Evidence-Based Guideline for Suctioning the Intubated Neonate and Infant

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Abstract

The endotracheal tube (ETT) is the most common artificial airway used in NICUs. Suctioning of the ETT is imperative to maintain patency and prevent complications. An extensive review of the literature revealed a lack of standardized criteria or guidelines for suctioning the ETT of neonates and infants in the NICU. The purpose of this article is to report the implementation of an evidence-based guideline that can be utilized in NICU care.

Premature infants frequently require the use of an artificial airway and mechanical ventilation to support respiration and to maintain oxygenation and ventilation. An endotracheal tube (ETT) is the most commonly used artificial airway in neonates.[1] The presence of an ETT impairs the body's ability to mobilize and expectorate secretions and may increase mucus production. An ETT in the trachea causes damage to ciliated cells, inhibits the cough reflex, and bypasses the body's humidified airway.[2] Damage to the airway and risks associated with ETT suctioning may be reduced or eliminated by decreasing the length of time neonates and infants remain intubated.

ETT Suctioning in Neonates and Infants

ETT suctioning is an essential component of care for the intubated patient. Suctioning of an artificial airway clears the airway of secretions, potentially improving oxygenation and ventilation.[3] The American Association of Respiratory Care (AARC) states that "successful suctioning of an intubated patient improves air exchange and breath sounds, decreases the peak inspiratory pressure (PIP), decreases airway resistance, increases dynamic compliance, increases tidal volume delivery when using pressure-limited ventilation, improves arterial blood gas values, improves oxygen saturation, and removes secretions" (p. 502).[4]

In the NICU, ETT suctioning is a common procedure performed by nurses and respiratory therapists. However, it is not a benign procedure. Associated risks include cardiac dysrhythmias, hypoxemia, atelectasis, bronchospasm, infection, trauma to the mucosal linings and cilia of the airway, and increased intracranial pressure.[1,5] ETT suctioning of infants and children with small ETTs that have internal diameters of <4 mm may cause an immediate decrease in dynamic compliance and expired tidal volume regardless of lung pathology.[6] Despite the risks associated with suctioning, failure to suction when needed can result in a plugged ETT and the trauma of reintubation, atelectasis, and decreased oxygenation and ventilation. Optimal hydration and adequate warming and humidification of inspired gas maintain the normal consistency of secretions, reducing the risk of a plugged ETT.[7]

Currently, no published standard criteria or guidelines exist for assessing the need for suctioning or for performing the procedure. Suctioning techniques vary and may not be evidenced based. There is a need to develop a standardized evidence-based guideline for evaluating when and how to suction the intubated neonate and infant.

Accepted for publication November 2007. Revised September 2008.

CLINICAL QUESTIONS

Every aspect or step of the suctioning procedure was delineated, and questions were formulated for an extensive literature search of relevant research or research-based articles published on identified steps. Articles were reviewed and evaluated for relevance and level of evidence, and an evidence-based suctioning guideline was developed that can be implemented in NICUs caring for intubated neonates and infants. The questions included the following (neonates are included in the general category of infants):

1. What are the clinical indications of the need for ETT suctioning in infants and neonates?
2. In intubated infants requiring suctioning, is hyperoxygenation more effective than hyperinflation in reducing complications associated with the suctioning procedure?
3. In intubated infants, is suctioning only when clinically indicated compared to suctioning at preset intervals as effective in maintaining ETT patency and decreasing the incidence of infection?
4. What is the recommended suction catheter size and insertion depth when suctioning intubated infants?
5. What is the recommended negative pressure, length of time negative pressure should be applied, and number of catheter passes when suctioning intubated infants?
6. In intubated infants, is the open suction technique more effective than the closed suction technique in minimizing changes in baseline physiologic parameters and preventing atelectasis?
7. In intubated infants, is instilling normal saline (NS) or not instilling NS more effective in removing secretions from the endotracheal tube and maintaining ETT patency?

THE SEARCH FOR EVIDENCE

A literature search was conducted using PubMed, Ovid, CINAHL, and the Cochrane Databases. The literature search was initially limited to studies/articles published since 1995, but with the limited available data, the search was expanded to include literature published as early as 1975 because many of these older studies continue to serve as references for newer studies/articles. The following key words and phrases were used: *neonate, infant, suctioning, endotracheal suctioning, normal saline instillation, suctioning the ETT of neonates, suctioning neonatal ETT, suctioning the artificial airway of neonates, ETT suctioning of neonates, suctioning the neonate, open versus closed ETT suctioning of neonates, catheter insertion depths in neonates, preoxygenation and suctioning neonates,* and *negative pressure and neonatal suctioning.* Once an article was selected for review, the "related articles" links in the search engine were used to view and select additional articles related to the topic in order to expand the search. The reference lists of all articles obtained were searched for related pertinent articles. A total of 62 articles containing original research, expert opinion, or established best practice concerning suctioning the artificial airway were included in the review. Although many of the research studies cited are old, newer research on this topic was not found. Twenty-two articles that related specifically to ETT suctioning of the neonate and infant are included in Table 1.

What Are the Clinical Indications of the Need for ETT Suctioning in Infants and Neonates?

Nine of the 62 articles reviewed addressed the clinical indications for ETT suctioning. Four out of 9 articles were expert opinon level and addressed only adults, 1 neonatal article was expert opinion level, 2 were national surveys, 1 article was a literature review, and 1 included the AARC Clinical Practice Guideline. All 9 articles recommended that the decision to suction should be based on individual patient assessment and identified the followng clinical signs that may indicate the need for suctioning: visible secretions in the ETT, audible secretions, coarse and/or decreased breath sounds, oxygen desaturations, decreased chest excursion, changes in blood gas values, changes in respiratory rate and pattern, bradycardia, patient agitation, and increased proximal airway pressure on the ventilator.[3,4,8–14]

In Intubated Infants Requiring Suctioning, Is Hyperoxygenation More Effective than Hyperinflation in Reducing Complications Associated with the Suctioning Procedure?

Because of the risks associated with ETT suctioning procedures, measures must be taken to prevent complications related to hypoxemia.[10] In survey and review articles, methods commonly used to prevent hypoxemia during suctioning include **hyperoxygenation** and **hyperinflation**.[11,15,16]

Hyperoxygenation. Hyperoxygenation is the administration of oxygen (O_2) at a percentage greater than the patient's baseline requirement up to 100 percent.[7,11,14] Hyperoxygenation techniques include preoxygenation (prior to suctioning), insufflation (providing increased oxygen during suctioning), and postoxygenation (slow wean of oxygen back to baseline). Several studies have been conducted to determine the effectiveness of hyperoxygenation in the prevention of hypoxemia.[15] In our review of the literature, only four studies addressing hyperoxygenation were found, all of which were on small numbers of adult patients and were published in the 1970s and 1980s and, therefore, not listed in Table 1. The use of 100 percent O_2 for preoxygenation prior to ETT suctioning in preterm newborns may lead to hyperoxemia (defined as partial pressure of oxygen in arterial blood [PaO_2] >100 mmHg—probably lower in the very low birth weight [VLBW] infant). Hyperoxemia is associated with oxygen free-radical damage, which is associated with major morbidities such as periventricular leukomalacia (PVL), retinopathy of prematurity (ROP), and chronic lung disease (CLD), which may have serious long-term effects.[17,18] Both hypoxemia and hyperoxemia should be avoided in preterm neonates. In a survey article, Tolles and Stone report that an O_2 increase of 10–20 percent may be sufficient to prevent hypoxemia with ETT suctioning.[12] Increasing oxygen from

TABLE 1 ■ Articles Reviewed Specific to Suctioning the Intubated Neonate/Infant

Reference	Sample	Evidence-Based Questions	Methods	Level of Evidence	Conclusions
Brodsky et al.[39] (1987)	Microscopic pathology at autopsy of 51 LBW infants who underwent uncontrolled deep endotracheal suctioning	What are the effects of suctioning techniques used in the clinical setting on the histopathology of the distal tracheobronchial tree in LBW infants?	Retrospective study. Comparison was made between study infants and 25 infants suctioned to the tip of the ETT only. Study was not randomized or controlled.	IV	Routine suctioning should be performed to the tip of the ETT only. Suctioning should be as brief as possible.
Tolles[12] (1990)	National survey, descriptive research	What are the current suctioning techniques for neonates from institution to institution?	Written survey sent to all of the perinatal and neonatal centers across the U.S.	V	There is a great deal of variation in endotracheal suctioning procedures used in the U.S. 35% of respondents do not hyperoxygenate. Of those who do, it is not a routine procedure but based on past response to suctioning. 87.7% vary the percentage of oxygen used to hyperoxygenate according to the infant's needs, and 4.9% increase oxygen by 10%. 41.9% routinely hyperinflate prior to suctioning using either the ventilator or manual resuscitation bag. 4.9% use in-line suction adapters. 91% use NS to irrigate prior to suctioning. 12.3% follow current guideline of an ID:ED ratio of 1:2 or less. Because the ETTs used in neonates are considerably smaller than those used in adults, it is understandable why the current guidelines are difficult to follow.
Shorten et al.[1] (1991)	25 newborns requiring ventilator care in the NICU	What are the physiologic effects of endotracheal suctioning with and without saline instillation on infants with respiratory distress?	A completely counterbalanced factorial-within subjects design was used to compare 2 treatment conditions: tracheal suctioning without instillation and tracheal suctioning with instillation. The order of treatment was randomized. The same nurses performed both treatment conditions. All suction treatments were supervised by the same investigator.	IV	Under carefully controlled conditions, heart rate and BP are not influenced significantly by saline instillation with tracheal suction compared to suction without instillation.

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baseline requirements should be based on infant response to care, handling, and previous suctioning.

In 1975, Harken studied the effectiveness of 30 seconds of preoxygenation delivered by a manual resuscitation bag on suction-induced hypoxemia. The study group consisted of 11 adult postcardiothoracic surgical patients. Although results revealed no significant rise in PaO_2, the study was limited by small sample size, weak methods, and absence of a control group.[19]

Adlkofer and Powaser conducted a study in 1978 to evaluate the effect of preoxygenation on suction-induced hypoxemia among 64 adult intensive care patients. The control group of 54 patients received no preoxygenation. The 10 patients in the study group received preoxygenation. Preoxygenation was

TABLE 1 ■ Articles Reviewed Specific to Suctioning the Intubated Neonate/Infant (continued)

Reference	Sample	Evidence-Based Questions	Methods	Level of Evidence	Conclusions
Hodge[34] (1991)	The literature is reviewed and a protocol developed for the care of the infant requiring ETT suctioning in the NICU and stepdown unit	What is the relationship between cerebral blood flow velocity in the anterior cerebral arteries and ETT suctioning? Are traumatic sequelae associated with deep ETT suctioning? What is the appropriate catheter size for ETT suctioning? What negative pressure should be used for ETT suctioning? How often should ETT suctioning be performed? Should preoxygenation/ hyperinflation be used? How many catheter passes should be made? Should an irrigant be used?	How the literature search was conducted or articles selected to review was not discussed.	V	Procedures such as suctioning and positioning enhanced fluctuations in systemic BP and cerebral blood flow velocity. Occurrence of pneumothorax resulting from perforation of the lung by suction catheters suggests the need for changes in routine suctioning practices. An appropriately sized catheter that does not totally occlude the ETT allows atmospheric air to continue to enter the lungs during the application of negative pressure. A negative pressure of no more than 50–80 cm H_2O is used for the infant. An infant should never be placed on a routine suctioning schedule. Oxygen saturation and chest expansion should be monitored to determine the appropriate parameters for preoxygenation and hyperinflation, which can then be individualized based on physiologic changes during suctioning. The use of preoxygenation/hyperinflation warrants further investigation to demonstrate its effectiveness in the newborn population The suction catheter is not advanced beyond the length of the ETT. Repetitive catheter passes are not used unless the amount of secretions warrants it. The direct instillation of water or saline as a means of thinning secretions is questionable. If NS is used, it should be instilled just prior to the pass of the catheter to enhance retrieval of the solution. A hazard of saline instillation is the potential contamination of the contents of the saline vial during opening.
Wilson et al.[40] (1992)	97 infants with birth weight <2.5 kg on admission to a single NICU who were ventilated with RDS	Will longer intervals between suctioning (every 12 hours vs every 6 hours) in ventilated neonates with RDS in the first few days of life result in increased number of blocked (plugged) ETTs?	Babies were randomized to receive ETT suctioning either every 6 hours or every 12 hours during the first 3 days of life.	V	It is safe to aspirate ETTs infrequently during the first few days in infants with uncomplicated RDS.
Beeram & Dhanireddy[60] (1992)	18 newborn infants with RDS (9) and meconium aspiration syndrome (9)	What is the effect of NS prior to tracheal suctioning on lung mechanics in ventilated newborn infants?	Single study site. Convenience sample. Each infant served as his/her own control. NS used and then not used. Randomized. The study was not blinded.	II	NS instillation into the trachea during suctioning has no deleterious effects on lung mechanics in newborn infants.

