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Sucking and swallowing in infants and diagnostic tools

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Preterm infants often have difficulties in learning how to suckle from the breast or how to drink from a bottle. As yet, it is unclear whether this is part of their prematurity or whether it is caused by neurological problems. Is it possible to decide on the basis of how an infant learns to suckle or drink whether it needs help and if so, what kind of help? In addition, can any predictions be made regarding the relationship between these difficulties and later neurodevelopmental outcome? We searched the literature for recent insights into the development of sucking and the factors that play a role in acquiring this skill. Our aim was to find a diagnostic tool that focuses on the readiness for feeding or that provides guidelines for interventions. At the same time, we searched for studies on the relationship between early sucking behavior and developmental outcome. It appeared that there is a great need for a reliable, user-friendly and noninvasive diagnostic tool to study sucking in preterm and full-term infants.
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Introduction

Oral feeding in infants should be efficient to preserve energy for growing. Moreover, it should be safe so as to avoid aspiration, and it should not jeopardize respiratory status. This can only be achieved provided sucking, swallowing and breathing are properly coordinated. This means that the infant can suck efficiently and that it can swallow rapidly as the boluses are formed, thus minimizing the duration of airflow interruption. Put differently, an infant's oral feeding skills are reflected by its skill to organize and coordinate oral-motor functions efficiently so that it takes in enough calories to grow.[1]

There are several circumstances that could compromise normal coordination of sucking and swallowing. Congenital or acquired damage to the central nervous system during the neonatal period may lead to feeding difficulties, such as slow or weak sucking. It could be the first indication that the infant has neurological problems.[2] Dysphagia is common in infants suffering from cerebral palsy or other developmental deficits.

Preterm infants frequently have feeding problems during their first year of life. It is unclear whether these problems are related to the neurological problems these infants often exhibit later on.[3] Preterms in need of artificial respiration have more difficulty in stabilizing their physiological parameters. It is unclear whether their sucking and swallowing problems stem from their reaction to the tubes, from their breathing difficulties or from a combination of both.

There is an urgent need for a user-friendly, reliable and noninvasive tool that objectively measures sucking and swallowing movements and the coordination between sucking, swallowing and breathing. On the one hand, such a tool would be useful to determine what kinds of interventions are required to facilitate sucking and swallowing. On the other hand, some predictions could be made regarding the further development of the infant. In addition, infants could be followed up to determine if and to what extent sucking behavior has predictive value for the infant's outcome at a later age.

The aim of this review is threefold. Our first aim is to find out what is known about the normal developmental course of sucking and swallowing during early age. Our second aim is to evaluate a number of currently available diagnostic methods that measure the coordination of sucking and swallowing with breathing. Finally, our aim is to establish the prognostic value of an abnormal developmental course of sucking, swallowing and breathing for the infant's later neurodevelopmental outcome.

To achieve these aims, we searched the literature on Medline and CINAHL using Silver Platter and WinSPIRS. The restrictions we used were AGE (All Infants). TG: Human, PT: Journal-Article, publication date: 1995–2006. This search strategy consisted of all combinations of (1) Sucking Ability [Mesh] OR Sucking Behaviour [Mesh] AND (2) Deglutition [Mesh] AND Respiration [Mesh].

Fifty-two articles were found in this way. On the basis of the titles and abstracts, we selected 25 articles for further reading. The main selection criterion was the patient group. We excluded articles on infants with cleft palate, Pierre Robin sequence and cerebral palsy. We included articles on preterm and full-term infants

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without congenital anomalies. We selected a further 25 articles by reviewing the references of all the articles identified.

The normal developmental course of the coordination of sucking, swallowing and breathing from fetal life up to 10 weeks' post-term

Sucking and swallowing, and the brain structures involved

The sucking pattern of full-term infants is composed of the rhythmic alternation of suction and expression. Two forms of sucking are distinguished: nutritive sucking (NS) and non-nutritive sucking (NNS). NS is an infant's primary means of receiving nutrition while NNS can have a calming effect on the infant. Moreover, NNS is regarded as an initial method for exploring the environment. The rate of NNS is approximately twice as fast as that of NS.[4–6] Both NNS and NS provide insight into an infant's oral-motor skills. In NS however, the ability to integrate breathing with sucking and swallowing is a prerequisite for coordinated feeding.

During NS, fluid moves primarily due to change in pressure. With the oral cavity sealed, as the jaw and tongue drop down, the cavity is enlarged. This enlargement creates negative intraoral pressure, suction, which draws fluid into the mouth and propels the expressed fluid backwards toward the pharynx for the swallow. Jaw and tongue movements are also involved in the propulsion of the fluid. As the tongue compresses the nipple, sufficient positive pressure, compression, is created by the jaw and the front part of the tongue pressing the nipple against the hard palate to draw the fluid from the nipple. The tongue plays a key role in all aspects of sucking by helping to seal the oral cavity. It does so, anterior, in conjunction with the lower lip, and posterior, by sealing against the soft palate during swallowing. In addition, the tongue stabilizes the lower jaw and transports the bolus to the pharynx. The jaw provides a stable base for movements of the tongue, lips and cheeks.

