. Model-based means and standard errors were reported along with the *P* value for the interaction term for intervention type and time, testing the hypothesis that the relationship of intervention type on each outcome differs over time. Respiratory clinical severity score measures were compared between the 2 interventions using a linear mixed-effects model to evaluate differences in pre- and post-suction values for each suction intervention. The global and regional tidal variation and ΔEELI values were evaluated descriptively using boxplots by post-suctioning time to visually assess their variability. Paired *t* tests were used to assess differences in sputum mass before and after suctioning between the 2 techniques. Spearman correlation, which assesses the direction and strength of association between 2 measures, was used to explore the association between sputum mass and ΔEELI. Changes related to regional lung distribution were described but not compared through statistical testing. A *P* value of .05 was used to determine statistical significance. Adjustments for multiple comparisons were not completed. SAS 9.4 (SAS Institute, Cary, North Carolina) was used for all other analyses.

Results

Subjects

A total of 19 children were enrolled in the study from February 2017 to July 2018; 16 subjects completed the study and are included in the analysis. One patient's caregivers decided to withdraw after consent was obtained due to the time commitment, and 2 patients did not have study interventions following consent due to the availability of the research team. Of the 16 subjects enrolled in the study, 8 were randomized to receive nasal aspiration followed by nasopharyngeal suctioning, and 8 were randomized to receive nasopharyngeal suctioning followed by nasal aspiration. All subjects' demographic data are presented in Table 1. One subject was missing ΔEELI values for the time points at 10 min and 20 min for the nasopharyngeal suctioning. One subject was missing both pre-suction and post-suction respiratory score data for the nasopharyngeal intervention, and 1 subject was missing breathing frequency data at 20 min and at 30 min for the nasal aspiration.

Table 1. Subject Demographics

Characteristic	Value
Age at admission, months	5.4 (5.9)
Female	7 (43.7)
Race/ethnicity	
Non-Hispanic white	9 (56.3)
Non-Hispanic, other race, or not specified	7 (43.7)
Length, cm	64.8 (10.3)
Weight, kg	6.8 (2.5)
Hospital length of stay, d, median (IQR)	2.9 (4.6)
Parent/caregiver report of duration of illness, d	5.9 (3.2)
Respiratory score on admission	5.9 (2.5)

Data are reported as mean (SD) except where otherwise indicated.
IQR = interquartile range

Indices of Lung Volume (EIT)

There were no differences in global tidal variation based on intervention over time between nasal aspiration and nasopharyngeal suctioning ($P = .93$) (Fig. 2). Also, there were no differences in global ΔEELI measurements based on suction intervention over time ($P = .53$) (Fig. 3). Figure 4 presents regional distribution of tidal variation and EELI data, respectively. Figure 5 displays representative regional changes in tidal variation for 1 subject who had a positive response with both suctioning techniques, based on improvement in the dependent lung regions.

Physiologic Measurements

No differences in heart rate, S_{pO_2}, P_{tcCO_2}, or breathing frequency were observed between nasal aspiration and nasopharyngeal suctioning. Model-based means and physiologic measurement comparisons for these outcomes are reported in Table 2. Change in pre-suction to post-suction clinical respiratory score was not different between nasal aspiration and nasopharyngeal techniques (0.06 ± 1.39 vs 0.56 ± 1.50, respectively, $P = .59$).