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TABLE 1 ■ Articles Reviewed Specific to Suctioning the Intubated Neonate/Infant (continued)

Reference	Sample	Evidence-Based Questions	Methods	Level of Evidence	Conclusions
Young[16] (1995)	Systematic literature review	What complications are associated with suctioning the intubated neonate? What techniques limit complications of suctioning the intubated neonate?	Search strategy and how articles were selected for review were not well described.	V	Auscultation of all lobes and assessment of infant's activity, tolerance of the procedure, and type and amount of secretions should be part of the respiratory evaluation. Frequency of suctioning should be individualized and based on infant's respiratory status and clinical condition. Nurses must be cautious in using hyperinflation, especially in preterm infants who are susceptible to barotrauma. Hypoxemia and hyperoxemia are undesirable and best avoided. Research to date indicates that oxygen increase no more then 10–20% above baseline is appropriate. A shallow suction technique is supported in the literature. ID:ED ratio of 0.5:0.66 is recommended. This standard is difficult to achieve for VLBW infants due to narrow endotracheal lumen. A 5-6 French gauge catheter approximates this ratio but still almost totally occludes the 2.5 ETT. A vacuum pressure of 50–100 mmHg is safely acceptable for the intubated infant. There are no research-based answers for how long to suction a pediatric patient. The importance of aseptic techniques during tracheal suctioning is generally recognized. Wearing gloves on both hands during suction would reduce the incidence of herpetic whitlow infection of clinicians' hands. Irrigant solutions should not be routinely used. If used, NS 0.9% should be measured at 0.1–0.2 mL/kg and instilled just prior to suctioning.
Schindler[25] (1996)	Systematic review	What are the current strategies used to prevent chronic neonatal lung disease?	Search terms were *bronchopulmonary dysplasia, lung injury,* and *ventilation strategies.* How articles were selected for review was not discussed.	V	Maintaining oxygenation and yet preventing secondary lung disease due to oxygen toxicity and barotraumas are of paramount importance in the management of acute lung disease in the neonatal period. Newer ventilator strategies, monitoring of pulmonary mechanics, surfactant, high-frequency ventilation, nitric oxide, ECMO, careful fluid balances, and avoidances of prolonged muscle paralysis and steroids all have a beneficial role in attaining this goal.

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defined as use of the "sigh" mode on the ventilator without increasing current O_2 percentage delivered or use of a manual resuscitation bag coupled with increasing the percentage of O_2. Patients who did not receive preoxygenation experienced a significant decrease in PaO_2, whereas patients who received preoxygenation experienced no significant change in PaO_2 after suctioning.[20] Limitations of this study included small sample size. In addition, atelectasis, which contributes to low

TABLE 1 ■ Articles Reviewed Specific to Suctioning the Intubated Neonate/Infant (continued)

Reference	Sample	Evidence-Based Questions	Methods	Level of Evidence	Conclusions
Darlow et al.[43] (1997)	8 infants with mean birth weight of 1,900 g and mean gestational age of 32.6 weeks	Is the composition of material obtained by dry shallow ETT suctioning different from that obtained by use of saline lavage and deep suctioning?	11 pairs of dry and saline lavage samples were collected over a 24-hour period. All samples were obtained when suctioning was clinically indicated and in infants judged to have at least moderate tracheal secretions. Six samples were obtained using dry shallow ETT suctioning and 5 using saline lavage and deep ETT suctioning.	IV	There were no significant differences between the lavage and dry aspirates as determined by the Wilcoxon signed rank test. Dry suctioning is as appropriate as saline lavage for obtaining samples of lung secretions for research.
Gannon et al.[30] (1998)	Literature review	What is the current understanding of evidence for pulmonary and neurologic injury and benefits associated with ventilation at both low and high $PaCO_2$ levels? What is the evidence for pulmonary and neurodevelopmental sequelae with various ventilator strategies and devices?	Review of the literature is discussed and recommendations made. How articles were selected for review was not discussed.	V	In general, $PaCO_2$ levels between 40 and 55 mmHg appear to be safe. Clearly, very low $PaCO_2$ levels during hyperventilation can be associated with bad outcomes.
Stenson et al.[28] (1998)	245 neonates without immediate life-threatening congenital malformations, which were mechanically ventilated in the newborn period	Can outcomes of neonatal mechanical ventilation be improved by regular pulmonary function testing?	Random assignment to treatment or control group.	IV	Although primary analysis did not show any substantial benefit associated with regular measurement of static respiratory system compliance, this may reflect a Type II error, and a moderate benefit has not been excluded. Larger studies are required to establish the value of on-line monitoring techniques now available with neonatal ventilators.

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PaO_2 levels or values, may have been significantly improved or eliminated by use of the sigh mode and/or manual bagging.

Lucke conducted a study using 17 adult intensive care patients to compare the effectiveness of using the ventilator sigh mode or MRB with 100 percent O_2. Patients were suctioned using both techniques in random order. Results revealed a significantly greater increase in PaO_2 and oxygen saturations (SaO_2) with preoxygenation using the ventilator sigh mode.[21]

Following a different approach, Rogge and colleagues compared hyperoxygenation using 100 percent O_2 with use of O_2 that was 20 percent higher than the patient's baseline. The study group comprised 11 adult patients with chronic obstructive pulmonary disease. Patients received hyperinflation and hyperoxygenation at one and one-half their calculated tidal volume with either 100 percent O_2 or O_2 20 percent above their baseline using an MRB, followed by 10 seconds of continuous ETT suctioning. This sequence was repeated three times. Results did not reveal a significant difference in SaO_2 values between the two methods. The researchers concluded that hyperoxygenation at 20 percent above baseline is sufficient to prevent hypoxemia.[22]

Though hyperoxygenation appeared to be effective and its use promising in these four adult studies, generalizability of the data to the newborn population was, and is limited. Care must be taken when using oxygen in newborn infants.

TABLE 1 ■ Articles Reviewed Specific to Suctioning the Intubated Neonate/Infant (continued)

Reference	Sample	Evidence-Based Questions	Methods	Level of Evidence	Conclusions
Wrightson[8] (1999)	Systematic literature review	When should an intubated infant be suctioned? How deep should the catheter be passed? How many passes are necessary? Should saline be instilled? Should the head be turned to different positions? Is chest physiotherapy (CPT) warranted? How can hypoxia and desaturations be minimized? How much time is needed to recover after ETT suctioning?	Search strategy and how articles were selected for review were not well described.	V	"Suctioning Smarter" protocols are based on research, not on tradition. We must eliminate harmful suctioning techniques such as frequent and deep suctioning, head turning, and multiple catheter passes. The use of saline instillation and CPT should be questioned. Unit protocols should provide guidance and education. They should teach the nurse how to decide when to intervene and how to interpret patient responses. Comprehensive infant assessment and research-based suctioning protocols will improve outcomes by helping NICU nurses to "suction smarter."
Cordero et al.[51] (2000)	175 LBW infants consecutively born, intubated, and ventilated in the delivery room	Do LBW infants treated with closed vs open tracheal suctioning in an NICU differ as to airway bacterial colonization, nosocomial pneumonia, bloodstream infection, incidence and severity of BPD, neonatal mortality, frequency of suction, reintubation, and nurse preference?	Infants were randomized on admission to the NICU to open vs closed suctioning. Tracheal aspirates were sent for culture on admission and weekly thereafter. Nosocomial infection was documented by positive blood culture after 48 hours of life. Radiographs taken before, during, and after tracheal aspirate culture were graded for pneumonia and BPD. Nurse preference for open or closed suctioning was recorded.	IV	Closed suction alleviates the physiologic disadvantage of ventilator disconnection without increasing the rate of bacterial airway colonization, frequency of ETT suction and reintubation, duration of mechanical ventilation, length of hospitalization, incidence of nosocomial pneumonia, nosocomial bloodstream infection, severity of BPD, and neonatal mortality. Closed suctioning is perceived by nursing staff to be easier, less time-consuming, and better tolerated by small premature infants requiring mechanical ventilation >1 week.

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Hyperinflation. Hyperinflation before suctioning is the second method reviewed for preventing hypoxemia during suctioning. Hyperinflation is defined as an abnormal increase in functional residual capacity; it can be achieved either by increasing the ventilator tidal volume or by using a manual bag. Hyperinflation increases functional residual capacity and can decrease the occurrence of atelectasis and intrapulmonary shunting. (Shunting occurs when alveoli are being perfused but not ventilated because of atelectasis.) The exact degree of hyperinflation needed to prevent a decrease in PaO_2 remains unknown.[13] Complications associated with the use of excessive tidal volumes during hyperinflation include decreased cardiac output and blood pressure as a result of increased intrathoracic pressure, as well as damage to lung tissue because of volutrauma.