The next phase is pharyngeal. Swallowing is elicited involuntary by afferent feedback from the oral cavity and has a duration of approximately 530 ms. It depends on a critical volume of fluid, gathered in the valleculae. To initiate and modify the swallow, the pharynx and larynx are richly supplied with chemoreceptors, slow-adapting stretch and pressure receptors and temperature receptors.

Effective sucking requires coordination of both the swallowing and breathing processes in which many brain structures are involved, including cranial nerves, brain stem areas and cortical areas. The rhythmic processes involved in NS are under maturing bulbar control, especially in the regions of the nuclei ambiguus, solitarius and hypoglossus in the lower medulla. Efferent and afferent cranial nerves (N V, VII, IX, X and XII) are involved in deglutition (which includes mastication, respiration and swallowing). These movements are considered to be under the control of central pattern generators and are controlled by sensory feedback and suprabulbar parts of the brain. The central pattern generator for sucking seems to consist of two distinct parts: (a) the brain stem (in the nucleus tractus solitarius and the dorsal medullar reticular formation) for motor control, and (b) parts of the surrounding reticular formation for sensory control.

During pharyngeal swallowing, respiration is inhibited centrally.[7] The three parts of the cerebral cortex that are involved in chewing and swallowing are the primary motor cortex, the premotor cortex anterior to it and the anterior insula.[8] These areas process incoming and outgoing signals to and from the swallowing center in the brain stem. This is the case for both the reflexive and voluntary stages of swallowing.

The development of sucking and swallowing from fetal age to term age

At approximately 26 days' fetal age, the developmental trajectories of the respiratory and swallowing systems diverge and start to develop independently. Swallowing in fetuses has been described as early as 12 to 14 weeks' gestational age. A sucking response can be provoked at 13 weeks' postconceptional age by touching the lips.[9] Real sucking, defined by a posterior–anterior movement of the tongue, in which the posterior movement is dominant, begins at 18 to 24 weeks' postconceptional age.[10] Between 26 and 29 weeks' gestational age, there is probably no significant further maturation of sucking.[6,11]

By week 34, most healthy fetuses can suck and swallow well enough to sustain nutritional needs via the oral route, if born at this early age. Sucking movements increase in frequency during the final weeks of fetal life. This is accompanied by an increase in amniotic fluid swallowed by a fetus during pregnancy from initially 2 to 7 ml a day to 450 ml a day. This is approximately half of the total volume of amniotic fluid at term.[8,12,13]

The development of sucking and swallowing from birth at term up to the first months of life

The normal maturation of sucking and swallowing during the first months of life after full-term birth can be summarized by increased sucking and swallowing rates, longer sucking bursts and larger volumes per suck.[6,14–17] The skill of safe and efficient oral feeding is based on oral-motor competence, neurobehavioral organization and gastro-intestinal maturity.[18] It is important that the behavioral states are well controlled, that the airway is patent and that the overall cardiorespiratory activity is stable.[19] Internal factors that influence the normal development of sucking and swallowing patterns are the infant's state of health, his oral feeding experience, the ability to regulate oxygen, development of alertness and sucking strength and the organization of the sucking pattern. External factors are size and speed of milk flow, the impact of nasogastric tubes in place during feeding and the type of feeding support provided by the caregiver.[1]

Normal infants are able to adapt to varying environments. They are able to distinguish differences in fluctuations of milk flow, nipple hole, taste and temperature, and they can adapt their sucking behavior to these variations.[17]

Rhythmicity. The underlying rhythms of sucking and swallowing follow quantifiable, predictable maturational patterns that correlate with postmenstrual age (PMA). From this point of view, it is likely that these behavioral patterns are congenital rather than acquired.[20] However, the rhythmicity of the suck–swallow–breath relationship depends also on nonmaturational factors, such as satiety, behavioral state and milk flow. Milk flow depends on the hole size of the nipple (bottle feeding), the milk ejection reflex (in breastfeeding), but it also depends on the infant. Within certain ranges the infant can autoregulate milk flow by changing the suction pressure and frequency.[17,21]