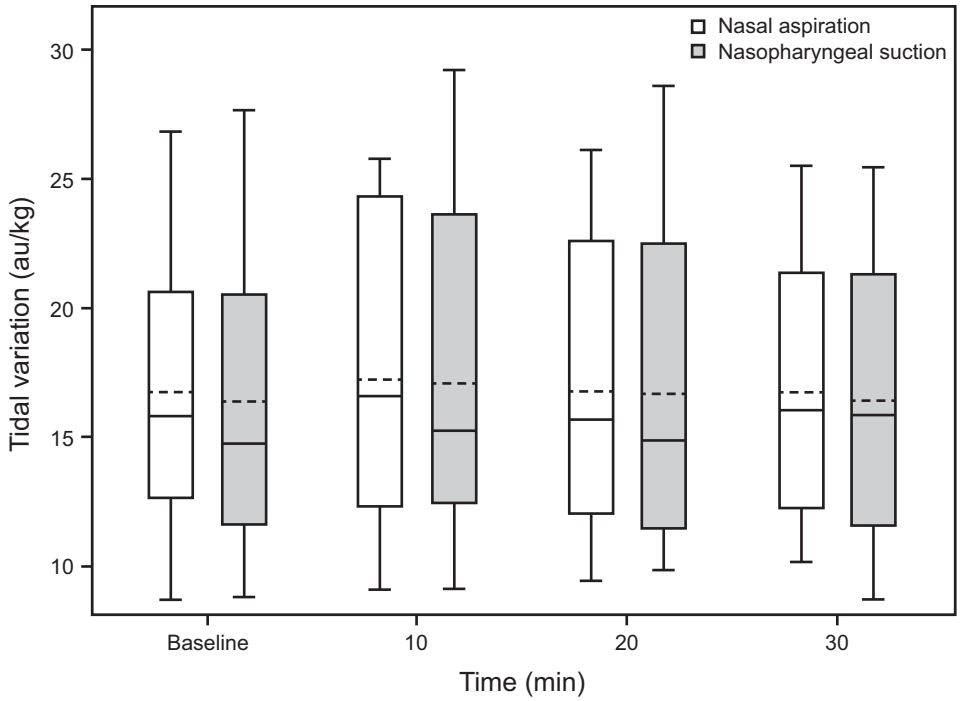

Fig. 2. Values represent weight-adjusted, global tidal variation (arbitrary units/kg) at baseline and at 3 time points (10, 20, and 30 min) after nasal aspiration and nasopharyngeal suctioning. Dashed lines denote the mean, and solid lines denote the median. Boxes represent 25th and 75th percentiles. There were no differences in global tidal variation based on intervention over time between nasal aspiration and nasopharyngeal suctioning ($P = .93$).

Sputum Mass

The mean sputum mass recovered from the airways did not differ between nasal aspiration and nasopharyngeal techniques (548 ± 496 mg and 860 ± 435 mg, respectively; $P = .14$). Sputum mass was not associated with ΔEELI at 30 min for nasal aspiration ($\rho = 0.11$, $P = .69$), but there was a moderate positive association for nasopharyngeal suctioning ($\rho = 0.50$, $P = .048$).

Adverse Events

There were no observed bradycardic episodes, hypoxemic episodes, or vomiting in any subjects to suggest clinical deterioration with either suctioning intervention. One subject had blood-tinged mucus with both nasal aspiration and nasopharyngeal suction, and 2 subjects had blood-tinged mucus with nasopharyngeal suctioning alone.

Discussion

The major findings from this study indicate that nasal aspiration and nasopharyngeal suctioning are effective in removing mucus from airways, based on recovered sputum mass. Although the sputum mass removed from subjects' airways between the suctioning techniques was not shown to be statistically different, mean sputum mass during nasopharyngeal suctioning was 36% greater than that obtained with nasal aspiration. The moderate association between sputum mass and ΔEELI at 30 min for nasopharyngeal suctioning is a finding that warrants further evaluation. Interestingly, the greater mucus mass obtained with nasopharyngeal suctioning in the absence of increased risk from clinical deterioration due to airway obstruction or alveolar de-recruitment after suctioning may be clinically meaningful to some bedside clinicians.

The intent of suctioning infants with bronchiolitis is to remove accumulated secretions, optimize lung mechanics and volumes, improve gas exchange, and reduce work of breathing without causing unnecessary harm to the patient. This is the first study to address objective measures of clinical improvement or deterioration based on changes in gas exchange, heart rate, and estimates of lung volumes in spontaneously breathing infants with viral bronchiolitis between 2 widely used suctioning techniques. Previous studies have reported cardiorespiratory instability in critically ill infants during suctioning to be partially attributed to alveolar de-recruitment with loss of lung volume.[23] Several other in vivo studies have used EIT to estimate lung volume changes in critically ill subjects between different forms of suctioning techniques (ie, open vs closed) during conventional and high-frequency oscillatory ventilation. [17,18,24-27]