In this review, six studies addressing hyperinflation, including barotrauma and volutrauma, were found. Again, these studies were conducted on small numbers of adult patients in the 1980s and 1990s. Lucke conducted a study in 1982 comparing two methods of preoxygenation and hyperinflation during tracheal suctioning, The study included eight medical and nine surgical critical care patients. Subjects were assigned to receive two commonly used methods of preoxygenation/hyperinflation in random order before, during, and after ETT suctioning. The preoxygenation/hyperinflation methods used were sighing generated with a manual resusitation bag connected to 15 liters/minute of wall O_2 or sighing with a mechanical ventilator using 100 percent O_2. Results revealed an increase in PaO_2 and SaO_2 on all patients who received preoxygenation/hyperinflation with the mechanical

TABLE 1 ■ Articles Reviewed Specific to Suctioning the Intubated Neonate/Infant (continued)

Reference	Sample	Evidence-Based Questions	Methods	Level of Evidence	Conclusions
Cordero et al.[36] (2001)	180 consecutively born VLBW infants	Will decreasing suctioning frequency from every 4 to every 8 hours (plus as needed) have no clinically important effect on the primary outcomes of nosocomial bloodstream infection, ventilator-associated pneumonia, bacterial airway colonization, secondary outcomes of reintubation rates, need for postural drainage, severity of BPD, neonatal mortality, duration of mechanical ventilation, or duration of hospitalization?	90 infants stayed on mechanical ventilation >7 days and were suctioned every 4 hours and as needed compared to 90 on mechanical ventilation >7 days who received ETT suctioning every 8 hours and as needed.	IV	Tracheal intubation interrupts the transport of respiratory secretions up the mucociliary escalator, allowing mucus accumulation and inspissation within the ETT, leading to partial or complete tube obstruction. Thus, ETT suctioning helps to maintain an unobstructed airway. Visible secretions in the ETT, acute oxygen desaturations, change in quality of breath sounds, and quantitative and qualitative changes in respiratory secretions constitute objective criteria for ETT suctioning. There is consensus that routine suctioning is no longer justified and that suctioning frequency should be individualized. An every 8 hour plus as-needed ETT suctioning protocol can be implemented without increasing adverse events or neonatal mortality. ETT suctioning should be done as rarely as possible but as frequently as needed.
Pritchard et al.[17] (2001)	Systematic meta-analysis	What are the effects of preoxygenation compared to no preoxygenation for ETT suctioning on ventilated newborn infants?	Meta-analysis search strategies and study selection criteria were well described.	I	No recommendations for practice can be confidently made.
Woodgate[37] (2001)	Meta-analysis	What are the effects of ETT suctioning without disconnection in intubated ventilated neonates?	Search strategy and how articles were selected for review were well defined.	I	There is insufficient evidence to decide between ETT suctioning with or without disconnection. There is, however, evidence of some benefit from performing suctioning without disconnection for some specific short-term outcomes. Further research should be done to fully assess this practice with particular focus on extremely low birth weight infants and different modes of mechanical ventilation and to address clinically important outcomes.
Youngmee & Yonghoon[44] (2003)	27 ventilated high-risk infants in a single NICU, average birth weight 2.092 kg and mean gestational age 33 weeks	What are the effects of shallow and deep ETT suctioning on oxygen saturation and heart rate in high-risk infants?	Experimental within-subject repeated-measures design. The order in which subjects received shallow or deep ETT suctioning was randomly assigned. 4 senior nurses performed the suctioning procedure after in-service education.	IV	There was no significant change in heart rate or oxygen saturation during either deep or shallow ETT suctioning. Deep suctioning did not appear to have any beneficial effect in improving oxygenation. There is a potential hazard of serial application of deep ETT suctioning of direct irritation with negative pressure on the lower respiratory epithelium. Comprehensive reviews on ETT suctioning support using shallow suctioning, possibly without NS.

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Reference	Sample	Evidence-Based Questions	Methods	Level of Evidence	Conclusions
Spence et al.[45] (2003)	Meta-analysis	What are the complications and effectiveness of deep vs shallow suctioning of the ETT in ventilated infants?	Search strategy and selection of articles were well described.	I	There were no randomized controlled trials found. This systematic review has failed to determine whether deep or shallow suctioning of the ETT is more effective or causes less harm for ventilated neonates and infants. Based on the evidence discussed in the background, deep suctioning is potentially harmful to the trachea and bronchi in ventilated neonates. However, there are methodological deficiencies in these studies that limit validity of the findings.
Pritchard et al.[18] (2003)	A systematic review was attempted, but only 3 studies were identified. 2 authors were not reached for clarification. Therefore, only 1 trial was reviewed.	What is the evidence to support routine preoxygenation for ETT suctioning for mechanically ventilated infants?	Key words used for the search were *endotracheal suctioning, newborn, preoxygenation, preterm, systematic review,* and *ventilation.*	VII	No confident recommendations could be made from the results of this review.
Kalyn et al.[35] (2003)	200 infants total: 61 weighed <1,000 g, 72 weighed 1–2,000 g, and 67 weighed >2,000 g	What is the effect of open vs closed suctioning on physiologic variance, recovery time, and complications in intubated infants?	Crossover trial conducted in a single NICU. Each infant was suctioned by 1 of a group of 7 caregivers who were part of the research team. The first suction method was randomly assigned, followed by the alternate suction method after a 90-minute washout period.	IV	Systolic BP increased more significantly with the open suction than the closed method. Although there was no significant difference in mean or diastolic BP, there was a trend toward higher BP with the open method. Following the closed method, the length of time required for the physiologic parameters to return to baseline values was significantly shorter in the closed method group. The authors recommended that closed suction adapters be considered for implementation with all intubated infants.

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ventilator. The PaO_2 and SaO_2 decreased in 35 percent of subjects with the use of an MRB for preoxygenation/hyperinflation.[21] Studies conducted by Stone and associates in 1991 examined the effects of hyperinflation delivered by a ventilator on oxygenation and hemodynamic effects. Thirty-four adult cardiac surgical patients were randomly assigned to receive three hyperinflation breaths at one of five different tidal volumes. Significant increases in mean arterial pressure, pulmonary arterial pressure, pulmonary airway pressure, and cardiac output were observed in all patients. However, the study was limited by its small sample size, and ETT suctioning alone can cause hemodynamic changes.[23]

According to Wainwright and Gould, hyperinflation in conjunction with hyperoxygenation is effective in prevention of hypoxemia during suctioning. However, hyperinflation caused by the use of a manual resusitation bag can cause respiratory damage as a result of variations in tidal volumes and airway pressures.[24]

Barotrauma refers to lung tissue injury resulting from the pressure used to inflate the lungs; it was once believed to be a key factor in the development of CLD in newborns.[25–29] However, recent data suggest that volutrauma rather than barotrauma may be the major causative factor.[26,30] Volutrauma refers to injury to lung tissue caused by overdistention of the lungs when large tidal volumes are used for inflation.[26,28] In a study conducted by Dreyfuss and coworkers, substantial pulmonary edema was observed in rats that were mechanically ventilated using high tidal volumes for 20 minutes. No pulmonary edema was noted in rats that were mechanically ventilated with high PIPs but low tidal volumes.[31] In their

TABLE 1 ■ Articles Reviewed Specific to Suctioning the Intubated Neonate/Infant (continued)

Reference	Sample	Evidence-Based Questions	Methods	Level of Evidence	Conclusions
Clifton-Koeppel[38] (2006)	Literature review	How does ETT suctioning really work? Frequency; how often? What is the role of preoxygenation? Insertion depth: Is there still debate? Which suctioning technique, closed vs open, maintains better physiologic stability and lung volumes? What are the side effects to ETT suctioning? Should NS be routinely used during ET suctioning?	Article selection was not described. Reviewed articles were used to recommend best practice.	V	Secretions should be kept loose with adequate humidification to facilitate the use of small suction catheters at low negative pressure for very short suction duration with fewer repetitions. There are considerable intrapulmonary pressure changes during ETT suctioning in newborns, primarily because of the use of very small ETTs. Performing ETT suctioning on an as-needed basis is prudent. Avoid using 100% oxygen unless clinically indicated. Use of 10–20% oxygen above baseline has not been studied to determine effectiveness in preventing hypoxia. Despite the abundance of anecdotal and case reports and small studies documenting the hazards of deep suctioning, there have been no randomized controlled trials comparing deep vs shallow suctioning. Although no recommendations can be made regarding closed vs open suctioning technique, there appears to be short-term benefit from using the closed system. Implementation of facilitated tucking during ETT suctioning reduces pain associated with the procedure. Routine use of NS should be done with caution.

Levels of Evidence: Level I = Evidence from a systematic review or meta-analysis of all relevant randomized controlled trials (RCTs) or evidence-based clinical practice guidelines based on systematic reviews of RCTs; Level II = Evidence obtained from at least one well-designed RCT; Level III = Evidence obtained from well-designed controlled trials without randomization; Level IV = Evidence from well-designed case-controlled and cohort studies; Level V = Evidence from systematic reviews of descriptive and qualitative studies; Level VI = Evidence from a single descriptive or qualitative study; Level VII = Evidence from the opinion of authorities and/or reports of expert committees

study, Hernandez and colleagues placed casts around the chest walls of rabbits with normal lungs, demonstrating that the use of high peak pressures resulted in no lung injury when tidal volume was limited by chest wall restriction.[32] Carlton and associates conducted a similar study using lambs. By binding the chest walls of term lambs, the researchers were able to demonstrate that the increased lymph flow associated with ventilation using high tidal volumes could be prevented with restriction of chest wall movement even when high PIPs were used.[33] Of the 22 neonatal/infant studies/articles reviewed, 3 addressed hyperinflation to prepare neonates for suctioning.[12,30,34] Limited data are available about the role of hyperinflation in prevention of hypoxia during suctioning of the neonate or infant. The risks of damage to lung tissue, barotrauma, and volutrauma and the potential risk of intraventricular hemorrhage (IVH) caused by changes in cerebral blood flow with decreased cardiac output and blood pressure that may occur with the use of higher tidal volumes suggest that hyperinflation may not be the optimal method of preventing hypoxia during ETT suctioning of neonates and infants.

Insufflation as a technique to achieve hyperoxygenation involves the use of special adapters or catheters that permit continuous ventilation during ETT suctioning. Of the 22 neonatal/infant studies/articles reviewed, 4 addressed the use of insufflation.[12,35–37] Most studies involving insufflation have been conducted in adults. All studies and articles reviewed, including neonatal/infant and adult, revealed that use of these systems decreases hypoxia and the occurrence of ventilator-associated pneumonia (VAP) and that the systems are easy to use. More research is needed to describe potential benefits in the neonatal population.[8]

In Intubated Infants, Is Suctioning Only When Clinically Indicated Compared to Suctioning at Preset Intervals as Effective in Maintaining ETT Patency and Decreasing the Incidence of Infection?

Despite the risks associated with ETT suctioning, failure to suction or inadequate suctioning may be harmful. Because of the small size of the ETTs used in neonates, the risk of ETT occlusion requiring reintubation is high.[38] The optimal frequency of ETT suctioning has not been determined.[7] Our

TABLE 1 ■ Articles Reviewed Specific to Suctioning the Intubated Neonate/Infant (continued)

Reference	Sample	Evidence-Based Questions	Methods	Level of Evidence	Conclusions
Kaiser et al.[5] (2008)	73 VLBW infants intubated during the first week of life	What are the acute effects of clinically indicated suctioning procedure on cerebral hemodynamics of normotensive ventilated VLBW infants with normal cranial ultrasounds? Are changes in cerebral blood flow volume associated with changes in mean arterial BP, $PaCO_2$, or PaO_2?	VLBW infants in a single NICU were enrolled in the study if they required mechanical ventilation and had an umbilical arterial catheter in place. Infants served as their own controls. BP, $PaCO_2$, PaO_2, and cerebral blood flow were continuously measured before, during, and after suctioning. Standard suctioning protocol included: suction only when clinically indicated, no preoxygenation or hyperventilation, wall suction set at 80–100 cm H_2O. If oxygen saturation decreased to <80% or heart rate decreased to <100, several ventilator manual breaths were given. If desaturation and bradycardia continued, fraction of inspired oxygen was increased 10%. If the problem continued, bag and mask ventilation with similar mean airway pressure was administered and additional suction passes delayed until vital signs returned to normal. The process was repeated once or twice more until the airway was clear. Saline was rarely used with tracheal suctioning during the first week of life.	IV	Prolonged increases in cerebral blood flow volume were observed following tracheal suctioning in relatively low-risk ventilated VLBW infants during the first week of life. This is concerning because increases in cerebral blood flow in premature infants and neonatal animals have been associated with brain injury. It is clear that, although necessary, tracheal suctioning should not be routinely scheduled, but performed on an as-needed basis in vulnerable VLBW infants during the first week of life.

