Interventions to Improve Oral Feeding Performance of Preterm Infants

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Abstract

This review presents a summary of our current understanding of the development of preterm infant oral feeding skills, the feeding issues they are facing, and evidence-based approaches that facilitate their transition from tube to oral feeding.

The field of infant oral feeding research is understudied as the recognition of its importance truly came about with the increased preterm population and the realization that a large number of these infants are not safe and competent oral feeders. It is understandable that this research has taken a “back seat” to the more immediate concerns of saving these babies’ lives. However, the time has now come when these infants make up a large proportion of patients referred to feeding specialists for unresolved oral feeding problems during their stay in neonatal intensive care units (NICUs) as well as post-discharge. Unfortunately, due to the limited research so far conducted in this domain, available therapies are limited and lack evidence-based support. Fortunately, this growing medical concern is stimulating deeper research interests and funding.

It is hoped that the information provided will assist the development of systematic differential diagnostic approaches to address infant oral feeding issues.

This review is a summary of our understanding of the development of oral feeding skills in infant, the feeding issues they face, the evidence-based interventions that can facilitate their transition from tube to oral feeding, and the translational impact that these approaches may have for current practices. The information is also relevant to term neonates exhibiting similar difficulties as together preterm and term infants reveal the developmental continuum of the human neonate.

As the survival of preterm infants is increasing due to medical advances, concerns of health professionals and families are shifting towards resolving pragmatic issues such as infants’ ability to feed by mouth. The American Academy of Pediatrics (AAP) recommends that attainment of independent oral feeding be a major criterion for hospital discharge (AAP Policy Statement, 2008). Consequently, infants’ inability to reach this milestone often extends their hospitalization, increases financial burden, and very importantly, delays mother-infant reunion. Potential long-term feeding aversion further adds to the overall concern of how to optimize oral feeding performance in this population of newborns.

The field of infant oral feeding research is understudied as the recognition of its importance truly came about with the increased preterm population and the realization that a large number of these infants are not safe and competent oral feeders. It is understandable that this research has taken a backseat to the more immediate concerns of saving these babies’ lives. However, the time has now come when these infants make up a large proportion of patients
referred to feeding specialists for unresolved oral feeding problems during their stay in neonatal intensive care units (NICUs) as well as post-discharge. Unfortunately, due to the limited research so far conducted in this domain, available therapies are limited and lack evidence-based support. Fortunately, this growing medical concern is stimulating deeper research interests and funding.

In general, for any illness, medical managements only proceed following an adequate understanding of the symptoms and cause(s) leading to them. Thus, prior to any treatment, a differential diagnosis is first advanced based on a systematic review of potential pathophysiologies implicated (i.e., an attempt to narrow down the most probable candidates at the root(s) of an illness). With such approach, caregivers, by process of elimination, develop roadmaps/algorythms for how to best proceed with the care of individual patients.

Infants’ inability to feed by mouth is not an illness, but rather a drawback as their physiologic functions are not yet mature to confront their extra-uterine environment. As such, management of infant oral feeding issues would benefit from the differential diagnostic model followed by medical teams. To do so, one must first gain an understanding of the extra-uterine maturational processes of the physiologic functions implicated in oral feeding so that, at any time in the course of these infants’ development, tasks asked of them can be tailored around their functional maturity levels. Identification of the functions most likely at the origin of the observed symptoms would direct interventions toward protecting, correcting, or enhancing their functionality (e.g., sucking, swallowing).

Such understanding can best be attained by following the growth and development of feeders and growers who have no specific medical issues besides their prematurity. What we learn from these infants will help us devise efficacious therapies that take into account their continuously maturing skills. Once this milestone is attained, we will be better prepared to address more complicated cases with infants who, in addition to their prematurity, present with additional pathologies (e.g., poor lung function, cardiac anomalies, intraventricular hemorrhages, or genetic anomalies).

**Development of Infant Oral Feeding Skills**

The ability of infants to suck and transport a bolus from the oral cavity to the stomach safely and efficiently requires the proper development of sucking, swallowing, respiration, esophageal function, and, most importantly, the coordination of all these activities.

**Nutritive Sucking**

Nutritive sucking comprises two components: suction and expression. Suction corresponds to the generation of an intraoral negative pressure to draw liquid into the mouth (i.e., similar to drinking from a straw). This is achieved by closure of the nasal passages by the soft palate, the tight seal of the lips around the breast or bottle nipple, and lowering of the lower mandible (Wolf & Glass, 1992, p.18). Expression relates to the positive pressure exerted by the tongue against the hard palate by compression or stripping to eject milk (Lau, Sheena, Shulman, & Schanler, 1997; Waterland, Berkowitz, Stunkard, & Stallings, 1998). A descriptive scale of the emergence and maturation of these 2 components has been published (Lau, Alagugurusamy, Schanler, Smith, & Shulman, 2000). It is characterized by 5 sequential steps: (1) appearance of expression; (2) expression acquires rhythm; (3) appearance of suction; (4) suction acquires rhythm, suction/expression alternation appears; and (5) establishment of a rhythmic alternation of suction/expression with increasing suction amplitude (see Figure 1).
An “immature” suck consisting of expression alone is sufficient for completing a bottle feeding, albeit not as efficiently as with the mature alternating suction/expression characteristic of term infants (Lau et al., 1997). The absence of suction early on may explain preterm infants’ inability to breastfeed. As the human nipple is not as rigid as that of a bottle, infants would need suction to latch on to the nipple-areolar complex when feeding (Lau & Hurst, 1999; see Figure 2). This may be further complicated by the varied shapes, sizes, and functions of the maternal nipple (Table 1).