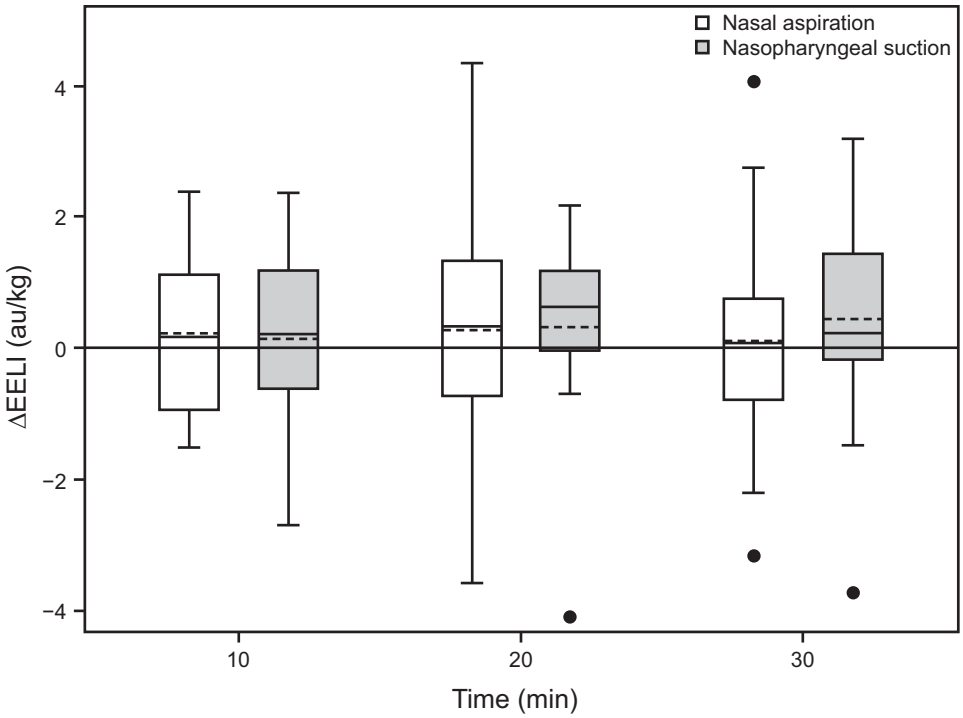

Fig. 3. Values represent weight-adjusted (arbitrary units/kg) change in end-expiratory lung impedance (ΔEELI) calculated as the difference between pre-suction EELI and at 3 time points (10, 20, and 30 min) after nasal aspiration and nasopharyngeal suctioning. Dashed lines denote the mean, and solid lines denote the median. Boxes represent 25th and 75th percentiles. Outliers are defined as data points outside ± 1.5 times the interquartile range. There were no differences in ΔEELI measurements based on suction intervention over time (P = .53) between the 2 suctioning techniques.

It is possible that the different suctioning methods may have influenced the regional distribution of tidal variation and EELI by removing mucus from the gravity-dependent (ie, dorsal) sections of the lungs in these supine subjects. Although we observed good visual responses to suctioning in some subjects (ie, Fig. 5), global EIT data did not show differences among the study cohort, and the study was designed only to observe descriptive information on regional ventilation homogeneity between the 2 methods. This is not surprising, considering that spontaneously breathing infants have been reported to be highly capable of adapting their breathing pattern to maintain EELV and functional residual capacity.[13-15]

Neither form of suctioning had a profound improvement or deterioration on noninvasive estimates of ventilation distribution, gas exchange, or respiratory severity scores. These important physiologic short-term outcomes may suggest that this group of infants with viral bronchiolitis tolerated both techniques with no added risk for clinical deterioration or other adverse events. There were some instances in which a small amount of bleeding was observed with both nasal aspiration and nasopharyngeal suction. However, unlike our results, Gomes et al[7] reported from a randomized controlled trial in 100 infant subjects ($\leq$ 12 months old) that the proportion of subjects who vomited or had nasal bleeding was much greater in subjects who received nasopharyngeal suction than nasal aspiration suction. These known risks may be mitigated using a standardized suctioning process and saline to lubricate the airways. This adds to the limited body of evidence guiding clinicians in selecting appropriate suctioning techniques in infants with viral bronchiolitis.