Levels of Evidence: Level I = Evidence from a systematic review or meta-analysis of all relevant randomized controlled trials (RCTs) or evidence-based clinical practice guidelines based on systematic reviews of RCTs; Level II = Evidence obtained from at least one well-designed RCT; Level III = Evidence obtained from well-designed controlled trials without randomization; Level IV = Evidence from well-designed case-controlled and cohort studies; Level V = Evidence from systematic reviews of descriptive and qualitative studies; Level VI = Evidence from a single descriptive or qualitative study; Level VII = Evidence from the opinion of authorities and/or reports of expert committees

review documented five studies addressing the frequency of suctioning in neonates and infants.[5,34,36,38,39]

ETT suctioning should be performed whenever clinically indicated, with special consideration for the potential complications associated with the procedure. It may be required at some minimum frequency to maintain the patency of the artificial airway used.[4] Thorough review of available literature suggests suctioning "when clinically indicated" or "as needed." However, the two studies regarding neonatal suctioning addressed suctioning at preset intervals. Study results revealed that suctioning frequency could safely be decreased without increasing the occurrence of ETT occlusions, VAP, nosocomial sepsis, bacterial colonization of the airway, reintubations, severity of bronchopulmonary dysplasia (BPD), duration of mechanical ventilation, length of hospital stay, and mortality.[4,36,40]

Wilson and coworkers conducted a small study between February 1987 and April 1988 to determine if reducing suctioning intervals in mechanically ventilated neonates from every 6 hours to every 12 hours increased the occurrence of ETT occlusion, VAP, or nosocomial sepsis. Ninety-seven low birth weight (LBW) infants with uncomplicated respiratory distress syndrome (RDS), who were mechanically ventilated during the first few days of life were randomly assigned to receive ETT suctioning every 6 hours or every 12 hours. Results revealed no difference in outcomes between the two groups. The authors concluded that it is safe to decrease the frequency of ETT suctioning.[40] Again the study was limited by small size and the preferential selection of infants being treated for RDS in the first three days of life, when mucus production is minimal.

Cordero and colleagues conducted a study to determine if decreasing the frequency of ETT suctioning increased the incidence of nosocomial sepsis, VAP, and colonization of bacteria in the airway. Secondary outcomes included the incidence of reintubation, need for postural drainage, duration of mechanical ventilation, severity of BPD, duration of hospital stay, and mortality. One hundred eighty VLBW infants, defined as weighing <1,500 g at birth, who were intubated for more than seven days were divided into two groups. Group 1 received ETT suctioning every four hours and as needed. Group 2 received ETT suctioning every eight hours and as needed. Infant population and demographics were similar in the two groups. Each group was suctioned in the same manner. Results revealed that suctioning frequency could be safely decreased without increasing the risk of adverse effects.[36]

Neonatal research has focused on suctioning at preset intervals. There is a paucity of evidence to support suctioning neonates and infants only as needed. However, because of the risks associated with the suctioning procedure and damage to the tracheobronchial mucosa, clinical experts concur that suctioning should be based on a thorough clinical assessment and not performed routinely.[1,2,6,7,10,36,38]

What Is the Recommended Suction Catheter Size and Insertion Depth when Suctioning Intubated Infants?

Catheter Size. Based on reviews of five articles, including one relating specifically to infants, the size of the suction catheter should not exceed one-half the diameter of the ETT, providing an internal-to-external diameter (ID:ED) ratio of 0.5–0.66. Using this ratio ensures that air continues to enter the lungs while air is being removed through the application of negative pressure. Use of this size catheter also limits mucosal trauma and atelectasis.[7,13–15,34] It may be difficult to use a suction catheter with the recommended ID:ED ratio in the NICU because of the small size of the ETTs used for preterm neonates. A 5- or 6-French suction catheter almost totally occludes a 2.5 mm ETT but approximates the desirable ID:ED ratio with most of the other ETTs used.[16]

Insertion Depth. When the suction catheter is passed beyond the ETT, stimulation of the vagus nerve may cause bradycardia and hypotension. Prolonged coughing associated with suctioning increases intrathoracic pressure, causing decreased venous blood return to the heart and hypotension.[7] Deep ETT suctioning may cause irritation to the respiratory epithelium, resulting in inflammation and infection.[16,34] It may also result in trauma to the mucosa and adverse effects on the mucociliary transport mechanism of the respiratory tract.[41]

Of the 62 articles reviewed, 11 addressed depth of catheter insertion. Three articles were literature reviews, 4 were expert opinion, and 4 were research studies. The research studies included experimental, animal study, restrospective design, and a randomized-controlled trial.

Shallow ETT suctioning has been defined as the insertion of a suction catheter to a predetermined depth, usually the length of the ETT plus the adapter. In contrast, deep suctioning is the insertion of a suction catheter until resistance is met, followed by withdrawal of the catheter by 1 cm before application of negative pressure.[38]

Brodsky and associates conducted a retrospective study among 51 infants with birth weights <1,250 g, comparing the effects of unconcontrolled deep tracheal suctioning practiced in their NICU in 1977 to shallow suctioning practiced in 1980. Twenty-six intubated infants who were either nasally or orotracheally intubated and underwent uncontrolled deep suctioning were compared to 25 infants who were orotracheally intubated and underwent shallow ETT suctioning. Autopsy reports of these infants were reviewed and compared. Results revealed that, of the 26 intubated infants who underwent deep ETT suctioning, there was tracheal damage in 15 infants, ranging from mild (6) to severe (4). Two infants with mild damage at autopsy had no history of endotracheal intubation. There was no significant tracheal damage seen in 11 of the 26 infants. Autopsy reports of the 25 intubated infants in 1980 revealed tracheal damage in 10, ranging from mild (3) to severe (3). One of the infants in 1980 had no history of endotracheal intubation. There was no significant tracheal damage in 15 of the 25 infants. The study revealed that intubated infants in 1980 had lower birth weights and spent more time on the ventilator than the infants in 1977, suggesting that the mucosal damage was likely due to the deep suctioning technique.[39]

Historically, deep suctioning has been the standard in most NICUs. Bailey and coworkers conducted a study to determine if indeed, deep suctioning was the most commonly used technique in NICUs and to evaluate and compare the amount of airway tissue damage caused by shallow vs deep ETT suctioning. They mailed surveys to 961 physicians practicing in Levels II and III NICUs, asking practitioners if their unit used shallow, deep, or both suctioning techniques and if NS was or was not instilled routinely. Of the 405 responses, 82 percent stated that deep suctioning was standard practice. Seventy-eight percent stated that NS was instilled routinely.[42]

A second arm of this study used young rabbits to evaluate the extent of airway tissue damage that occurs with shallow vs deep ETT suctioning. Rabbits were used because the diameter of the trachea and the microscopic anatomy of the respiratory mucosa are similar to those of human infants. Seven rabbits were intubated. One was used as a control and received no ETT suctioning. Three rabbits received shallow ETT suctioning, and three received deep ETT suctioning. Experienced NICU nurses who were unaware of the purpose of the study performed the suctioning. After the rabbits were euthanized, their tracheas and mainstem bronchi were analyzed. Results revealed that the control rabbit that received ETT intubation but no ETT suctioning had tracheal inflammation, suggesting that the mere presence of a properly placed ETT is an irritant. The rabbits that received shallow suctioning had minimal to no necrosis of the tracheobronchial tissue. The rabbits that received deep suctioning had major disturbances of the tracheobronchial mucosa, increased mucus production, mucosal and submucosal inflammation, and loss of most of the cilia.[42]

Darlow and colleagues conducted a study to determine if secretions obtained from eight infants during shallow, dry suctioning were different from those obtained during deep suctioning using NS. Eleven mucus samples were obtained during shallow, dry suctioning and 11 during deep, lavage suctioning. Infants were suctioned when clinically indicated. Results revealed that the materials obtained with each suctioning technique were similar. The authors concluded that shallow suctioning is as effective as deep suctioning. The secretions were not analyzed for mucus or NS content. Limitations included small sample size and a comparison between two multiple variables: deep vs shallow and dry vs NS instillation. These limitations may have biased the results.[43]

Youngmee and Yonghoon conducted a study to evaluate the effects of shallow and deep ETT suctioning on heart rate and oxygen saturation in neonates. Researchers monitored the heart rate and saturation level of oxygen in hemoglobin (SpO_2) levels of 27 ventilated infants. All infants received both shallow and deep ETT suctioning. Results revealed a significant decrease in SpO_2 during the second suction catheter pass only with the deep suctioning. Results also revealed little change in heart rate with either suctioning technique.[44]

The optimal depth of catheter insertion during ETT suctioning has yet to be determined. A Cochrane review conducted by Spence and associates found insufficient evidence to determine or recommend which ETT suctioning method is more effective and less harmful to mechanically ventilated neonates and infants.[45] Current available evidence suggests that deep suctioning could be harmful to the trachea and bronchi. Therefore, the shallow suctioning technique is recommended.

What Is the Recommended Negative Pressure, Length of Time Negative Pressure Should Be Applied, and Number of Catheter Passes When Suctioning Intubated Infants?

Recommended Negative Pressure. Negative pressure applied during ETT suctioning can damage the mucosa. Damage occurs when tissue and capillaries are pulled into the holes of the suction catheter as negative pressure is applied. The degree of mucosal damage is directly related to the amount of negative pressure utilized, length of time the negative pressure is applied, and insertion depth of the catheter.[39,46] The amount of negative pressure used should be the lowest that adequately removes secretions. Hodge recommends negative pressures of 50–80 mmHg for neonates.[34] Birdsall suggests that negative pressures of 60–100 mmHg are safe for intubated infants.[47] According to the Neonatal Resuscitation Program developed by the American Academy of Pediatrics, the recommended amount of negative pressure is 100 mmHg.[48]

Czarnik and coworkers conducted a study using animals to evaluate the degree of tracheal damage with continuous vs intermittent suctioning. Continuous suctioning is defined as application of negative pressure throughout removal of the catheter from the ETT. Intermittent suctioning is defined as intermittent application of negative pressure during removal of the catheter. Results revealed no difference in the degree of mucosal damage between the two techniques. Results may be flawed, however, because of the negative pressures in excess of 200 mmHg used during suctioning.[41] The use of high pressures with suctioning does not increase the amount of secretions obtained. Therefore, use of lower negative pressure is recommended.[14]

Glass and Grap recommend the application of continuous negative pressure during catheter withdrawal. There is no evidence that intermittent application of negative pressure decreases damage to airway mucosa. Rotation of the suction catheter during removal is not recommended because catheter rotation has not been associated with increased retrieval of mucus and may increase mucosal damage.[14]

Length of Time Negative Pressure Applied. Of the 62 articles reviewed, 5 articles (four expert opinion [one neonatal] and one literature review) addressed the duration of time that negative pressure should be applied during suctioning. The suctioning procedure should be completed in the least amount of time possible. Most researchers recommend limiting the application of negative pressure to 10–15 seconds because longer durations are associated with an increased risk of hypoxemia, mucosal damage, and greater loss of lung volume.[7,13,15,16,49]

Number of Catheter Passes. Six of the 62 articles addressed the number of recommended catheter passes for ETT suctioning. Three of the articles were literature reviews and 3 were expert opinion. The number of catheter passes should be limited to as few as possible to prevent hypoxemia, mucosal trauma, and related injuries. Both catheter size and amount of negative pressure influence the number of catheter passes needed with each time the infant is suctioned. These should be balanced to minimize or prevent complications. Smith suggests that when more than one catheter pass is needed, the patient be given a recovery period between passes. This allows O_2 levels to return to baseline.[49] Glass and Grap recommend limiting catheter passes to no more than three to minimize damage to the mucosa.[14]