![Figure 1. 5 Stages of Nutritive Sucking](image-url)

It is interesting to note that nonnutritive sucking with a pacifier matures earlier than nutritive sucking as shown in the tracings of two preterm infants monitored for 2–3 minutes on a pacifier at the beginning of a feeding and immediately switched to bottle feeding thereafter (see Figure 3a, Figure 3b; Lau & Kusnierczyk, 2001). The infant taking all his feeding by mouth (ad libitum) used a mature sucking pattern on the pacifier, as well as during bottle feeding (see Figure 3a). This contrasts with the infant taking four oral feedings per day who used a mature

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**Figure 2. Types and Functions of Maternal Nipples**

![Diagram](image)

**Table 1. Types and Functions of Nipple-Areolar Complex**

<table>
<thead>
<tr>
<th>Appearance at Rest</th>
<th>Functions (during a feeding)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a. Normal/Prominent</strong> - At rest, nipple protrudes outward from areola</td>
<td><strong>Protracts</strong> – extends further outward with Suction facilitating adequate latch-on and “milking” of the lactiferous sinuses</td>
</tr>
<tr>
<td><strong>b. Flat</strong> – Nipple is flat with breast contour</td>
<td><strong>Protracts</strong> or <strong>Retracts</strong>, i.e., moving inward</td>
</tr>
<tr>
<td><strong>c. Inverted</strong> – All or parts of the nipple is drawn inward within areolar folds</td>
<td><strong>Simple inversion</strong> – moves outward with Suction <strong>Complete inversion</strong> - does not respond to manual pressure due to adhesions binding nipple inward</td>
</tr>
<tr>
<td><strong>d. Pedunculated</strong> - nipple sits on a stalk away from areola</td>
<td><strong>Nipple</strong> may be too big for infant’s mouth <strong>Stalk</strong> may protract or retract</td>
</tr>
</tbody>
</table>

nonnutritive pattern with the pacifier, but an immature nutritive pattern when given a bottle (see Figure 3b). This may be explained by the fact that nonnutritive sucking involves minimal swallowing (i.e., only saliva) in contrast to nutritive sucking. In the latter case, the sustained milk inflow into the mouth must be rapidly and safely transported to the stomach. This can only be achieved if sucking, swallowing, respiration, and esophageal function work hand-in-hand (Lau, 2006). As swallowing is minimal during nonnutritive sucking, it becomes debatable whether assessment of nonnutritive sucking alone is a sufficient marker for readiness to oral feed, although it is a good indicator of sucking per se (Lau & Kusnierczyk, 2001) as seen.

Figure 3. Nonnutritive and Nutritive Sucking Pattern of Two Preterm Infants at Different Stages of Oral Feeding Advancement

Infants were monitored for 2–3 min on a pacifier at the beginning of a feeding and immediately switched to bottle feeding thereafter: (a) The first infant fed *ad libitum* demonstrated both mature nonnutritive and nutritive sucking patterns (Stage 5); and (b) the second infant used a mature nonnutritive pattern with the pacifier (Stage 5) and immature nutritive pattern when bottle fed (Stage 2). Stages were assessed using the descriptive scale shown in Figure 1. Note. From Lau, C., & Kusnierczyk, I. (2001). Quantitative evaluation of infant’s nonnutritive and nutritive sucking. *Dysphagia, 16*, 58–67. Used with permission.

Swallowing Function

The swallowing process consists of an oral, pharyngeal, and esophageal phase with each phase of the reflex requiring complex sensorimotor interactions and executive motor outputs that developmentally immature infants may not readily accomplish (Leopold & Daniels, 2010; Wolf & Glass, 1992). As the frequency of nutritive sucking is around 1 suck per second (Wolff, 1968), transport of the bolus from the oral cavity to the stomach must occur swiftly before milk influx from the next suck takes place. Any delay(s) in bolus formation, pharyngeal, and esophageal transport will impact on safety and competency (Lau, 2006; Lau, 2012; Lau & Hurst, 1999; Wolf & Glass, 1992). Bolus formation in the oral cavity and propulsion into the pharynx to initiate
the swallow reflex may be affected by the proper coordination of the lingual musculature and that of the tongue with the soft palate (Bosma, Hepburn, Josell, & Baker, 1990; BuLock, Woolridge, & Baum, 1990; Goldfield et al., 2010; Leopold & Daniels, 2010; Miller & Kang, 2007; Omari et al., 1999). Appropriate pharyngeal transport of the bolus toward the esophagus requires proper closures of the nasal, laryngeal, and oral openings to prevent milk leakage (Dantas, Dodds, Massey, Shaker, & Cook, 1990; Wolf & Glass, 1992). This implies appropriate motor control of these anatomical structures and their coordinated interactions with the sensory-neural control of the pharyngeal musculature responsible for bolus transport to the upper esophageal sphincter (Donner, Bosma, & Robertson, 1985; Humbert, Lokhander, Christopherson, German, & Stone, 2012). Any delay(s) during this phase of swallowing increases risks of liquid penetration or aspiration into the larynx/lungs and bolus disintegration (Jadcherla, Hogan, & Shaker, 2010). To delay disintegration of a liquid bolus, increasing milk viscosity is often considered whether thickeners such as rice cereal, special formula, or human milk thickeners are used. The necessity of thickening milk remains debatable and deserves revisiting.

**Respiratory Function**

Preterm infant’s respiratory rates range between 40 – 60 breaths/min or 1.5 – 1 cycle/sec Swallows may last between 0.35 – 0.7 sec (Koenig, Daviers, & Thach, 1990). If an infant breathes at 1 cycle/sec and his/her swallow lasts 0.7 sec, only 0.3 sec is left for safe breathing. Under such conditions, few infants could tolerate oral feeding for a prolonged period of time.