Rhythmic stability can be expressed in a measure used by Gewolb *et al*.,[20,22] the coefficient of variation. The coefficient of variation is the standard deviation of the intervals between two processes (such as swallow–swallow, suck–suck, suck–swallow) divided by the mean interval between these processes. It is independent of the number of sucking movements per swallow. A low coefficient of variation indicates that the rhythm is normal. The higher the coefficient of variation, the more variable the rhythm. The rhythmic stability of sucking and swallowing changes during the first month of life, both individually and interactively. The biorhythms of sucking and swallowing follow a predictable maturational pattern (stabilization of sucking rhythmicity, more sucking movements and swallows in bursts and quicker and longer sucking bursts). This stabilization correlates more with PMA than with postnatal age.[20] The studies by Gewolb *et al*.[20] show that rhythm is an integrated part of maturation. Quereshi *et al*.[16] expand on this theme by explaining that the changes observed at 1 month of age may be an adaptation of the drinking pattern to include volition, with longer sequences and a larger number of sucking movements. It would seem, therefore, that these rhythms follow a reasonably predictable maturational pattern and that disturbance of this maturation could be an important diagnostic clue.

Interaction with breathing. Feeding activity appears to override normal ventilatory chemoreceptor control mechanisms[23] and the act of swallowing has a significant impact on breathing during feeding. As infants commonly swallow as often as 60 times a minute, and there is an airway closure averaging 530 ms associated with swallows, this means that during the initial period of continuous sucking, the airway closure lasts up to 30 s a minute.[24] This makes it important for respiration to be exquisitely coordinated with swallowing.

During feeding, swallowing is segregated from breathing. Sucking and breathing patterns create 'windows of opportunity' for swallows and the central nervous system may look for opportunities within ongoing sucking and breathing patterns in which to fit swallows, allowing an infant to continue feeding without interruption.[22] In full-term infants, the coordination between breathing and swallowing develops and matures during the first month of life.[16]

In general, swallowing rhythm is maintained at the expense of functional and rhythmic respiration, even in full-term infants.[25] Deviations from these patterns can be predictive of feeding, respiratory and neurodevelopment disorders.[25] Various studies demonstrated that sucking and swallowing influence the normal pattern of breathing: it decreased inspiratory time, decreased respiratory frequency, decreased minute ventilation and decreased tidal volume.[25,26] This is important in pathological circumstances when breathing is compromised.

Studies of the coordination between sucking, swallowing and breathing show the following possibilities: a swallow could be preceded by inspiration, expiration or apnea and could be followed by inspiration, expiration or apnea, yielding nine possible relationships.[21] Sixty percentage of full-term neonates have an inspiration–swallow–expiration (I–S–E) or an expiration–swallow–inspiration (E–S–I) relationship. Swallows followed by expiration would be safer because any milk remaining in the pharynx would be cleared before the next inspiration. Besides, it is most efficient to swallow after inspiration because then pharyngeal pressure is at its highest.[15] The optimal pattern in nutritive feeding thus seems to be I–S–E.

Whether breast-fed or bottle-fed with expressed breast milk, infants show a significantly higher breathing rate than when receiving other liquids. Coordination between swallowing and breathing could improve with breast milk.[27]

Special considerations on the development of sucking and swallowing in preterm infants

When describing the normal development of the preterm infant, one is in fact describing an abnormal situation: a preterm infant develops in an extrauterine environment while intrauterine development would be normal. This complicates the matter of distinguishing between normal and abnormal development of sucking and swallowing. Which aspects of the development of sucking and swallowing in the preterm infant are deviant and what is part of normal maturation? With this in mind, we would like to make the following comments.

The moment an infant gains sufficient control over his physiological parameters determines the time he is ready to successfully process oral feeding. From the literature, it would appear that it is taken for granted that on reaching term age, the infant has developed a sucking pattern (or that the infant is able to coordinate sucking, swallowing and breathing) that is comparable to that of a full-term infant. If the infant is unable to do this, his development is considered to be deviant or premature.[4]

Gewolb *et al*.[20] indicated that the number of sucking movements in preterm infants increases from 55 per minute at 32 weeks' PMA to 65 per minute at 40 weeks. This is comparable to

Table 1 The five primary stages of non-nutritive sucking (NNS) and nutritive sucking (NS)

Stage 1a	The sucking pattern consists primarily of arrhythmic expression without suction.
Stage 1b	Sucking with attempts to generate suction and expression.
Stage 2a	Although suction may be still absent, the expression component becomes rhythmic.
Stage 2b	The alternation of suction/expression begins to appear. Rhythmicity not yet established.
Stage 3a	Sucking still consists of rhythmic expression without suction.
Stage 3b	The appearance of more rhythmic alternation of suction/expression with longer sucking bursts and stronger suction amplitude.
Stage 4	Only rhythmic alternation of suction and expression is observed.
Stage 5	Greater suction amplitude and longer duration of sucking bursts than seen in stage 4

Adapted in 2005 by Rogers and Arvedson[19] from Lau and Schanler.[11]

the level reached by full-term infants at 1 month of age. On the one hand, this implies that during the first days after birth, the sucking rate does not follow the maturation curve. On the other hand, age expressed in terms of PMA correlates better with the development of sucking and swallowing than chronological age, which presumes that oral feeding is a congenital behavioral pattern rather than acquired behavior.[28]

Lau and Kusnierczyk[6] divided the normal maturational process into five primary stages based on the presence or absence of suction and rhythmicity for the two components of sucking: suction and expression/compression (Table 1). Lau and Kusnierczyk[6] used this scale to indicate the relation between the development of sucking and the preterm infant's oral feeding skill. The scale can be applied to both NS and NNS.