Direct stimulation of the respiratory mucosa with negative pressure and the suction catheter may cause laryngeal spasms and bronchospasms and increases the risk of barotrauma.[50] Laryngeal spasms and bronchospasms can lead to respiratory arrest. ETT suctioning should immediately be stopped if bronchospasms occur and postponed until appropriate treatment for the bronchospasms has been rendered.[49] Clinical signs of laryngeal spasms and bronchospasms include tachypnea,

TABLE 2 ■ Studies on the Effect of NS Instillation during ETT Suctioning, Level IV Evidence*

Study	Sample	Method	Instrument	Strengths	Limitations	Results
Hanley et al.[61] (1978)	5 dogs and 2 humans	NS was tagged with technetium, and serial images of NS distribution were recorded over 30 minutes.			Small sample size	NS remained in trachea and mainstem bronchi, with none reaching the periphery of the lungs by 30 minutes.
Bostick & Wendelgass[62] (1987)	45 postop open-heart patients	Subjects were divided into 3 groups that received different amounts of NS (Group 1: no NS; Group 2: 5 mL NS; Group 3: 10 mL NS).	PaO_2 was measured before suctioning and 20 minutes after suctioning with Laboratory 813 Blood Gas Analyzer that was calibrated every 8 hours. Amount of secretions was measured using Fischer Scientific Gram-atic Balance that was calibrated prior to each measurement.	Groups consisted of equal numbers of randomly selected and assigned patients.	Small sample size; single-site study; inability to measure percentage of NS in obtained secretions	There was no significant difference in postsuctioning PaO_2 in either group; however, there was a trend toward lower postsuctioning PaO_2 values with larger amounts of NS. Postsuction sputum weights increased with larger amounts of NS, but the increase was small and not statistically significant.
Ackerman & Gugerty[63] (1990)	26 patients with ETTs or tracheal tubes	Each patient received ETT suctioning without NS and with 5 mL NS.	O_2 saturations were measured before suctioning and 5 minutes after suctioning; amount of secretions was measured.		Small sample size	O_2 saturations decreased immediately after suctioning, with and without saline instillation, but the decrease in saturations was greater with NS installation. O_2 saturations obtained 5 minutes after suctioning increased above baseline when no NS was used, but just reached baseline when NS was used. There was a statistically significant difference in sputum weights (amount was greater with NS), but clinical significance was questionable because sputum was not analyzed.

* Level IV Evidence = Evidence from a single descriptive or qualitative study.

apnea, increased work of breathing, decreased or absent breath sounds, oxygen desaturations, and changes in heart rate.

In Intubated Infants, Is the Open Suction Technique More Effective than the Closed Suction Technique in Minimizing Changes in Baseline Physiologic Parameters and Preventing Atelectasis?

There are two methods of ETT suctioning: open and closed. The open suctioning technique requires disconnecting the neonate or infant from the ventilator. Recovery periods are given between suction catheter passes, and additional breaths are given by MRB or by placing the neonate or infant back on the ventilator. Potential risks or complications associated with open suctioning include hypoxemia; atelectasis; pneumonia; trauma to the airway; sepsis; dislodgment of the ETT; and changes in heart rate, blood pressure, and cerebral blood flow. In contrast, the closed suctioning technique involves attachment of a sterile, closed, inline suction catheter to the ventilator circuit, which allows passage of a suction catheter through the ETT without disconnecting the infant from the ventilator. Mechanical ventilation continues without interruption of positive end expiratory pressure (PEEP). This minimizes changes in oxygen saturation and decreases atelectasis.[7,35,37,38,51,52] Nine articles addressed the use of closed and open suctioning systems, including three

TABLE 2 ■ Studies on the Effect of NS Instillation during ETT Suctioning, Level IV Evidence* (continued)

Study	Sample	Method	Instrument	Strengths	Limitations	Results
Gray et al.[64] (1990)	15 critically ill intubated patients with pulmonary disease	Each patient received ETT suctioning without NS and with 5 mL NS performed 90 minutes apart.	Heart rate, BP, respiratory rate, arterial blood gases (ABGs), arterial blood saturation, amount of secretions obtained, and patient discomfort were assessed before, immediately after, and 15 minutes after suctioning.	There were well-defined, measurable variables; methodology was well described.	Small sample size; single-site study	Statistically significant changes in heart rate, BP, respiratory rates, blood gas, and pH occurred immediately after suctioning in both groups, with no statistically significant differences between methods. All values returned to baseline 15 minutes after suctioning. Cough was elicited more frequently with NS use, and sputum weights following NS use were greater, although the clinical significance was unclear because sputum was not analyzed.
Shorten et al.[1] (1991)	27 newborn infants in respiratory distress who were intubated, had an indwelling arterial line, were "clinically stable" with no change in BP or ventilator settings during the previous 4 hours, had previously received ETT suctioning at least 3 times, and were not sedated	Each infant was suctioned without NS and with NS (0.25 mL for infants weighing <1,500 g; 0.5 mL for infants weighing >1,500 g).	Heart rate, BP, and ABGs were measured before suctioning, immediately after suctioning, and at predetermined intervals after suctioning. Oxygenation was measured using the ratio of arterial oxygen tension to alveolar oxygen tension (a/APO_2).	The suctioning procedure was performed by the same staff member; all suction treatment was supervised by the same research investigator.	Convenience sample; not randomized, same nurse performed suctioning procedures and may have unconsciously deviated from the study procedure based on infant status.	No significant differences in heart rate, BP, or a/APO_2 between those suctioned with and without NS.

* Level IV Evidence = Evidence from a single descriptive or qualitative study.

literature reviews, one meta-analysis, one Cochrane review, and four randomized trials.

Cordero and colleagues conducted a study of 133 intubated LBW infants to evaluate differences in airway bacterial colonization, sepsis, incidence and severity of BPD, neonatal mortality, reintubation, suctioning frequency, and nurse preference between open and closed suctioning techniques. Study participants were divided into two groups. Group 1 received open ETT suctioning, and Group 2 received closed ETT suctioning. Results revealed similar airway bacterial colonization between the two groups. Most of the tracheal cultures were negative during the first week of mechanical ventilation, but by week 2, most infants in both groups were colonized with Gram-positive cocci. Colonization with Gram-negative bacilli was more common by week 3. Five patients in Group 2 developed pneumonia, compared with six in Group 1. Coagulase-negative Staphylococcus sepsis occurred in four infants in Group 2 and three in Group 1. Gram-negative bacilli were responsible for five cases of sepsis in Group 2 and seven cases of sepsis in Group 1. The number of suctioning procedures, reintubations, and the incidence and severity of BPD were comparable between the two groups. Of the nurses surveyed concerning suctioning preferences, most preferred the closed suctioning techniques, stating it was "easier to use, better tolerated by the infants, and less time-consuming" (p. 154).[51]

In a study conducted by Kalyn and associates, 200 infants requiring intubation and mechanical ventilation were assigned to one of three groups based on birth weight (<1,000 g, 1,000–2,000 g, and >2,000 g). The study evaluated physiologic stability during open and closed suctioning. All infants received both open and closed suctioning by a member of the research team. The first suction method performed on each infant was randomly selected, and after a 90-minute rest period, the second method was performed. Physiologic stability was measured using heart rate, respiratory rate, blood pressure (BP), SpO_2, transcutaneous

TABLE 2 ■ Studies on the Effect of NS Instillation during ETT Suctioning, Level IV Evidence* (continued)

Study	Sample	Method	Instrument	Strengths	Limitations	Results
Beeram & Dhanireddy[60] (1992)	9 infants with RDS and 9 infants with meconium aspiration syndrome (MAS) who were intubated and had umbilical arterial catheters in place	Each infant was suctioned 12 hours apart without NS and with 1 mL of NS.	Transcutaneous O_2 saturations, heart rate, BP, and pulmonary mechanics (dynamic compliance, airway resistance, tidal volume, and work of breathing) were measured on the same ventilator settings 10 minutes before; during; and 10, 20, and 30 minutes after suctioning.	Randomized study	Small sample size; convenience sample	In those with RDS and MAS, presence or absence of NS during suctioning had no effect on pulmonary compliance, tidal volume, work of breathing, heart rate, and BP. In those with MAS, decreased airway resistance and increased basal airway resistance occurred with NS, but suctioning without NS had no effect on airway resistance; a transient decrease in O_2 saturation occurred after suctioning with and without NS. In those with RDS, no change in airway resistance occurred during suctioning with or without NS; a transient decrease in O_2 saturations occurred only with instillation of NS.
Ackerman[57] (1993)	40 critically ill, intubated male patients who were aged >40 years	Patients were suctioned as needed with 5 mL NS with every other suctioning.	O_2 saturations were measured before suctioning, immediately after suctioning, and at 1-minute intervals for 5 minutes after suctioning using a Mennon pulse oximeter interfaced with Mennon Horizon 2000 monitors for Medical ICU/ Coronary ICU patients and Hewlett-Packard pulse oximeters for Surgical ICU patients.	Patients served as their own controls.	Small sample size; single-site study	Little difference in O_2 saturations occurred immediately after suctioning, but the effect increased over time, with the instillation of NS having significant negative effects on O_2 saturations at 2, 3, 4, and 5 minutes after suctioning.

* Level IV Evidence = Evidence from a single descriptive or qualitative study.

partial pressure of oxygen ($TcPO_2$), transcutaneous partial pressure of carbon dioxide ($TcPCO_2$), and end tidal carbon dioxide ($ETCO_2$). Results demonstrated no significant difference in baseline heart rate and $TcPCO_2$. Both SpO_2 and $TcPO_2$ levels decreased significantly from baseline with both suctioning methods. The change was greatest, however, with open suctioning. Systolic BP increased significantly more during open suctioning, but there was no significant difference in diastolic and mean BP with either method. Significant decreases in heart rate were noted with each pass of the suction catheter during open suctioning. $ETCO_2$ measurements were statistically lower with open suctioning, though no changes in clinical status were observed. The length of time required for all physiologic parameters to return to baseline values was significantly shorter with closed suctioning.[35] Limitations of the study included use of a small sample size, a single center, and a non-blinded research team member for the suctioning procedure. The

TABLE 2 ■ Studies on the Effect of NS Instillation during ETT Suctioning, Level IV Evidence* (continued)

Study	Sample	Method	Instrument	Strengths	Limitations	Results
Hagler & Traver[59] (1994)	ETTs from 10 ICU patients who were aged ≥18 years and had been intubated for ≥48 hours	ETTs were obtained immediately after extubation, and all ETTs were randomly subjected to catheter insertion and NS instillation. During catheter insertion, a sterile suction catheter was inserted through the entire ETT until a 5 cm length of catheter protruded from the end of the tube. The catheter tube was then cut off with sterile scissors and placed in a sterile container. During the NS instillation procedure, 5 mL prepackaged sterile NS was instilled through the entire length of the ETT, and the liquid was drained into a sterile cup.	Specimens were taken to the lab within 30 minutes after collection and within 90 minutes of extubation. Lab specimens were processed by certified lab technicians. Catheter specimens were processed by sonification in 1 mL NS prior to plating. The NS instillation specimens received no further dilution before plating. Low-range colony counts were identified by simultaneous preparation of a 1:40 dilution plate inoculated by drop from a Pasteur pipette. Bacterial colony counts were taken after 48 hours of incubation in a Forma Scientific incubator.	Randomized, quantitative culture results	Small sample size; bacteria identified in cultures may not be representative of bacteria present in all patients.	Suction catheter insertion dislodged up to 60,000 viable bacterial colonies, and NS instillation dislodged up to 310,000 viable bacterial colonies.
Akgul & Akyolcu[65] (2002)	20 intubated ICU patients being mechanically ventilated for pulmonary or cardiovascular problems or for trauma	Each patient received ETT suctioning with and without NS.	Heart rate, O_2 saturations, and ABGs were measured before and for 5 minutes after suctioning.	Well-defined variables and measurable outcomes	Small sample size; most patients 60–69 years of age with respiratory insufficiency, so results may not be generalizable.	No significant difference in ABGs (pO_2, pCO_2, HCO_3, and O_2 saturation) with or without NS instillation. No significant difference was seen in pH before or 5 minutes after suctioning without NS, but a significant increase in pH followed NS instillation. Significant increases in heart rate occurred at 4 and 5 minutes after suctioning with NS, but no increase occurred when NS was not used. No significant differences were noted in O_2 saturations via pulse oximeter with or without NS use.