**Esophageal Function**

The study of esophageal function in preterm infants has been restricted by the technologies available. Fortunately over the last decade, novel devices designed for their small size and fragility have emerged such as endoscopic manometry, multichannel intraluminal impedance (MII), and pH-MII.

**The Upper Esophageal Sphincter (UES)**

The upper esophageal sphincter (UES) plays an important role in bolus transport from the pharynx to the esophageal body. Studies have highlighted how readily oral feeding issues may arise when pharyngeal-UES and UES-esophageal interactions are dys-coordinated. A recent study conducted on preterm infants (28 ± 1.9 weeks gestation [GA] and monitored for 4 weeks between 31 to 36 weeks postmenstrual age [PMA]) observed that most preterm infants demonstrated poor PMA-related pharyngeal pressures that lead to poor coordination of pharyngeal bolus propulsion and timing of UES relaxation. However, increased pharyngeal pressure with well-developed UES and esophageal motility appear by 33 to 34 weeks PMA (Jadcherla, Duong, Hoffmann, Hoffmann, & Shaker, 2005; Rommel el al., 2011).

**Esophageal Motility**

It is recognized that esophageal motility in preterm infants is immature, a likely the result of the immaturity of the central and peripheral neuro-motor properties of the esophageal body (Gupta et al., 2009). Two categories of waves are identified: peristaltic and non-peristaltic. The peristaltic group distinguishes between the antero- and retro-grade waves. The anterograde wave travels from the UES down to the lower esophageal sphincter (LES) and is responsible for the bolus transport to the stomach. The retrograde wave travels in the opposite direction towards the UES and, at times, is blamed for occurrences of regurgitation. The non-peristaltic group includes synchronous and incomplete wave patterns. With maturity, a decrease in incomplete non-peristaltic and increase in anterograde peristaltic waves are observed (Jadcherla, Duong, Hoffmann, & Shaker, 2003; Omari et al., 1995).

**Lower Esophageal Sphincter (LES)**

The primary role of the LES is to control the antero- and retro-grade nutrient flow across the esophageal-gastric junction. Two types of LES relaxation (LESR) can be distinguished. The swallow-related LESR (SLESR) is associated with the anterograde transport of nutrients into the
stomach. The transient LES relaxation (TLESR), in turn, is independent of swallowing and associated with belching or gastro-esophageal reflux (GER). TLESR may occur under different conditions that are not necessarily related with nutrient intake (Omari, 2006). It remains unclear whether TLESR occurs more frequently in preterm vs. term infants.

**Gastric Emptying**

Little is known about the development of gastric emptying in preterm infants. Gastric residual is routinely measured prior to enteral/oral feeding. Depending upon individual NICU practices, feeding may be halted depending upon the measured residual. It is of interest to mention that Omari et al. (2004) observed that lateral positioning of an infant following a feeding may facilitate gastric emptying (Omari et al., 2004; van Wijk et al., 2007).

**Suck-Swallow-Respiration-Esophageal Coordination**

Oral feeding problems would be minimized with the proper maturation of the above physiologic functions. However, it is their “coordinated” interactions that will ensure safety and efficiency. But it is yet unclear what such coordination consists of. In practice, caregivers often presume that sucking, swallowing, and respiration are coordinated if an infant feeds with no adverse events, such as oxygen desaturation, bradycardia, apnea, coughing, and choking. But such presumption is not always correct as observed with aspiration/pneumonia potentially caused by silent aspiration (Arvedson et al., 1994; Kelly, Huckabee, Jones, & Frampton, 2007; Weir, McMahon, Taylor, & Chang, 2011).

The physiologic functions implicated with oral feeding are rhythmic/phasic by nature. Indeed, nutritive sucking occurs around 1 cycle/sec, nonnutritive sucking around 2 cycle/sec (Wolff, 1968), infant respiratory rates vary between 30 – 60 breaths/min, and heart rate between 120 – 160 beats/min. As such, one may speculate that coordination would be optimized if these functions were to work in phase vs. out of phase from each other (see Figure 4). Indeed, when in phase, an additive/synergistic net effect would be expected, whereas when out-of-phase, the expected net effect would be reduced.

**Figure 4. Net Effects of Phasic Systems Working In and Out of Phase**

![Net Effects of Phasic Systems Working In and Out of Phase](image-url)
We conducted a study to characterize the coordination of sucking, swallowing, and respiration (Lau, Smith, & Schanler, 2003). We investigated separately the suck-swallow and swallow-respiration interactions. Infants born between 26.8 ± 2.7 weeks GA demonstrated a consistent suck: swallow ratio of 1:1 when introduced to oral feeding at 34 ± 1.2 weeks PMA, suggesting that the sucking and swallowing functions were coordinated. On the other hand, rather than defining coordination of swallow-respiration as a consistent ratio, we speculated that its proper coordination was more relevant to safety (i.e., minimizing liquid penetration into the larynx). We reasoned that the riskier times to swallow would be during inhalation as air rushes into the lungs and deglutition apnea as increased risks of aspiration and oxygen desaturation would occur, respectively (see Figure 5). As such, the percent frequency of when swallows occurred during the different phases of respiration was monitored. Table 2 shows that preterm infants swallowed most frequently during these two riskier phases of respiration. Fortunately, with maturation as observed with term subjects, the occurrence of swallows shifted to start and end of inhalation when no air flow occurs. It is of interest to note that adults primarily swallow during exhalation (McFarland, Lund, & Ganger, 1994; Nishino & Honda, 1982). McFarland et al. (1994) observed that, in adults, swallowing occurred at different phases of respiration depending upon the feeding/eating posture and speculated that such alteration resulted from the mechanical properties of the upper body (McFarland et al., 1994). If correct, infant feeding positions may affect the swallowing safety with respect to respiration. An intriguing thought that would require future studies for evidence-based confirmation.