Non-nutritive sucking. In the past, several studies on NNS were performed in preterm infants because this behavioral pattern is more readily observed in preterm infants than is NS. Usually, NNS is at the same stage of development as NS or one level ahead.[6,11] The stage of NNS is an indication of the infant's oral-motor skills. If an infant shows stage 5 NNS and its NS skill is stage 2, then the coordination of swallowing or breathing is ineffective. Oral feeding performance improves as the infant's sucking skills mature.[6,9] A significant correlation was found between the level of maturation of an infant's sucking skill and gestational age and the infant's skill to ingest oral food.

Several studies have shown the advantages of NNS. These include a quicker change from tube feeding to oral feeding and better saturation during NS when the infant received NNS prior to NS. NNS at the empty breast promotes infant-state control, weight gain, breast-feeding skill and milk production in the mother.[6,29,30]

Rhythmicity. In preterm infants of 26 to 33 weeks' gestational age at birth, Gewolb *et al*.[20] found that the basic rhythmic nature of swallowing stabilizes before suck rhythmicity does. A stable swallow rhythm already exists at the age of 32 weeks' PMA and does not change from 32 weeks' PMA to term age. Concerning sucking rhythm, stability is established later.

Mizuno and Ueda[15] found significantly increased sucking efficiency, (sucking pressure and frequency) between 34 and 36 weeks' gestational age. They found a 30 s continuous phase (during the continuous phase, the sucking pattern is stable and is only influenced by oral reflex activity) and an intermittent phase (the sucking pattern changes and becomes less stable as a result of fatigue, gastro-intestinal and respiratory influences) during sucking. Although only bottle-fed infants were observed in most studies, it is supposed that the basic rhythmic pattern is similar in breastfeeding, even though breastfeeding often involves more sucking movements.

Interaction with breathing. The coordination of breathing and swallowing undergoes significant developmental maturation from 34 to 42 weeks' PMA. Generally speaking, minute ventilation increases during sucking and swallowing with increasing PMA.[16] This might influence sucking and swallowing patterns in infants whose minute ventilation is at risk under normal circumstances, for example, in infants suffering from bronchopulmonary dysplasia (BPD). Gewolb *et al*.[20,31] described the development of sucking and swallowing in preterm infants suffering from severe BPD. Up to 35 weeks' PMA, sucking and swallowing develop as in healthy preterm infants. Subsequently, difficulties in coordinating breathing and sucking arise to an increasing extent, but the rate of swallowing, length of the swallowing sequence and the swallow–swallow interval are not influenced by BPD. The main problem arises in the coordination between breathing and sucking and swallowing. Because of BPD, swallowing is relatively long to meet the infant's ventilatory demands, whereas sucking patterns are not adapted to this situation. If the infant continues to suck, desaturation occurs due to the necessity to swallow, with insufficient time to breathe, leading to deglutition apnea. Only after a number of weeks after term age does coordination recover and does the infant develop a normal sucking pattern once again. This may possibly be caused by discongruent maturation of the breathing and swallowing centers in the brainstem. The coordination of swallow–respiration and suck–swallow rhythms may be predictive of feeding, respiratory and neurodevelopmental abnormalities.[23] Infants with BPD, however, do not follow predicted maturational patterns of sucking–swallowing rhythmic integration. A follow-up study of Gewolb and Vice[32] suggests that ventilatory needs may modulate sucking rhythm and organization.

Hanlon *et al*.[33] investigated the maturation of deglutition apnea times in full-term and preterm infants (28 to 37 weeks' gestational age). They found that deglutition apnea times decrease as infants mature, as does the number and length of episodes of multiple-swallow deglutition apnea. The maturation appears to be related to PMA rather than feeding experience (chronological age).

Reliance on preterm infant behavioral cues for impaired oxygenation during bottle feeding will be insufficient for the detection of oxygen desaturation during oral feeding. Attention to changes in breathing sounds and to the pattern of sucking are potentially important intervention strategies to prevent the decline of oxygenation during feeding. Sucking pauses may be a moment when preterm infants aim to regulate their breathing pattern and thereby increase oxygenation.[34] It remains unclear whether this pattern changes on reaching term age. In preterm infants, the predominant breathing patterns are E–S–I and E–S–E with 'apnoeic swallows' or 'apnoeic-related' swallows accounting for approximately 30% of all swallows in infants $\leqslant$35 weeks' PMA and approximately 15% in preterm infants of 35 to 40 weeks' PMA. This is quite different from the situation in full-term infants, where the predominant pattern is I–S–E and where 'apnoeic(-related)' swallows are rare.