* Level IV Evidence = Evidence from a single descriptive or qualitative study.

instillation of NS with suctioning may have contributed to alterations in physiologic parameters.

Mechanically ventilated patients experience a significant loss of lung volume when disconnected from the ventilator. Suctioning may cause further loss of lung volume. Recruitment of lung volume takes place gradually and varies, depending on underlying lung pathology. Choong and associates conducted a study using 14 paralyzed patients, aged 6 days to 13 years, to compare loss of lung volume between open and closed suctioning. All patients received open and closed suctioning in the same manner performed by one of two researchers. Changes in lung volume were measured

TABLE 2 ■ Studies on the Effect of NS Instillation during ETT Suctioning, Level IV Evidence* (continued)

Study	Sample	Method	Instrument	Strengths	Limitations	Results
Ridling et al.[66] (2003)	24 critically ill, intubated patients (aged 10 weeks to 14 years)	Patients were randomly assigned to either Group 1 (which received NS with suctioning) or Group 2 (which received no NS with suctioning).	O_2 saturations were recorded before suctioning and at 1, 2, and 10 minutes after suctioning using a Nellcor pulse oximeter. The number of times ETT became occluded was counted. Occurrences of pneumonia during intubation were also recorded. Data were collected by a nurse who was not involved in the suctioning procedure.	Prospective, randomized study	Convenience sample; small sample size; variety of ages and ETT sizes; number of care providers performing suction procedure not limited	Significant O_2 desaturations lasting up to 2 minutes occurred after suctioning with NS instillation. No ETT occlusions or nosocomial pneumonia occurred in either group.

* Level IV Evidence = Evidence from a single descriptive or qualitative study.

before and during each pass of the suction catheter with respiratory inductance plethysmography. This technique noninvasively measures tidal volume and changes in end-expiratory lung volume. The study revealed greater loss of lung volume with open suctioning, with the most significant loss occurring during disconnection from the ventilator. The loss of lung volume that occurred during the application of negative pressure was comparable between the two groups.[53]

Freytag and colleagues conducted a study to evaluate microbial colonization of closed, in-line suction catheters. Tracheal aspirates, suction catheter tips, and catheter segments were obtained from 23 mechanically ventilated adult patients. The tracheal aspirates and catheters were cultured and microbial growth documented at 24 and 72 hours. The goal was to determine if microbial colonization increased with prolonged catheter use. Participants were divided into two groups. Each participant received two multiple-use, in-line suction catheter systems. In Group 1, the first in-line suction catheter was left in place for 24 hours, then removed and analyzed. The second in-line catheter was left in place for 72 hours before being removed and analyzed. The process was reversed in Group 2. A total of 46 catheter tips and segments was analyzed. Forty-four of 46 were colonized with a variety of Gram-positive and Gram-negative bacteria and yeast. Catheter tips and segments that had been in place for 72 hours had increased microbial growth. However, the difference in microbial growth between the two time intervals was statistically insignificant. A great deal more bacteria and yeast were isolated from tracheal cultures obtained from patients after use of suction catheters for 72 hours.[54]

Woodgate and Flenady conducted a Cochrane review to evaluate the effects of tracheal suctioning without disconnection from the ventilator in intubated neonates. Only two articles met the criteria for their review. Results from the review revealed that, although there was evidence that ETT suctioning without disconnection from the ventilator provided short-term benefits, there was insufficient information to determine best practice between open and closed suctioning on LBW neonates.[37] However, results of two studies conducted by Choong and associates and Kalyn and coworkers after Woodgate and Flenady's review revealed that closed suctioning was associated with fewer changes in oxygen saturation and blood pressure, less atelectasis, and shorter length of time required to return to baseline physiologic parameters. These studies also revealed no increase in number of reintubations, bacterial colonization, or frequency and severity of BPD when comparing closed suctioning to open suctioning.[35,53] Therefore, the use of closed suction systems is recommended for infants and neonates.

Cost is also a major concern when considering the type of suctioning system to use. Cordero and colleagues found that although the cost of the multiuse, closed system suction catheter is higher, when compared with the number of suction catheters used with open suctioning, the costs of the two systems are comparable.[51]

In a meta-analysis conducted in 2007, Jongerden and associates compared the effectiveness of closed suction systems to open on patient outcomes, bacterial contamination, and costs in adult intensive care unit patients. Results revealed no significant differences in the incidence of VAP and mortality between the two suction systems. The closed suctioning system produced statistically significant differences in mean airway pressure and heart rate, both of which were lower with closed suctioning. Prolonged use of the closed suctioning system was associated with increased bacterial colonization of

TABLE 3 ■ Evidence-Based Guideline for Suctioning

Statement	Level of Evidence
1. Suction only as needed based on patient assessment.	I, II, III, V, VI, VII
a. Visible secretions in ETT	
b. Audible secretions	
c. Changes in respiratory rate and/or rhythm	
d. Presence of rhonchi, coarse and/or decreased breath sounds upon auscultation of the chest	
e. Oxygen desaturations	
f. Changes in blood gas values (increased $PaCO_2$ and/or decreased PaO_2)	
g. Bradycardia	
h. Restlessness and agitation	
i. Increased proximal airway pressure on the ventilator	
2. Wash hands and wear appropriate personal protective equipment (PPE).	IV
3. Assess the need for increased O_2.	IV, V, VII
a. If the infant requires increased O_2 for care, increase infant's oxygen to the level required for care.	
b. Assess the infant with each hands-on care for amount of O_2 required to maintain saturations within the ordered limits, and adjust O_2 as necessary.	
4. Select a suction catheter that is less than one-half the diameter of the ETT. Do not use a catheter larger then a number 6 French to suction a 2.5 ETT.	V
5. Insert the catheter so its tip ends at the tip of the ETT and does not touch the carina.	II, IV
a. Insert the catheter to a predetermined length posted at the bedside; line up the centimeter markings on the suction catheter with the centimeter markings on the ETT.	
b. Insert the catheter to the predetermined color marking on the suction catheter when using a closed, inline suction system.	
6. Negative pressure:	V, VII
a. Should not exceed 100 mmHg.	
b. Should be applied only during withdrawal of the catheter.	
c. Should not be applied for more than 15 seconds.	
7. Number of catheter passes:	V,II
a. Should not exceed 3 per suctioning procedure.	
b. Infants should be allowed rest/recovery periods between catheter passes.	
8. NS should ***not*** be instilled routinely.	IV, V
9. After suctioning:	II, IV
a. Reconnect the patient to the ventilator as soon as possible if the open technique is used.	
b. If O_2 was increased, wean to baseline requirement.	
c. Auscultate chest for improvement and/or changes in breath sounds.	
10. Properly dispose of suction material and PPE.	
11. Wash hands.	IV

Levels of Evidence: Level I = Evidence from a systematic review or meta-analysis of all relevant randomized controlled trials (RCTs) or evidence-based clinical practice guidelines based on systematic reviews of RCTs; Level II = Evidence obtained from at least one well-designed RCT; Level III = Evidence obtained from well-designed controlled trials without randomization; Level IV = Evidence from well-designed case-controlled and cohort studies; Level V = Evidence from systematic reviews of descriptive and qualitative studies; Level VI = Evidence from a single descriptive or qualitative study; Level VII = Evidence from the opinion of authorities and/or reports of expert committees

the device, but was not associated with increased incidence of VAP. Data obtained during their meta-analysis did not support the concept that the closed system was more cost-effective than the open system.[55]

In Intubated Infants, Is Instilling Normal Saline (NS) or Not Instilling NS More Effective in Removing Secretions from the Endotracheal Tube and Maintaining ETT Patency?

Instillation of NS during ETT suctioning has become a common practice in the care of intubated neonates and infants. However, there is no recent evidence supporting its use or benefit.[56] The rationale for the use of NS is to loosen secretions, lubricate the suction catheter, increase secretion removal, elicit a cough reflex, and mobilize and thin secretions.[57] Risks associated with the instillation of NS include many of the same risks as ETT suctioning without it, such as cardiac dysrhythmias, hypoxemia, atelectasis, bronchospasm, infection, trauma to the mucosal linings and cilia of the airway, and increased intracranial pressure, which may be more pronounced due to the addition of the added liquid to the trachea. Instillation of NS into the trachea may introduce bacteria that colonize the upper airway into the lower airway. This may increase the risk for VAP.[3]

Numerous studies have been conducted over the past 35 years regarding the use of NS during ETT suctioning. These have addressed concerns such as the effects of NS use on physiologic parameters, blood gases, oxygen saturation, dislodgment of bacteria from the upper airway into the lower airway, and thinning and amounts of secretions. Few studies supported NS use. However, there is an abundance of available data that address the adverse effects and complications associated with the use of NS (Table 2). Therefore, the routine instillation of NS during ETT suctioning is not recommended.[2,3,56–59]

RESEARCH IMPLICATIONS

Data regarding ETT suctioning of neonates and infants are limited, and generalization of data obtained from adult studies can be difficult. Limitations of previous studies include small sample sizes, few randomized studies, poorly described methodology, and lack of blinding of researchers directly involved with the study procedures and data collection. More research is needed to evaluate suctioning technique in mechanically ventilated neonates and infants.

Studies should address patient preparation, including the role of preoxygenation, and make specific recommendations for maintaining physiologic arterial oxygen levels during suctioning that are appropriate for neonates and infants of different gestations and respiratory pathology. This would potentially limit production of oxygen-free radicals, which have been implicated in ROP, IVH, and PVL.[17,18] Investigation of the safety and necessity of NS instillation and the effects of its use on all physiologic parameters of neonates and infants of different gestations and pulmonary disease states is needed. Future studies should investigate the appropriate amount of negative pressure to use and the effect of closed vs open suction techniques on the incidence of VAP, airway microbial colonization, and nosocomial sepsis. Studies should utilize larger sample sizes, be multicentered to ensure appropriate representation of all populations, and be randomized when possible. Caregivers and data collectors should be blinded to the purpose of the study and to the arm of the study (intervention vs control) patients are in.

CLINICAL IMPLICATIONS

Nurses and respiratory therapists need to be thoroughly educated about respiratory conditions specific to their patient population—specifically, patients requiring intubation and mechanical ventilation. They must have proficient assessment skills and recognize changes in clinical condition that indicate the need for suctioning. Performance proficiency in the suctioning procedure and knowledge of the risks and benefits of suctioning are imperative (Table 3).

ETT suctioning should be performed only when clinically indicated, based on patient assessment. Clinical signs include changes in respiratory rate and pattern, visible secretions in the ETT, secretions audible with respirations, coarse and/or decreased breath sounds upon auscultation of the chest, oxygen desaturations, increased $PaCO_2$, decreased PaO_2, bradycardia, patient agitation or restlessness, and changes in the proximal airway pressure waveform on the ventilator.