Figure 5. Respiratory Phases When Swallowing May Occur

(i) during inhalation; (start i) at start of inhalation; (end i) at end of inhalation; (e) during exhalation; (5i) during inhalation with incomplete inhalation; (5e) during exhalation with incomplete exhalation; DA during respiratory pauses ≥ 2 sec (Lau et al., 2003).

Table 2. Percent Occurrence of Swallow-Respiratory Interfacing with Maturation

<table>
<thead>
<tr>
<th>Preterm Infants</th>
<th>Term Infants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deglutition Apnea</td>
<td>Deglutition Apnea</td>
</tr>
<tr>
<td>Inhalation</td>
<td>Start Inhalation</td>
</tr>
<tr>
<td>Start Inhalation</td>
<td>End Inhalation</td>
</tr>
<tr>
<td>End Inhalation</td>
<td>Inhalation</td>
</tr>
<tr>
<td></td>
<td>Deglutition Apnea</td>
</tr>
</tbody>
</table>

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Concerns over the dys-coordination of sucking, swallowing, and esophageal function primarily reside in the adverse occurrences of regurgitation, choking, aspiration, GER, and/or potential gastro-esophageal reflux disorder and esophagitis. This topic is not addressed here as it falls under a distinct medical issue of its own.

**Deterrent Factors That Can Affect Oral Feeding**

Aside from immature physiologic functions, oral feeding problems can also be of non-oral feeding origins, namely infants’ clinical status, the NICU environment, and/or infants’ own behavioral states and organization.

**Infant Clinical Status**

In addition to their overall clinical status, appropriateness of oral feeding naturally depends on their condition during the feeding. Any change in color from “pink” to “dusky” or “blue” would be indicative of progressive oxygen desaturation which would lead to apnea and/or bradycardia if unattended to. Although infant heart rates average between 120 – 160 beats/min, it is important to be cognizant that there will be outliers with baseline rates below 100 beats/min. As such, verifying that alarms are set accordingly would be prudent.

**NICU Environment**

Awareness that infants have been abruptly transitioned from an in- to extra-uterine environment is important. Light, sound, touch, temperature, and mobility inside and outside the womb are strikingly different (see Table 3). As such, the smoother the transition, the less stressful infants’ adaptation will be.

**Table 3. NICU Environment Inside vs. Outside the Womb**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Inside the womb...</th>
<th>Outside the womb...</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Light</strong></td>
<td>Dark</td>
<td>Bright</td>
</tr>
<tr>
<td><strong>Sound</strong></td>
<td>Muffled (voices)</td>
<td>Loud (alarms)</td>
</tr>
<tr>
<td><strong>Touch</strong></td>
<td>Consistent containment, smooth, calming</td>
<td>Inconsistent containment, impersonal, aversive</td>
</tr>
<tr>
<td><strong>Thermal</strong></td>
<td>Constant, warm</td>
<td>Fluctuating</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td>Day/night maternal input, fluid environment, Supported flexed posture</td>
<td>Limited maternal input dry environment, Unsupported extended posture</td>
</tr>
</tbody>
</table>

**Infant Behavioral States**

The Newborn Individualized Developmental Care and Assessment Program (NIDCAP) distinguishes 6 behavioral states (Als, 1986): (1) deep sleep, seldom seen in the preterm infant; (2) light sleep; (3) drowsy/alert inactive; (4) quiet awake and/or alert; (5) actively awake and aroused; and (6) highly aroused, agitated, upset, and/or crying. Oral feeding is best recommended when infants are at states 3, 4, and 5 (Gill, Behnke, Colon, & Anderson, 1992; White-Traut, Berbaum, Lessen, McFarlin, & Cardenas, 2005). Awareness that preterm infants’ behavioral states can fluctuate rapidly would assist caregivers understand why an infant’s feeding can also fluctuate during a feeding. Halting a feeding may be appropriate if an infant cannot regain a proper feeding state.

**Infant Organization**

Behavioral organization/disorganization is a term frequently used by therapists that encompass a number of observational indicators so as to obtain a sense of the overall well-being of the infant. For instance, an infant will be deemed organized if calm, relaxed, with regular breathing, arms folded in midline, eyes closed or open. Disorganization will be characterized by
splayed hands, protruding tongue, nasal flaring, gaze aversion, grimacing, arms extended, and/or increased head/limb agitation (Wolf & Glass, 1992, p.160).

**Modalities to Enhance Infant Oral Feeding Performance**

To enhance infant oral feeding performance, it is essential to first identify and evaluate the severity level(s) of their symptoms, identify the most probable functional weakness(es), and consider the available evidence-based interventions to resolve the problem.

**Commonality of Symptoms**

A number of symptoms during oral feeding are observed regardless of the origins of the causes if feeding is maintained. From their practice, healthcare providers customarily associate fatigue with one or more of the following: poor tone, changes in behavioral state (e.g., sleep), “shut down,” increase duration of sucking pauses, increased milk leakage or drooling. To the author’s knowledge, no study has specifically demonstrated that these events are correlated to fatigue. This is likely due to the fact that fatigue per se is a non-specific symptom that results from many causes. If there is no specific measure of “medical fatigue” in adults, it would be even more difficult to define one in infants due to their developmental immaturity. This comment perfectly relates to the subjectivity/bias that we, as caregivers, may have when caring for our patients. If feeding is maintained in the presence of any of the above symptoms, increased respiratory rate, and eventually oxygen desaturation, apnea and/or bradycardia will occur. If the cause is due to suck-swallow-respiration incoordination, coughing, choking, aspiration, poor self-pacing, oxygen desaturation, apnea and/or bradycardia may be observed. Signs of reflux may include choking, coughing, aspiration, arching, esophagitis, and/or oral feeding aversion. If little attention is paid to the appearance order of these symptoms, by the time they are observed, identification of the original culprit(s) is difficult due to the commonality of the symptoms (see Table 4). However, if infants were closely watched from the start of a feeding, their sequential appearance, be it through their behavior or the alarm monitor, can provide early clues as to the origin of the problem. For instance, by regularly watching the alarm monitors, one can catch whether oxygen desaturation, cardiac or respiratory activity pattern is first to change. Often times, this would appear before any observable behavior takes place.