Diagnostic methods to investigate an abnormal developmental course of the coordination of sucking, swallowing and breathing

The reasons to carefully study both the preconditions for sucking and how an infant sucks are to determine if an infant is ready to feed orally and to detect the nature of the feeding problems. In addition, an abnormal sucking pattern may be an indication of the neurological development of the infant that is not progressing normally.

We performed a literature search for both types of assessments and distinguished between the following elements:

1. the reliability of the study
2. the reliability and validity of the tool
3. whether the tool can be used for preterm infants
4. whether the tool is designed for breastfeeding, bottle feeding or for both
5. for which age is it suited?
6. how invasive is it/hands off or hands on?
7. what does it measure?
8. is the tool designed for NS or NNS or for both?
9. how much does the tool cost and what costs are involved in its use?

Determining whether an infant is ready to feed orally

Certain physiological parameters, behavioral aspects, NNS and the infant's behavioral state are important indicators, apart from the infant's oral-motor functioning, to determine whether a preterm infant is ready to feed orally.[1,34]

The vision on readiness is strongly determined by the fast-increasing options of medical treatment of preterm infants in the NICU. Basing ourselves primarily on the date of publication of the articles from our literature search, we selected six approaches that all stem from nursing practice. On the basis of the setup of the study, whether or not it is standardized and the description of the items to be observed, we selected two methods (Table 2).

McGain and Gartside[35] described the use of NNS to promote awake behavior for feeding, the use of behavioral assessment to identify readiness for feeding and systematic observation of and response to infant behavioral cues to regulate frequency, length and volume of oral feeding.

They used individualized semi-demand feeding. This means that every 3 h the infant is offered NNS for 5 to 10 min, followed by an assessment of the infant's behavioral state. If asleep, the infant is permitted to sleep for another half an hour and then again offered NNS. If awake and restless, the infant is offered nipple feeding, if the infant is still sleeping, the feeding is given by gavage.[1]

Thoyre *et al.*[1] developed the Early Feeding Skills Assessment. This tool is a 36-item observational scale divided into three sections: early feeding readiness, oral feeding skills and oral feeding recovery. In addition, the Early Feeding Skills Assessment must be re-administered at each feeding to determine whether the infant is able to feed orally, how it reacts to the feeding and how it recovers from the effort. The physiological parameters are monitored during feeding. In the case of early feeding readiness, the infant has to demonstrate 'behavioural organization and energy for the work of feeding by attaining and maintaining an awake state, a flexed body posture with sufficient muscle tone, and interest in sucking' (1, p. 10). Gestational age is less important. For oral feeding skill, the coordination of sucking, swallowing and breathing, and the sucking and swallowing movements are observed. During 5 min following feeding, the caregiver observes the behavioral and physiological recovery from feeding to determine oral feeding recovery. This information is of great importance when deciding whether or not to feed the infant orally the next time it needs to be fed.

Methods for detecting feeding problems in young infants

To detect feeding problems, a diagnostic tool is needed to assess the oral-motor patterns underlying poor feeding.

In general, one can distinguish between clinical feeding assessment and swallowing assessment.[7] Whether NNS or NS and swallowing are observed as standard procedure depends on the infant's age and on the clinical situation.

No standardized method is available to assess NNS. A common approach to assess NNS is to place one's little finger into the infant's mouth halfway the tongue. The rate of NNS should be approximately two sucks per second. If the infant shows good NNS, this does not automatically mean that it is ready for oral feeding. During NNS, only sucking and breathing are coordinated, and not sucking, swallowing and breathing as in NS.[9]

Table 2 Standardized diagnostic tools for assessing an infant's readiness for oral feeding