Once the need for suctioning has been established, the patient should be adequately prepared for the procedure to prevent hypoxemia. The need for preoxygenation should be assessed, taking into account previous response to care, handling, and suctioning.[22]

Catheter size should not exceed one-half the diameter of the ETT.[7,14,34] The catheter should be inserted so that the catheter tip ends at the tip of the ETT and does not touch the carina.[16,38,39] Negative pressure should not exceed 100 mmHg and should be applied only during withdrawal of the catheter for no more than 15 seconds.[13,48,49] The number of catheter passes should be kept to the minimum necessary and should not exceed three.[14] Infants should be given rest breaks between catheter passes to allow oxygen levels to return to baseline.[49]

Sterile NS should *not* be instilled during ETT suctioning. Small amounts of sterile NS may be used after suctioning to cleanse the catheter only in closed, inline suction systems.

As soon as the suctioning procedure is completed, the infant should be reconnected to the ventilator if the open suction method was used. The chest should be auscultated for improvement or changes in breath sounds. Oxygen should be weaned and the infant continuously monitored until all physiologic parameters have returned to baseline values.

Implementing this evidence-based guideline will decrease the risks of suctioning. These risks include physiologic instability, pneumonia, tracheal injury, hyperoxygenation, and the stress of a potentially uncomfortable procedure. Following the guideline should potentially improve outcomes for the intubated neonate or infant.

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Trichophyton tonsurans— Ringworm in an NICU

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Ringworm is a common fungal infection of the skin of children and adults, but it is rare in neonates, especially in those who have never left a modern intensive care unit. We report such a case of dermatophytosis caused by *Trichophyton tonsurans* in a 23-day-old premature baby, which responded quickly to the application of topical miconazole 2 percent cream.

Abstract

Ringworm is very rarely found in the neonate, especially infants who have been confined from birth to an intensive care unit. We report an infection with the dermatophyte *Trichophyton tonsurans,* the most common cause of tinea capitis in children but not yet described in a premature baby who has never left the nursery. Our case illustrates the need to consider this diagnosis among the causes of dermatitis in the newborn, especially in at-risk populations such as indigenous Australians. Though our infant's presentation was the classic "ring" shape, a literature review revealed varied presentations. In contrast to the usual need for long-term antifungal medication, our case responded rapidly to a topical azole preparation. Although we did not screen visiting family members, screening would have been appropriate, and those found positive might have benefited from at least antifungal shampoo.

CASE REPORT

A male infant, Baby Y, was born at 31 weeks gestational age by spontaneous vaginal delivery to an Aboriginal mother after premature and prolonged rupture of membranes (33 hours). Limited antenatal care meant that maternal history data were unavailable. The infant weighed 1,840 g at birth, which was appropriate for his gestational age. Not requiring any respiratory support, he was upgraded to full enteral feedings fairly quickly. On day 10, he began having apneic episodes with bilious aspirates. An abdominal x-ray showed signs of possible necrotizing enterocolitis (NEC), so feedings were stopped and intravenous therapy begun. A 7-day course of triple antibiotic therapy, consisting of penicillin, gentamicin, and metronidazole, was administered. When the antibiotic course was completed, feedings were restarted and the infant was once again on full feedings by day of life 19. At 20 days of age, the infant experienced a recurrence of the bile-stained aspirates, again causing concern that the problem was attributable to NEC. He was therefore transferred from the special care nursery to our tertiary center for neonatal intensive care.

Oral feedings were discontinued and total parenteral nutrition (TPN) and triple antibiotic therapy were begun. He was cared for in an open care cot (open crib). On examination, the infant was pink, active, and well-perfused. Despite an abdominal x-ray showing no evidence of *pneumatosis intestinalis,* this management continued for 10 days. Blood cultures were negative. The infant received TPN for 16 days, at which point he was placed back on full feedings.

On DOL 23, the infant developed a pink, macular, elevated rash on his right cheek, which advanced peripherally over the next day (Figure 1). It became paler in the middle and, with its distinct outer edge, developed a ringlike appearance. Skin swabs for bacterial culture revealed normal skin flora. Scrapings of the edge of the rash with a scalpel blade, after preparation with potassium hydroxide in the laboratory,

Accepted for publication October 2008. Revised December 2008.

FIGURE 1 ■ Ringworm on the cheek, spreading centrifugally and marked by an inflammatory reaction.

revealed microscopically the presence of fungal hyphae and microconidia. After a week, the fungal growth was identified as *Trichophyton tonsurans.* In the meantime, the ringworm was treated with local application of miconazole 2 percent cream four times a day. The rash improved within 1 day and had disappeared by the 4th day, at which point treatment was stopped. The rash did not reappear. The mother had no obvious fungal infection of her hands, face, or scalp, but cultures were not taken. At this time, the infant was on gavage feedings of expressed breast milk and Pepti-Junior (Nutricia, Asia-Pacific Ltd.), a semi-elemental formula based on medium-chain peptides.

PATHOPHYSIOLOGY

Fungi are composed of long branching filaments with relatively stiff cell walls, known as *hyphae.* They reproduce by creating spores called *conidia* (Figure 2). It is the appearance of these components, their behavior clinically, and their reaction to various staining and culture techniques in the laboratory that permit classification of the genus and species of dermatophytes. It is believed that 1.5 million species of fungi inhabit Earth, playing a fundamental role in the decomposition of dead plants and animals and the subsequent recycling of chemicals.[1] It is fortunate that only a few are pathogenic to humans, whereas some are very helpful with their production of antibiotics, such as penicillin.[2] The antibacterial effect of penicillin was discovered by Alexander Fleming in 1929, when he noted that a fungal colony *(Penicillium notatum)* had grown as a contaminant on an agar plate streaked with the bacterium *Staphylococcus aureus* and that the bacterial colonies around the fungus were transparent because their cells were lysing.[3]

Of the pathogenic fungi, only three genera are described as dermatophytes because of their tendency to infect human skin. They are Trichophyton and Epidermophyton, which are mostly anthropophilic, passing from human to human host, and Microsporum, a mostly zoophilic fungus going from animal hosts (especially dogs and cats) to humans. Aided by dissolving keratin enzymes and other components, from which they gain their nutrition, these fungi enter the host through breaks in the skin. They then spread outward in the superficial layer, the stratum corneum. Penetration into the deeper layers of the dermis is rare.[4] No case of systemic infection has been reported in either the adult or premature infant.

The body reacts to the invasion by mounting an inflammatory response with, in particular, neutrophils accumulating at the site through cell-mediated immunity. The protective role of circulating antibodies is minimal. The fungus multiplies rapidly (remember, mushrooms can appear overnight!), growing outward. This centrifugal progress is revealed by the associated redness, mild swelling, and scaliness of the inflammatory reaction at the aggressive edge, leaving a pale interior—hence, the "ringlike" form.[5] Occasionally, there is a more enthusiastic reaction, with production of vesicles, pustules, nodules, and exudate, and secondary bacterial infection. This is particularly so with infection of the hair follicles of the scalp. The latter can evolve into a boggy area of induration known as a *kerion.*[4]

Fungal infections are typically described by their site of infection. Thus, *tinea capitis* is a fungal infection of the scalp; *tinea corporis,* of the body; and *tinea pedis,* affecting the foot.[6]

The infant in our case report was infected with a member of the Trichophyton genus of dermatophytes, which characteristically causes inflammatory or chronic noninflammatory, fine, scaly lesions of the skin, nails, and scalp. On laboratory testing, the agent was identified as the species *T. tonsurans* (Figure 3). Infection with this species has been described on hairless skin of neonates who had contracted the infection in the community.[7,8] Review of the literature fails to reveal reports of its occurrence within a modern special care nursery, although infection with other dermatophytes, such as *T. rubrum,* has been described.[9,10]

INCIDENCE

T. tonsurans is a common dermatophyte in both Aboriginal and non-Aboriginal communities in Australia, where, as in North America, Europe, and Asia, it has replaced the zoophilic *Microsporum canis* as the most common cause of *tinea capitis.*[11] In one child care center in North America, *T. tonsurans* was "conservatively confirmed in at least 22.4 percent and as many as 51.3 percent of the total population in any given month" (p. 2367).[12] In the U.S., *T. tonsurans* is found particularly in African Americans; in England, it is "epidemic" in immigrants from Africa; and in Spain, it is mostly associated with immigrants from Africa.[13–15] In some indigenous communities in North Australia, including the one in which the mother of Baby Y lived, ringworm is also described as "epidemic" (R. Messer [pediatrician, Cairns Base Hospital, Qld., Australia],

FIGURE 2 ■ Filamentous and budding hyphae and small round conidia, or reproductive spores, of *T. tonsurans.*

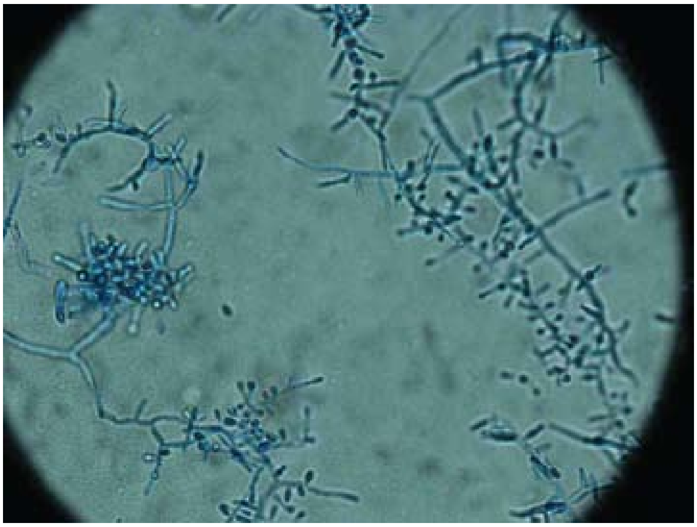
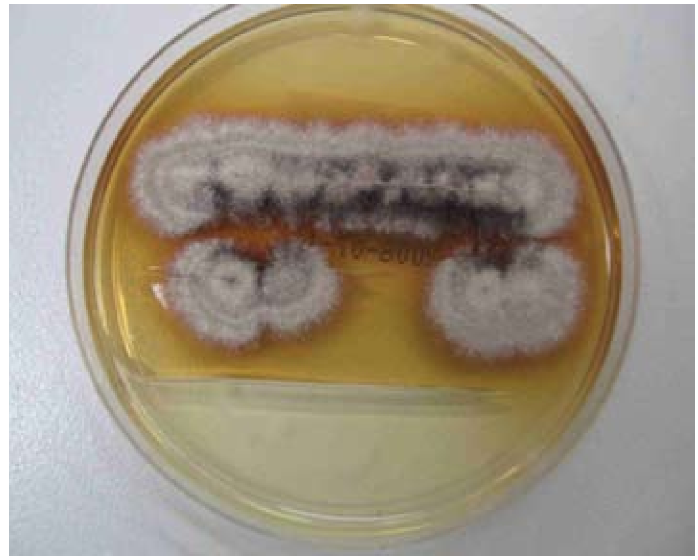


FIGURE 3 ■ *T. tonsurans* growing on laboratory medium.

The collection of filamentous hyphae, called a mycelium, produces the fungus's fluffy appearance.