<table>
<thead>
<tr>
<th>Physiological</th>
<th>Behavioral</th>
</tr>
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<tbody>
<tr>
<td>Oxygen desaturation</td>
<td>Poor tone</td>
</tr>
<tr>
<td>Apnea/bradycardia</td>
<td>Fall asleep</td>
</tr>
<tr>
<td>Tachypnea</td>
<td>Agitated</td>
</tr>
<tr>
<td>Choking/coughing</td>
<td>Pushing away</td>
</tr>
<tr>
<td>Aspiration</td>
<td>Turning head away</td>
</tr>
<tr>
<td>Emesis</td>
<td>State change “shut down”</td>
</tr>
<tr>
<td>Milk leakage</td>
<td>aversive to feeding</td>
</tr>
</tbody>
</table>

**Evaluation Modalities**

The development of instruments to evaluate infant oral feeding skills comprises qualitative and quantitative approaches. Qualitative approaches, primarily conducted through observational techniques, document the presence/absence of specific behaviors and/or cues (Palmer, Crawley, & Blanco, 1993; Thoyre, Shaker, & Pridham, 2005). However, care must be taken in data analyses not to incorporate individual biases. Intra- and inter-reliability testing is essential. Using
full term infants' behavioral repertoire for instance as control standards would be inappropriate insofar as preterm infants have not yet attained the same level of behavioral maturity due to the immaturity of their motor and/or sensory development. A good example is illustrated again by the occurrence of silent aspiration detected only after aspiration/pneumonia presents (Arvedson et al., 1994; Weir et al., 2011).

Quantitative approaches require special equipment that can offer accurate measures of specific outcomes (e.g., sucking amplitude (mmHg), sucking frequency, temporal profiles of suck-swallow-respiration or esophageal motility). Some are offered through specialty services (e.g., pediatric gastroenterology for endoscopic manometry, MII, pH –MII; speech language pathology for modified barium swallow study). Others are commercially available (e.g., NTrainer, Innara Health, Olathe KS; Finan & Barlow, 1996) or remain in the research domain (Lau & Schanler, 1996; Medoff-Cooper, Weininger, & Zukowsky, 1989; White-Traut et al., 2013). Unfortunately, they are not readily available for the daily use of feeding therapists in NICUs.

We recently developed a simple quantitative scale for preterm infants (26 –36 weeks GA), that does not require any special equipment to measure infant oral feeding skills (OFS; Lau & Smith, 2011). OFS levels were delineated by infants’ respective proficiency (PRO) defined as the percent volume taken during the first 5 min of a feeding/total volume prescribed and rate of transfer (RT) defined as the total volume taken over the duration of an entire feeding (ml/min). Four OFS levels were delineated by PRO ≥ or < 30% and RT≥ or < 1.5 ml/min. OFS 1, the most immature, was defined by PRO < 30% and RT < 1.5 ml/min; OFS 2 by PRO < 30% and RT≥1.5 ml/min; OFS 3 by PRO ≥ 30% and RT< 1.5 ml/min, and OFS 4, the most mature, by PRO ≥ 30% and RT ≥1.5 ml/min. PRO was used as an index of infants’ “true” skills as fatigue was deemed minimal and RT, a resultant of infants’ overall skills when fatigue came into play, was used as an index of overall endurance (see Figure 6). Two observations of note were made. First, within each GA stratification (26–29 weeks, 30–33 weeks, 34–36 weeks), infants exhibited all 4 OFS levels at similar PMA, albeit smaller percentile of infants demonstrated OFS levels 1 with greater GA. Such broad variance in OFS supports the notion that preterm infants born at similar GAs do not mature at the same rate (see Figure 7). Second, the overall feeding performance or transfer (OT; % volume taken/volume prescribed for a feeding) of infants was significantly correlated with OFS levels, but not with GA, suggesting that the maturity level of infants’ oral feeding skills were the determinant of their feeding performance rather than their GA. It is of interest to note that infants using OFS levels 2 and 3 perform equally well (i.e., taking between 70 to 80% of their prescribed feeding). This would suggest that good skills and good endurance are equally efficient (see Figure 8).

Figure 6. Interpretation of OFS Levels as a Function of Feeding Skills and Endurance
Potential Interventional Modalities

Insofar as oral feeding issues may be of oral- and/or non-oral origin, availability of interventions addressing both possibilities must be taken into account. Sensorimotor interventions such as tactile/kinesthetic, vestibular, and auditory stimulation have been demonstrated to benefit infant growth and development (Dieter & Emory, 1997; Korner, 1990; White-Traut et al., 2002). Additionally, common sense judgment when caring for infants often helps in identifying non-oral feeding issues that may interfere with an infant’s feeding performance.

Studies have identified well-tolerated evidence-based modalities to assist oral feeding issues originating at the levels of sucking, swallowing, swallowing-respiratory interfacing, and/or esophageal functions.