Literature describing the optimum type and frequency for suctioning this patient population is extremely limited and has primarily focused on nonphysiologic outcomes. The American Association for Respiratory Care recommends that suctioning should only be initiated in response to clinical signs and symptoms that indicate presence of secretions in the airways.[2] One study reported that lapses of $>$ 4 h between suctioning events (using any method) during the first 24 h of hospitalization may result in increased length of hospital stay.[5] Investigators have reported that more frequent use of nasopharyngeal suction during the first 24 h was associated with longer hospital stay for infants with bronchiolitis than did use of nasal aspiration (2.35 ± 0.2 d with 60% nasopharyngeal suction vs 1.75 ± 0.2 d with no "deep suction").[5] These researchers attributed these findings to the increased likelihood of edema and irritation in the upper airways with the use of the more invasive nasopharyngeal catheter. However, based

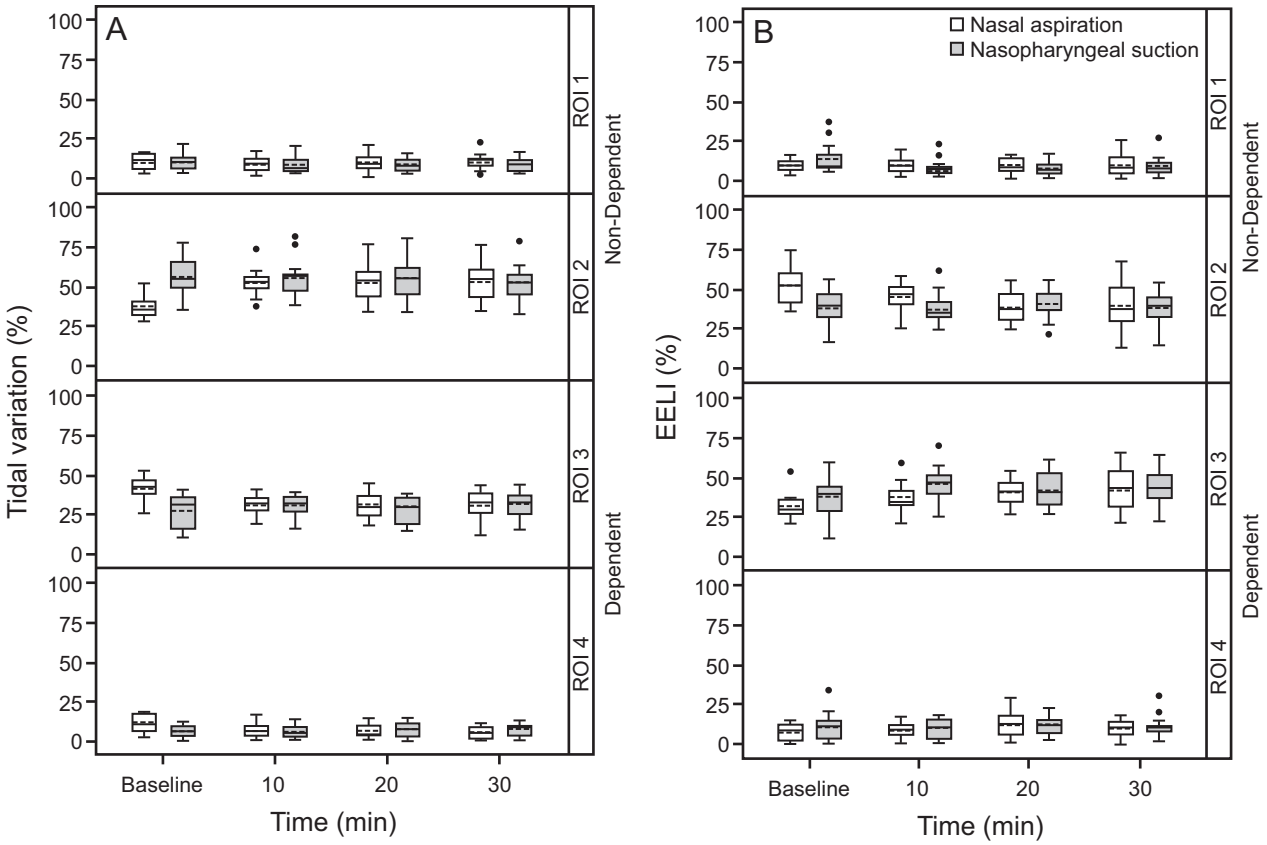

Fig. 4. Regional distribution of ventilation was evaluated descriptively by assessing (A) tidal variation and (B) end-expiratory lung impedance at baseline (pre-suction) and at 10, 20, and 30 min. Dashed lines denote the mean, and solid lines denote the median. Boxes represent 25th and 75th percentiles. Outliers are defined as data points outside ± 1.5 times the interquartile range. Regional data are shown as the proportion of global tidal variance and ΔEELI change between 4 cross-sectional horizontal ROIs: ventral (ROI 1), mid-ventral (ROI 2), mid-dorsal (ROI 3), and dorsal (ROI 4). ROI = region of interest.

on our findings, both suctioning techniques appear to be safe for removing sputum from the airways of infants with bronchiolitis. Due to a lack of standard clinical guidelines for suctioning indication or frequency in this population, institutional policies and professional experiences usually guide suction practices.