2008, personal communication). The health and well-being of indigenous Australians is poor. Overall, they experience lower levels of access to health services than the general population, are more likely than nonindigenous people to be hospitalized for various diseases and conditions, and are more likely to experience disability and reduced quality of life as a result of ill health. Health care for this group presents challenges because their access to medical staff is limited by the rural nature of their communities; most health concerns are addressed by Aboriginal health workers and rural nurses.[16] Recruitment of medical staff is mainly to metropolitan areas, where the lifestyle is more attractive.[17]

When Baby Y's mother visited her child in the NICU, she exhibited no obvious skin lesions. There was no particular reason for her baby's susceptibility to this infection, apart from the general vulnerability of a premature baby in a warmed environment. Our unit has a family-centered approach to care, founded on a collaborative- and relationship-based model of family advocacy and empowerment, with open and honest communication.[18–20] Parents are involved in the care of their baby and updated regularly on progress. As it is with all families of infants in our NICU, the importance of hand washing was also discussed with this family. Given that ringworm is epidemic in indigenous communities, and that approximately 15 percent of the infants in the NICU are of indigenous families, it is surprising we have had only one similar infection.

DIAGNOSIS

Diagnosis of *T. tonsurans* infection is based on microscopic findings from skin scrapings taken from the edge of the lesion and from results when the sample is incubated on Sabouraud media, using chloramphenicol and gentamicin as selective agents. In our case, after a week the fungal growth was identified as *T. tonsurans.* Unlike some of the dermatophytes, *T. tonsurans* cannot be identified with the fluorescent Wood's lamp, leaving many cases undetected.[5]

There is thought to be a high prevalence of undetected *T. tonsurans* in household contacts of the index case (the first person who presents as ill and draws attention to a family), particularly in children. Vargo and Cohen would suggest that we should have taken scalp scrapings with a toothbrush from such contacts of Baby Y and cultured the scrapings. This would have identified asymptomatic carriers and reduced the reservoir of disease and the potential for reinfection.[21]

TREATMENT

Modern treatment of fungal infections, in general, involves attacking the production or integrity of the cell wall of the fungus with polyenes such as amphotericin, allylamines such as terbinafine, or azoles such as fluconazole. Griseofulvin was traditionally used because of its interference with microtubules within the fungus. Not surprisingly, all these treatments have side effects, such as headache, nausea, transient rash, diarrhea, and photosensitivity.[5] The polyenes, however, have a greater number of such side effects and are therefore reserved for serious systemic fungal infections. Most treatments are given intravenously or orally, but several of the azoles, including miconazole 2 percent, clotrimazole 1 percent, and bifonazole 1 percent, are available for topical application, where they are generally well tolerated with only occasional local irritation.[2] Positive contacts would historically have been treated with griseofulvin, but more recent reports suggest that 2 percent ketoconazole shampoo may be more effective. This treatment is more likely to achieve compliance than a prolonged course of oral medication.[22]

We are pleased that Baby Y responded well to topical miconazole 2 percent cream. There is a reported need for weeks of oral therapy with such drugs as terbinafine and griseofulvin for children with *T. tonsurans tinea capitis.*[13] We believe that restriction of the infection to the cells of the skin without involvement of the follicles on the neonate's scalp was the reason for this positive response. Also, this infection remained localized. Had it been widespread or complicated with kerion, nontopical therapy may have been appropriate, although the safety of some of the proposed enteral drugs has not yet been established for the neonatal population. Response of other dermatophytes to topical therapy in the nursery is not new; topical treatment has been used effectively in a 21-day-old neonate with *T. tonsurans* infection of the face. He had acquired this in the community and required hospitalization.[10,23]

CONCLUSION

Our case report and review of the literature emphasize the need to consider dermatophytosis in the differential diagnosis of dermatitis in the newborn and also the need for confirmation through appropriate laboratory testing. Scrapings of the advancing edge or the base of vesicles need to be secured for this testing. Vigilance with regard to hand washing should be emphasized. Topical antifungal therapy was effective in this case. We should have, however, screened contacts of Baby Y and, at least, offered ketoconazole shampoo.

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Transthyretin (aka Prealbumin): Why Is It Part of TPN Labs?

Column Editor
Patricia Nash, MSN, NNP-BC

As in other NICUs, our patients on total parenteral nutrition (TPN) have routine labs done for monitoring. In our unit, these labs include electrolytes, hemoglobin, triglycerides, liver function studies, and transthyretin (TTR) (still called prealbumin). In polling the other neonatal nurse practitioners, I realized that none of us completely understood the utility of following the TTR level. That was the impetus for this column.

A review of the literature searching the terms *transthyretin* and *prealbumin* produced numerous articles in the 1980s, but very few since 2000. Perhaps the reason is that the physiology and utility of TTR are already well understood by those well versed in nutrition. For the rest of us, this article reviews the physiology and usefulness of TTR as a nutritional marker in the neonatal population.

PHYSIOLOGY

Transthyretin is a protein synthesized in the liver.[1–5] It has four identical subunits and a relatively large molecular mass of 54,980 daltons.[2,5,6] Hepatic synthesis of TTR requires adequate oral or parenteral amino acid intake. It functions as a carrier, or transport protein, and in that capacity has two primary roles. Transthyretin acts as a minor thyroxin-binding globulin.[2,4–6] It also binds with the retinol binding protein–vitamin A complex to form a ternary (chemical complex containing three elements), thus stabilizing that complex and preventing it from filtration by the renal glomeruli during transport to target tissues.[1–9]

USE AS A NUTRITIONAL MARKER

Evaluation of feeding tolerance and anthropometric measurements is fundamental in the assessment of neonatal nutritional status.[1,2,10–12] Unfortunately, weight can be complicated by fluid retention and may vary with protein and electrolyte intake.[1,2] Length and head circumference are prone to measurement imprecision. Therefore, the nutritional status in the high-risk neonate must also be followed by laboratory studies.

Serum albumin levels have long been used as an index for evaluating protein energy status. Albumin's long half-life (15–20 days) limits its usefulness, however, especially in assessing acute nutritional depletion.[6,10–13] Transthyretin has a half-life of only 1.9 days and is therefore more reflective of short-term changes in nutritional status than is albumin.[1–4,8,11–14] The TTR level decreases in a catabolic state and as a result of acute stress injury—and thus is considered an indirect indicator of hepatic protein synthesis.[15]

Transthyretin has been used to monitor protein energy nutritional status in hospitalized adults.[14] Levels decrease promptly if the adult fasts or is malnourished, but normalize rapidly after the patient receives adequate nutritional support.[4] Transthyretin has also been used when evaluating children with kwashiorkor (protein malnutrition with swollen abdomen and weight loss) and has been found to be a very sensitive indicator of protein energy malnutrition.[10,13]

Studies in preterm neonates have also shown that TTR is sensitive to changes in amino acid intake and can be used as a biochemical marker of nutritional adequacy.[3] In a study of 17 infants ≤1,000 g, Moskowitz and colleagues found TTR to be a more sensitive indicator of nutritional intake than growth measurements and more sensitive than albumin in detecting short-term protein calorie deficits. In the infants they studied, TTR correlated with current protein intake, and the TTR level increased to that of a term infant when the protein intake exceeded 2 g/kg/day.[1] In a 1986 study, Helms and associates found that TTR levels varied with neonatal nutritional status prior to anthropometric changes.[16] Georgieff and coworkers studied 26 preterm infants and showed that TTR levels responded to same-week changes in nutritional intake and predated and predicted subsequent changes in growth velocity by one week.[14] Another study of 20 noninfected infants by Yoder and colleagues suggests, that TTR may serve as an indicator of the efficacy of nutritional support in noninfected infants with protein-calorie malnutrition.[6] This suggestion has been supported by later studies. In a 1990 study of 28 very low birth weight infants by Polberger and associates, TTR was shown to have a significant positive correlation with mean protein intake and not total energy intake. Transthyretin was also shown to strongly correlate with weight and length, as well as other indicators of protein nutritional status.[10] Finally, Delgado and coworkers found a positive linear correlation between TTR and the efficacy of parenteral support in 17 critically ill infants.[12] These studies show that TTR is valuable in assessing the adequacy of protein intake and, thus, nutritional status in neonates. They also indicate that changes in TTR likely occur prior to changes in weight, length, and head circumference, giving the clinician the opportunity to intervene before changes in growth velocity occur.

SERUM TTR LEVELS AND FACTORS THAT INFLUENCE THEM

Serum TTR levels are low during fetal life, but increase throughout gestation.[3,11,17] Serum TTR levels are lower in

TABLE 1 ■ Normal TTR Levels for Term and Preterm Infants

	Term Infants	Preterm Infants
Serum TTR level	7–39 g/dL	5–20 g/dL

Adapted from: Robertson, J. (2005). Blood chemistries and body fluids. In J. Robertson & N. Shilkofski (Eds.), *The Harriet Lane handbook: A manual for pediatric house officers* (p. 668). Philadelphia: Elsevier Mosby; and Siner, B. S., & Newman, N. S. (2002). Tables of normal values. In A. A. Fanaroff & R. J. Martin (Eds.), *Neonatal perinatal medicine: Diseases of the fetus and infant* (7th ed., p. 1653). St. Louis: Mosby.

term infants than in adults.[17] They are significantly lower in preterm than in term infants (Table 1).[8]

Conditions other than nutritional status can affect serum TTR levels. In fact, TTR has been identified as a negative acute-phase reactant. This means that as acute-phase reactants, such as C-reactive protein, increase in response to inflammation and acute infection, TTR levels decrease.[6,7,10,15,18] TTR levels also decrease following trauma and surgery and with liver disease, neoplasia, and decreased concentrations of cofactors such as iron and copper.[1,6,11] Likewise, TTR levels are significantly decreased in critically ill infants.[15] Conversely, exogenous treatment with glucocorticoids or the endogenous production of stress hormones increases serum TTR levels.[4] There is also a rapid increase in TTR during the recovery phase following respiratory distress syndrome.[1]

CLINICAL/NUTRITIONAL APPLICATION

Nutritional support of the neonate begins upon admission to the NICU, regardless of size or gestation. Amino acid solutions are generally started on admission, in an attempt to maintain a positive nitrogen balance and to prevent even short-term malnutrition. In the preterm infant, the standard for postnatal nutrition is the duplication of normal fetal growth and body composition. An increase in protein mass is a measure of true growth, which in turn is based upon nutritional protein intake. Protein gain generally increases linearly with protein intake over an intake range of 0.5–4 g/kg/day. Some researchers have observed that the protein need may be much higher in certain infants, up to 4.5 g/kg/day.[19] Consequently, tools such as TTR levels, which can be done by most hospital laboratories, can aid the clinician in determining protein need in individual patients. Because TTR has such a short half-life, nutritional support can be altered based on current protein accretion. TPN can be changed, feedings can be increased, or protein supplements can be added to feedings. These changes can be made in real time, before growth velocity is negatively affected.

CONCLUSION

Protein energy malnutrition may be related to significant morbidity in the high-risk neonate.[14] Consequently, these infants require close surveillance with markers that are easy to obtain, reflect recent changes in nutritional intake, and can potentially predict future changes in nutritional status before deleterious events such as decreasing weight and brain growth velocity can occur.[4] Transthyretin is part of our TPN laboratory studies because it is a nutritional marker of protein energy and thus can be used in determining the adequacy of protein intake parenterally or in combination with oral feedings. Compared with albumin, it more accurately reflects acute changes in protein nutrition because of its short half-life. TTR levels decrease rapidly in response to fasting and to protein malnutrition. Conversely, it increases rapidly as protein intake improves, and it appears to predate anthropometric changes by one week. Transthyretin levels, though, are affected by other factors, such as gestational age, degree of illness, inflammation, infection, and surgery. Therefore, to assess the adequacy of nutritional intake, TTR levels cannot be looked at in isolation, but only as part of the entire clinical picture.

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