Sucking

Nonnutritive oral stimulation, using different approaches, has been shown to improve the oral feeding performance of preterm infants. An association between improved stability in the nonnutritive sucking pattern following therapy with the NTrainer, a nonnutritive sucking assessment device (Innara Health, Olathe KS) and the percent of the total daily intake taken by mouth vs. tube was observed (Poore, Zimmerman, Barlow, Wang, & Gu, 2008). These investigators used a particular therapy protocol providing 3-min epochs stimulations up to 4 times/day during scheduled gavage feeds until infants were able to take 90% of their feeds by mouth for
2 consecutive days. The study of Fucile, Gisel, and Lau, 2002, conducted on very low birth weight (VLBW) infants used a 15-min stimulation program based on the Beckman’s principles (Beckman, 1986) beginning 48 hours after discontinuation of nasal continuous positive airway pressure (nCPAP) and provided once a day for 10 consecutive days, 15–30 mins prior to a gavage feeding. Subjects were monitored at 3 time points, when taking 1–2 (start of oral feeding), 3–5, and 6–8 oral feedings/day. Compared to control counterparts, infants’ OT and RT were enhanced and independent oral feeding attained was 7 days sooner (Fucile et al., 2005). In a subsequent study, in which VLBW infants received this therapy twice a day, 15-min per intervention, subjects similarly attained independent oral feeding more rapidly, demonstrated more mature OFS level profile, greater suction and expression amplitude, and decreased episodes of deglutition apnea were observed (see Figure 9; Fucile, Gisel, McFarland, & Lau, 2011; Fucile, McFarland, Gisel, & Lau, 2012; Lau, Fucile, & Gisel, 2012).

In a recent study on a similar population of infants, we investigated whether an “active” nonnutritive sucking exercise using a pacifier could replicate the benefits observed with the nonnutritive therapy described above. We reasoned that, if this were achieved, it would be an intervention that parents could provide to their infants. The sucking-pacifier exercise was offered 15-min per day, 5 days a week, beginning 48 hours post nCPAP and continued until infants attained independent oral feeding (8 oral feedings/day). The exercise consisted of gently moving the pacifier in a rhythmic up/down and posterior/anterior motion and reliably initiated sucking. Unfortunately, it did not offer the benefit observed with our original nonnutritive oral motor stimulation program provided by a therapist (Lau et al., 2012). Days from start to independent oral feeding and OFS level profile were not significantly different from those of control counterparts (Figure 10).

Figure 9. OFS Profiles of Infants Receiving Nonnutritive Oral Motor (NNMOT), Massage Therapy (MT), Combined NNMOT+MT, and Sham (Control) Interventions

Days from introduction of oral feeding to 3–5 and 6–8 oral feedings/day. SOF: Start of oral feeding * p<0.001 vs control (Lau et al., 2012).
Swallowing

As oral feeding can be affected by swallowing difficulties, we investigated the efficacy of a swallowing exercise to facilitate infant oral feeding. The study design followed that of the sucking-pacifier exercise. It consisted of placing a bolus of 0.05–0.2 ml of the milk infants were receiving at the time (e.g., mother’s milk, formula) via a 1-ml syringe directly on the medial-posterior part on the tongue, approximately at the level of the hard and soft palate junction, close to the site where the bolus rests prior to entering the pharynx (Arvedson & Lefton-Greif, 1998). The infants started with 0.05 ml and the volume was increased by 0.05 ml increment to a maximum of 0.2 ml until a swallowing reflex was observed or as tolerated (i.e., the intervention was halted at any sign of adverse events such as unstable vitals, choking, fatigue, and/or disorganization). A maximum volume of 0.2 ml was based on the knowledge that the bolus size of preterm infants averaged 0.14 ± 0.06 ml. This compares to an average of 0.22 ± 0.07 ml in term infants during their first month of life (Lau et al., 2003). Once the minimal volume necessary to initiate the swallow reflex was visually identified, it was used for the duration of the exercise. This program shortened the number of days from start to independent oral feeding by six days and OFS profile were significantly more mature as infants progressed vs. to control counterparts (see Figure 10).

Swallow-Respiration Interfacing — Feeding Positions

With the knowledge that preterm infants swallowed at riskier respiratory phases than term infants and that swallowing-respiration interfacings are affected by feeding/swallowing
positions (McFarland et al., 1994), we speculated that oral feeding performance of infants may be influenced by their feeding position. Additionally, we were aware that caregivers advocated for different feeding positions, albeit no evidence was available to support their benefits. Indeed, whereas feeding in the upright position was favored over the conventional semi-reclined position in the early 2000, over the last few years, the side-lying position was preferred. Two studies conducted on feeders and growers born ≤34 weeks GA, when fed in the side-lying position, did not demonstrate consistent benefits in infant physiological stability (e.g., oxygen saturation, heart rate) while infant consumption were not significantly different (Clark, Kennedy, Pring, & Hird, 2007; Dawson et al., 2013). In a sample of infants at similar GA requiring oxygen at time of oral feeding, such feeding position complemented with the CoReg feeding approach improved infant behavioral and physiologic responses vs. counterparts fed by the Usual Care. CoReg consists of the transmission of infant respiratory and swallowing sounds during feeding to caregivers via an earpiece so as to increase their sensitivity and responsiveness to the infant (Thoyre, Holditch-Davis, Schwartz, Melendez Roman, & Nix, 2012). From our own research, to determine whether these different positions benefit oral feeding performance, VLBW infants were randomized to being fed in the semi-reclined (control), upright, or side-lying position. When monitored at 1–2, 3–5, and 6–8 oral feedings/day, no differences were observed in days to independent oral feeding and OFS profiles (see Figure 11). Based on the average number of days to independent oral feeding, one may conclude that feeding in the upright and side-lying positions do not have any significant effect when compared to the semi-reclined feeding position (Lau, 2013). However, with the information provided by OFS profiles, an important observation was made. Statistical significance is based on the “averaging” of a particular measure for a given sample size of subjects. Knowing that infants within gestational and postmenstrual ages can demonstrate a wide range of OFS levels (Lau & Smith, 2011), large variances in any outcome measure will readily lead to statistical non significance. Although such analytical procedures is essential in order to identify the overall impact that an intervention can have on a particular subject population, it cannot identify individual subjects who may or may not have benefited from a treatment. As practitioners’ primary concern is to care for individual patients, we propose that routine monitoring of infant’s OFS levels can help identify those who benefited from a particular intervention from those who did not. In the case of feeding positions, such practice would identify infants who benefit from the semi-reclined, upright, or side-lying. If used appropriately, the OFS scale can become a useful “tool” to individualized therapy/care.
Swallow-Esophageal Interfacing