Assessment	*Description*	*Reliability of the study*	*Reliability and validity of the tool*	*Age suitability*	*Breast or bottle feeding*	*NS or NNS*	*What is measured?*	*Degree of invasiveness*	*Cost*
1. An evidence-based guideline for introducing oral feeding to healthy preterm infants, McCain[30]	The method combines the use of non-nutritive sucking to promote waking behavior for feeding, the use of behavioral assessment to identify readiness for feeding and systematic observation of and response to infant behavioral cues to regulate frequency, length and volume of oral feedings	A semidemand method based on a randomized experimental study of 41 healthy preterm infants (32–34 weeks PMA). Making the transition from gavage to oral feeding 5 days ($P<0.001$) faster compared to a control group ($n=41$)	Different elements of this approach are based on evidence found in references	Preterm infants	Both	Both	State, behavioral organization, suck–swallow–breathe pattern and cardiorespiratory control	Noninvasive	The method requires a trained nurse and time investment; no capital outlay required
2. Early Feeding Skills Assessment for Preterm Infants (EFS), Thoyre *et al.*[1]	A checklist for assessing infant readiness for and tolerance of feeding and for profiling the infant's developmental stage regarding specific feeding skills	The authors based all the items of the tool on 69 references. No information is provided about the results of the EFS, about the study group, control group, and so on	The authors state that 'content validity has been established with expert neonatal nurses' and 'intra- and inter-rater reliability have been found to be stable and acceptable', but no data are provided to support this statement	Preterm infants	Both	Both	EFS is a 36-item observational measure, used to assess four domains: to remain engaged in feeding; to organize oral-motor functioning; to coordinate swallowing and breathing and to retain physiological stablility	Noninvastive	Does not require any apparatus. Requires a 2-day workshop to train nursing staff in using the tool

Standardized assessments are available to assess NS or oral feeding. A literature search using the nine search elements mentioned earlier resulted in our finding seven assessment tools (Table 3). Four of these were suited exclusively for breastfeeding, two for bottle feeding and only one for both breastfeeding and bottle feeding. The assessments designed exclusively for breastfeeding also include maternal elements such as the mother's feeding position, nipple pain and the mother's health. The part aimed at the oral-motor patterns is limited: two out of five items in the case of latch, audible swallowing, type of nipple, comfort, hold (LATCH),[37,38] nine of the 22 subitems in the Preterm Infant Breast-feeding Behavior Scale,[43] four out of eight items in the breast-feeding evaluation for term infants.[44]

Seven out of eighteen items in the Systematic Assessment of the Infant at the Breast (SAIB).[36] The Preterm Infant Breast-feeding Behavior Scale was the only tool subjected to tests of validity and reliability.

The noninvasive assessment tools for bottle feeding only focus on the intraoral movements of the infant. Both assessments are still in an experimental stage ($N=1$ and $N=12$). Nevertheless, they seem to offer many possibilities for the future.[41,42]

Because the only assessment tool used for breastfeeding and bottle feeding is the noninvasive Neonatal Oral-Motor Assessment Scale (NOMAS),[4] we describe it here in more detail. The tool contains checklists for feeding behavior and provides an analysis of, and diagnoses, sucking patterns by assessing the oral-motor components of the tongue and jaw during neonatal sucking. In addition, it identifies the type of sucking pattern the infant uses. Two abnormal patterns are defined: a disorganized sucking pattern and a dysfunctional sucking pattern. A disorganized sucking pattern refers to a lack of rhythm in the total sucking activity. This means that the infant is unable to coordinate sucking and swallowing with breathing. When an infant's sucking pattern is disorganized, it is unable to feed well and may exhibit labored breathing with color changes and/or spells of apnea and bradycardia. A dysfunctional sucking pattern is characterized by abnormality in orofacial tone. In case of orofacial hypertonia, a restriction in the range of motion at the tempomandibular joint may result, in turn resulting in minimal jaw excursions and/or tongue retraction. In case of orofacial hypotonia, one may note a flaccid tongue and/or excessively wide excursions of the jaw when sucking. Infants with dysfunctional sucking patterns are likely to benefit from therapeutic intervention providing compensatory strategies during oral feeding.

Palmer published data concerning the reliability of the NOMAS in 1993. NOMAS is not a reliable tool as the intrarater agreement with respect to the diagnosis is 'moderate' to 'substantial' (Cohen's K between 0.40 and 0.65).[43] In recent years, a number of articles by Palmer[4,45–47] and others[48,49] have been published in which the NOMAS was employed as a diagnostic tool. The NOMAS seems particularly useful for studying full-term infants with sucking problems, but less so when it comes to sucking patterns in preterm infants.[49]

The prognostic value of an abnormal developmental course of sucking, swallowing and breathing for later neurodevelopmental and feeding outcome

It is known that early feeding problems may be the first symptom of disability. Infants with severe neurodevelopmental problems in later life did not generate sucking pressure or coordinate suction and expression during their neonatal period. Several studies found that both feeding problems and nutritional problems are most common in children with severe disability.[2,50] Gisel and Patrick[43] suggest that early quantitative assessment of feeding efficiency should be made to identify infants who cannot be nourished adequately without ancillary feeding. The identification of risk factors associated with malnutrition is important for its early detection and treatment and for the prevention of later behavioral, health and growth consequences. However, only few studies have prospectively identified risk factors in cohorts of full-term and preterm infants. Moreover, there are hardly any publications on the relationship between the development of sucking and later neurodevelopmental outcome, even though there are several authors who suspect that the relationship does exist.