Limitations

There are limitations to this short-term physiologic study. We enrolled a small number of subjects, and all were Supine positioned and moving spontaneously, so there were occasional gaps in the data captured. However, EIT values have been reported to be highly repeatable and to show little variation in infants who were repositioned or breastfed between measurements.[15] None of the subjects had EIT measurements during or immediately following each suctioning intervention due to crying or excessive movement. It is possible that there were differences in regional lung inflation during suctioning and the immediate period after suctioning, but these data were not obtained, although we did evaluate S_{pO_2}, heart rate, and the presence of other complications including gagging, vomiting, or nasal bleeding in real time during the suction procedures. We observed a larger volume of mucus obtained with nasopharyngeal suctioning, but this finding did not reach statistical significance. This may be due to the number of subjects enrolled in this study; a future study with a larger sample size may find a statistically significant difference in mucus volumes between suctioning modalities.

Bronchiolitis is a heterogeneous lung disease, and it is very likely that the EIT findings described in this study are representative of only a transverse section of subjects' lungs. Although there may not have been changes in the cross-section that was monitored, there may have been changes in areas that were not assessed. It is also possible that, over the course of the data collection, a subject's clinical condition may have been altered due to a number of factors unrelated to suctioning, including changes in pathophysiologic condition, caregiver interventions, or subject disposition.

Another limitation is that this study's power and sample size were based on significant differences in EIT values