Inappropriate swallow-esophageal interfacing is well-known to lead to regurgitation, reflux, esophagitis, and potential long-term feeding aversion if left untreated. As identification of the potential esophageal cause(s) cannot yet be readily identified, no succinct evidence-based support for a potential treatment has yet been described. However, in the meantime, other approaches ought to be considered such as allowing infants to regulate their own feeding with no “encouragement” from caregivers (see self-paced feeding below).

Massage/Tactile-Kinesthetic Therapy

Tactile/kinesthetic stimulation may focus on particular functions similar to a nonnutritive oral stimulation program aimed at sucking or a swallow exercise aimed at the swallow reflex. However, this type of stimulation can also be applied to the whole body as used in massage therapy. The latter practice has been used on infants for centuries in Eastern societies and its acceptance is growing in Western cultures (Fan, 2004; Fogaca et al., 2005; Leboyer, 1976). Massage therapy has demonstrated benefits for preterm infants (Diego et al., 2007; Field, Deigo, & Hernandez-Rief, 2011; Livingston et al., 2007; Mathai, Fernandez, Mondkar, & Kanbur, 2001). However, a recent Cochrane Review did not find sufficient support to recommend its use on infants due to the quality in study design and differing approaches used in the studies reviewed (Bennett, Underdown, & Barlow, 2013). In a recent study, we examined its impact on preterm infant oral feeding using the method developed by Field et al for this population (Field et al., 1986). With the same study design as our study on nonnutritive oral stimulation, VLBW infants who received the massage treatment attained independent oral feeding faster than control counterparts; their OFS profiles and the coordination of swallow-respiration were more mature.
However, combining both nonnutritive oral stimulation and massage treatment was not of further benefit (see Figure 9; Fucile et al., 2011; Fucile et al., 2012; Lau et al., 2012).

**Self-Pace Feeding**

The principle of self-paced feeding is based on the recognition that caregivers cannot identify infants’ true feeding ability or limitation solely from visual observations. As such, we reasoned that preterm infants with normally developing neurologic functions (i.e., “feeders and growers”), can reflexively protect themselves, if given that opportunity. To test this hypothesis, we developed a “self-paced” feeding system to give control of the feeding to the infants. This was achieved by eliminating the positive hydrostatic pressure always present when a bottle is tilted so that milk outflow only occurred when infants were sucking. This would allow them to pause/rest and breathe whenever necessary without milk dripping into their mouth. Additionally, this feeding system continuously prevented the natural vacuum-build up that occurs as a container empties thereby eliminating the resistance against milk outflow from the bottle that naturally occurs (Lau & Schanler, 2000). VLBW infants feeding with the self-paced system demonstrated significantly greater OT, RT, and PRO than counterparts feeding with a conventional bottle at 1–2, 3–5, and 6–8 oral feedings/day. Additionally, they demonstrated more mature sucking stages than recognized by caregivers (Fucile, Gisel, Schanler, & Lau, 2009). These data suggested that not only could interventions facilitate infant oral feeding, but tools could be developed to assist as well.

**Common Sense Modalities Affecting Non-Oral Feeding Issues**

Although infants cannot speak, they do communicate. Thus it is important to watch them as feeding progresses. Tables 5 and Table 6 list some of their communicative skills and “common sense” approaches to consider while feeding an infant, respectively.

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**Table 5. Babies Can Communicate — Watch for cues …**

<table>
<thead>
<tr>
<th>I am Ready To Feed</th>
<th>I am NOT ready, STOP feeding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes open or closed</td>
<td>Cannot wake up, eyes, closed</td>
</tr>
<tr>
<td>Responsive to light touch, relaxed</td>
<td>Frantic, arching,</td>
</tr>
<tr>
<td>Looks at caregiver</td>
<td>Staring, gaze aversion,</td>
</tr>
<tr>
<td>Regular breathing</td>
<td>Increased respiratory rate, vital instability, color change</td>
</tr>
<tr>
<td>Hands towards mouth, folded in midline</td>
<td>arms extended, fingers splayed, protruding tongue, grimacing, nasal flaring</td>
</tr>
<tr>
<td>Rooting or sucking</td>
<td>Spitting up, gagging, gasping, excessive yawning</td>
</tr>
<tr>
<td>Smooth motor movements</td>
<td>Tremor, startling</td>
</tr>
<tr>
<td>Calm/quiet</td>
<td>Panic or worried look</td>
</tr>
</tbody>
</table>

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Modalities and Considerations for Practice

Preterm infants are challenged not only by developmental delays due to their imposed extra-uterine maturation, but also by the negative sensory inputs in the NICU necessitated by their fragile medical condition and the tasks asked of them such as oral feeding. Oral feeding concerns, as mentioned earlier, is a relatively new recognition and thus lacks guidelines and evidence-based support for many of the current practices.