Since the rhythmic processes involved in feeding are under bulbar control, quantitative analyses of rhythms and patterns of feeding times can be meaningful. This is the case especially after the 35th week of PMA, not only as an indication of feeding problems but also as predictors of subsequent long-term neurological problems.[26]

The eating and drinking patterns of 34 former preterms (with an average gestational age of 34 weeks) and 21 healthy infants born at term were studied from 6 to 12 months.[50] At the age of 6 months, 12 former preterms were more likely to vomit and were slightly more inclined to cough when fed viscous food. At the age of 12 months, the same 12 children had more problems with small chunks in their food and they coughed much more often when eating chewable food. Only six of these children and their parents enjoyed the meal.

Palmer[48] followed 18 children whom she had assessed with NOMAS shortly after birth. She saw the children again between the ages of 24 and 36 months. For these assessments, she used the Bayley Scales of Infant Development and the Vineland Social Maturity Scale. All seven children who had a dysfunctional sucking pattern in infancy showed developmental delay. The two children who had a normal sucking pattern in infancy developed normally. Of the nine children who had shown a disorganized sucking pattern in infancy, four had developed abnormally at the age of 24 months. However, the numbers in this study are limited and no specific details are provided about the extent of the developmental delay.

Table 3 Standardized diagnostic tools for assessing NS or oral feeding

Diagnostic tool	*Description*	*Reliability of the study*	*Reliability and validity of the tool*	*Age suitability*	*Breast or bottle feeding*	*NS or NNS*	*What is measured?*	*Degree of invasive-ness*	*Equipment, costs, training*
1. Systematic Assessment of the Infant at the Breast (SAIB), Association of Women's Health, Obstetric and Neonatal Nursing, 1989[36]	Observations related to alignment (5 items), areolar grasp, (8 items) areolar compression (2 items) and audible swallow (3 items)	No data are available for assessing this tool. The setup of the tool is based on 21 references. Not subjected to any test of validity	No information is provided regarding reliability and validity	Suitable for fullterm infants, but probably also for preterm infants	Breast	NS	Eighteen aspects are observed, seven of which refer to sucking/swallowing movements	Not	Training of nurse and mother
2. The Neonatal Oral-Motor Assessment Scale (NOMAS), Palmer *et al.*[4]	Checklists of 26 items in categories of normal, disorganized and dysfunctional tongue and jaw movements	Thirty-six infants, term and preterm. No control group. Twenty references were used. For more than half of the items, there is no acknowledgement of the source. The method was not subjected to any test of validity	In a previous version, interrater agreement was determined on the basis of percentage agreement. After revision, the final scale was not tested for reliability	From birth up to 8 weeks' corrected age. Suitable for both groups, according to the authors. In the manual, hardly any distinction is made regarding the assess-ment of preterms	Both	Both	Coordination between sucking, swallowing and breathing. Jaw and tongue movements are divided into three categories for jaw movements and three categories for tongue movements	Hands off, bedside observation	Video camera. A 3-day certification course
3. LATCH: a breast-feeding charting system and documentation tool, Jensen *et al*.[37]	A systematic method for gathering information about individual breast-feeding sessions	Riordan *et al*.[38] measured the validity of 133 dyads and the relationship between the LATCH scores and duration of breastfeeding		No distinction is made in terms of gestational age when using this tool	Breastfeeding	NS	The tool assigns a numeral score to five key elements, two of which refer to sucking and swallowing	Mainly hands off, except for cervical auscultation	Training in scoring and cervical auscultation
4. Preterm Infant Breast-feeding Behaviour Scale (PIBBS), Nyqvist *et al*.[39]	Diary kept by mother: rooting, amount of breast in mouth, latching, sucking, sucking bursts, swallowing, state, letdown and time	Study of 35 infants: 12 fullterms (control group) and 23 preterms. Thirty-eight references. The source of all nine elements is acknowledged. The tool is subjected to tests of both reliability and discriminative validity	Interrater agreement of the PIBBS was tested on the basis of eight infants and adjusted accordingly. Subsequently, the interrater agreement of the tool was tested twice and adjusted	Suitable for both groups	Breastfeeding	NS	Nine aspects are measured and subdivided into 22 subitems. Nine of these refer to sucking	Hands off, direct observation	No apparatus. Training required