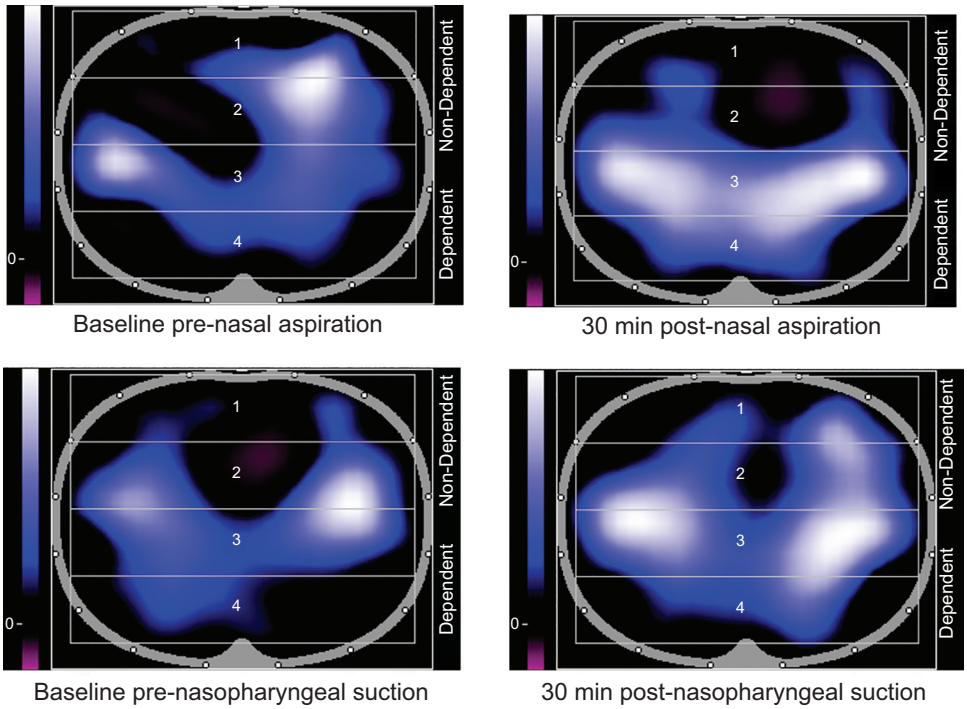

Fig. 5. Representative electrical impedance tomography image showing regional distribution of tidal variation at ventral (ROI 1), mid-ventral (ROI 2), mid-dorsal (ROI 3), and dorsal (ROI 4) lung sections pre-suction and at 30 min post-suction using nasal aspiration and nasopharyngeal suction techniques. The subject appeared to have an improvement in tidal variation in the dependent sections of the lungs with both suctioning techniques. ROI = region of interest.

Table 2. Model-Based Means and Standard Errors of Physiologic Measurements

Outcome	Intervention	10 Min	20 Min	30 Min	*P*
Heart rate, beats/min	Nasal aspiration	143.7 (3.9)	138.4 (3.9)	135.3 (3.9)	.31
	Nasopharyngeal suction	140.6 (3.9)	141.7 (3.9)	138.0 (3.9)	
S_{pO_2}	Nasal aspiration	95.1 (1.1)	95.5 (1.1)	95.0 (1.1)	.88
	Nasopharyngeal suction	94.7 (1.1)	94.7 (1.1)	94.2 (1.1)	
P_{tcCO_2}	Nasal aspiration	40.0 (0.5)	40.4 (0.5)	40.3 (0.5)	.41
	Nasopharyngeal suction	39.9 (0.5)	40.6 (0.5)	41.3 (0.5)	
Frequency, breaths/min	Nasal aspiration	26.6 (4.3)	36.2 (4.3)	32.6 (4.3)	.15
	Nasopharyngeal suction	41.7 (4.3)	36.1 (4.3)	37.5 (4.3)	

Data are presented as mean (standard error). Model-based means are adjusted for baseline values. *P* values are testing the hypothesis that the relationship between intervention type and each outcome differs over time.
P_{tcCO_2} = transcutaneously measured partial pressure of carbon dioxide

related to inline versus removal from invasive ventilation with open-suctioning in sedated subjects.[18] As such, this represents an extremely controlled setting with presumably less movement and artifact with the EIT measurements than our subjects. Therefore, we may have underpowered the study because our subjects were not intubated, critically ill, sedated, immobilized, or experiencing highly variable breathing patterns.

Lastly, subjects enrolled in this study were all previously healthy, were admitted to acute care, and were spontaneously breathing. Most had no supplemental oxygen requirements. It is feasible that evaluating subjects of higher acuity may have rendered different results. Thus, it is important to design additional studies that would observe outcomes related to frequency and type of suctioning interventions in subjects with varying degrees of respiratory severity.

Conclusions

There were no differences in subjects' short-term physiologic response to nasal aspiration and nasopharyngeal

suctioning. Because higher use of invasive suctioning has been linked in another study to longer hospital length of stay, it is possible that the frequent use of invasive suctioning may have cumulative negative effects. It would be beneficial to pursue further investigation into what subsets of patients may benefit more or less from invasive nasopharyngeal suctioning and at what frequency any mechanical suctioning should occur for optimum patient outcomes.

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