Due to limited availability of quantitative evaluation and diagnostic devices, caregivers have justifiably turned to qualitative methodologies. In this regard, the current popular cue-based feeding approach (Garber, 2013; Kirk, Alder, & King, 2007; Ludwig & Waitzman, 2007; Puckett, Grover, Holt, & Sankaran, 2008), has raised concerns as to whether preterm infants are sufficiently mature to demonstrate behaviors indicative of feeding readiness. Indeed, “[they may] not have yet developed the level of brain maturation that coordinates hunger/satiety with sleep/alertness [used for] cue-based feeding” (Nyqvist, 2012). As such, cue-based feeding may need to be a more individualized approach by taking into consideration the differing stages of behavioral development, clinical stability, motor skills, and endurance that individual infants encounter. Therefore, the currently identified “feeding cues” may not apply across the board to particular populations of infants (Barbosa, 2013; Garber, 2013; Nyqvist, 2012; Roca, 2013).

Practice of cue-based feeding in NICUs has grown over the last few years despite lack of solid evidence-based support (Tosh & McGuire, 2006). The notion of whether preterm infants have a “sense” of hunger/satiety is unknown. Hunger is defined as “a feeling of discomfort or weakness caused by lack of food, coupled with the desire to eat” (“Hunger,” n.d.). As a sensory stimulus, it implicates a certain level of neuro-physiologic-endocrine maturity that preterm infants may not have attained. Therefore, cues for hunger are difficult to identify. This is well illustrated by the study of Hodges and colleagues (2008) suggesting that qualitative assessment may differ between mothers “in the extent to which they perceive and rely upon infant hunger and fullness cues to initiate and terminate feeding”. Such variance in caregivers’ perception of what infant observational cues may project raises concerns over whether their nutritional needs

<table>
<thead>
<tr>
<th>Approach</th>
<th>Why</th>
<th>How</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce noise/light levels</td>
<td>- Minimize external over-stimulations, behavioral disorganization</td>
<td>- Switch off overhead light</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Moderate voice level</td>
</tr>
<tr>
<td>Adjust feeding position</td>
<td>- To facilitate organization, respiration, swallowing, decrease potential reflux</td>
<td>- Slightly upright, cradled</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Body/head in midline</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Upper chest/head well supported,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- No crouching</td>
</tr>
<tr>
<td>Let infant regulate milk flow</td>
<td>- We do not know infants’ physical and physiologic limitations</td>
<td>- Allow infant to self-pace (e.g., to rest, catch-up breathing)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Do not “encourage” feeding</td>
</tr>
<tr>
<td>Vary number and/or duration of oral feeding experience</td>
<td>- To reduce adverse events (e.g., fatigue, aspiration)</td>
<td>- Decrease number of daily oral feedings, or</td>
</tr>
<tr>
<td></td>
<td>- To develop good OFS- To offer positive experience</td>
<td>- Decrease oral feeding durations, or</td>
</tr>
<tr>
<td></td>
<td>- To avoid oral feeding aversion</td>
<td>- Maintain number of daily oral feedings, but decrease duration of oral feeding by tube feed remaining</td>
</tr>
<tr>
<td></td>
<td></td>
<td>→ offers positive oral feeding experience when fatigue is minimal</td>
</tr>
</tbody>
</table>

Table 6. Common Sense Approaches to Consider

<table>
<thead>
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<th>Approach</th>
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</tr>
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<tbody>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>→ offers positive oral feeding experience when fatigue is minimal</td>
</tr>
</tbody>
</table>
could be met on a consistent level. If only a cue-based feeding approach were used, knowledge of the maturation level of individual infants’ motor development at assessment times would be essential.

Little is known regarding when the sense of hunger/satiety develops. A hunger center in the lateral hypothalamus has been long recognized (Wise, 1974) and particular stomach, body, and antral muscular activity interacting with the lateral hypothalamic hunger site has been shown to regulate degrees of hunger/satiety (Kromin & Zenina, 2013). Additionally, hormonal involvement (e.g., insulin, ghrelin, growth hormone) are known to be implicated (Pradhan, Samson, & Sun, 2013). How the physiologic bases of hunger are reflected in preterm infants’ behavioral repertoire is unknown. It is primarily for these reasons that concerns have been raised over the use of cue-based feeding alone.

The above discussions are presented as potential means to develop an organized and more systematic differential diagnostic approach to address infant oral feeding issues.

In the presence of oral feeding symptoms, one may want to determine whether: (a) feeding ought to be halted (see Table 5); (b) NICU environment (light and sound), swaddling, feeding position are appropriate (see Table 6); or (c) the infant is feeding at his/her own pace with no encouragement from caregiver. At the end of the feeding, assessing OFS levels may help identify the quality of feeding skills and endurance (see Table 7). If feeding skills need to be improved, appropriate evidence-based directed intervention may be considered. If endurance is the issue, an “oral feeding training” may be beneficial (e.g., more frequent feeding sessions of shorter duration). Increasing training opportunities when fatigue is minimal will favor the development of good skills.

### Table 7. Potential Interventions to Consider

<table>
<thead>
<tr>
<th>OFS Levels</th>
<th>Feeding skills (PRO)</th>
<th>Endurance (RT)</th>
<th>Potential Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Poor</td>
<td>Poor</td>
<td>Appropriate evidence-based directed intervention(s) + “oral feeding training”</td>
</tr>
<tr>
<td>2</td>
<td>Poor</td>
<td>Good</td>
<td>Appropriate evidence-based directed intervention(s)</td>
</tr>
<tr>
<td>3</td>
<td>Good</td>
<td>Poor</td>
<td>“oral feeding training”</td>
</tr>
<tr>
<td>4</td>
<td>Good</td>
<td>Good</td>
<td>none</td>
</tr>
</tbody>
</table>

### Summary and Conclusions

In brief, this review presents the current understanding of the development of infant oral feeding skills from which efficacious evidence-based interventions were developed. As the goal of research is to advance medical practice, it underscores the translational value of these interventions. Currently, there are no robust guidelines to follow and the lack of evidence-based interventions used does not receive support from a number of disciplines.

### Acknowledgment

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References