Table 3 Continued

Diagnostic tool	*Description*	*Reliability of the study*	*Reliability and validity of the tool*	*Age suitability*	*Breast or bottle feeding*	*NS or NNS*	*What is measured?*	*Degree of invasive-ness*	*Equipment, costs, training*
5. Breast-feeding evaluation and education tool, Tobin[40]	A take-home sheet gives parents' ample criteria for determining how well breastfeeding is progressing	No data are available for assessing this tool. The setup of the tool is based on six references, four of which have not been published. Not subjected to any test of validity	No information is provided regarding reliability and validity	Suitable for full-term infants	Breastfeeding	NS	Eight aspects are observed, four of which refer to sucking movements. A description of the test has not been published	Hands off, direct observation	Applying the tool is typified as being 'simple' and 'inexpensive'
6. Analysis of feeding behavior with direct linear transformation, Mizuno *et al*.[41]	By placing markers on the lateral angle of the eye, tip of the jaw and throat during sucking while the face of the infant is recorded in profile, the jaw and throat movements are calculated using the direct linear transformation (DLT) procedure	Ten 'normal' infants (control group) and two infants with neurological disorders were studied. Eleven references were used. Not subjected to any substantial test of validity	According to their previously published data on infants with severe neurological disorders, who were unable to generate intraoral negative pressure, the authors observed a significant relationship between throat movement and suction pressure	Not indicated.	Bottle-feeding	NS and NNS	Suction and expression pressure and the movements of jaw and throat are measured to detect abnormal movements, for instance, in infants with neurological disorders	Hands off, direct observation	Digital videocamera. Training in placing the markers and in interpreting the analysis
7. Ultrasound observation of lingual movement patterns, Miller and Kang[42]	Examination of the lingual-hyoid mechanics with a noninvasive ultrasound imaging technique	$N=1$ as a pilot study to find out whether ultrasound can be used to determine abnormal lingual movements. Thirty-two references were used. Not subjected to any test of validity	The authors underscore the importance of lingual motor activity as a driver of sucking mechanics. In addition, they describe the differences in lingual movements between NS and NNS	Full-term and preterm	Bottle-feeding	NS and NNS	It is used to discern aspects of oral feeding candidacy, which is the evaluation of intraoral lingual movements during sucking	Hands on, yet noninvasive, according to the authors	B-mode ultrasound imaging system. Training in using ultrasound and in interpreting the images

Mizuno and Ueda[15] studied the relationship between the feeding behavior (measured in terms of expression and suction) of 65 neonates (mean gestational age 37.8 weeks, s.d. 0.5) and neurological development (measured with the Bayley Scales of Infant Development II) at 18 months of age. They found an association, namely, the weaker the suction and expression, the lower the score on the Bayley Scales of Infant Development II.

Pridham *et al*.[51] explored the level and variation in feeding skill performance in 45 preterm infants at 1, 4, 8 and 12 months' post-term age using the Child Feeding Skills Checklist. They found that feeding skill performance varied widely among infants at all four assessments. A minority of infants had a delay and lack of opportunity to engage skills like eating new food, drinking from a cup and self-feeding skills at the age of 8 and 12 months.

Medoff-Cooper[44] did a study in 19 very low birth weight infants to identify early predictors of developmental outcome. They found that the mean pressure generated by each suck and the length of sucking bursts correlated positively with the Psychomotor Scale of the BSID at the age of 6 months.

In summary, we can state that over the years, a relationship between sucking patterns and later outcome has been suggested by several authors, but exact data do not exist. There is an urgent need for prospective studies on feeding behavior and later neurodevelopmental and motor outcome. To begin with, a reliable and noninvasive research tool to assess sucking and its development is required to achieve this aim.

Conclusion

Many studies on sucking and the development of sucking in preterm infants and infants born at term have been published over the past 7 years. A number of these publications assume that there is a relationship between the way an infant sucks and his later neurodevelopmental and feeding outcome. In these studies, various aspects of learning how to suckle from the breast or how to drink from a bottle are mentioned and investigated. Internal and external factors are distinguished. Internal factors are stable physiological parameters, rooting, suction pressure and suction frequency, movements of jaw and tongue, the rhythmicity of the suck–swallow–breathe relationship, length of sucking bursts and alertness. External factors are milk flow, nipple size, nasogastric tube *in situ* and the role of the caregiver. Several research tools have been developed to assess sucking behavior. In these studies, only a few aspects of the development of sucking are measured or investigated; often they cannot be used for both breastfeeding and bottle feeding, are more or less invasive and require expensive or complicated measuring equipment. Most studies were done with a small experimental group and often without a control group. Only a few tools were tested for validity (specificity and sensitivity). Therefore, the need remains for a user-friendly, reliable and noninvasive tool to measure objectively all the aspects mentioned above and one that is applicable to both breastfeeding and bottle feeding. With such a tool in hand, we would be able to determine which interventions to use to enhance sucking and swallowing in newborns. It is tempting to speculate that such a tool could also predict later development or neurodevelopmental sequelae or later feeding problems. In that case, it would enable us to decide which interventions to use to enhance sucking and swallowing in infants, and hopefully improve their outcomes.

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