Prospective study of non-nutritive sucking and feeding skills in premature infants

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ABSTRACT

Objective The aim of the present work was to assess the value of non-nutritive sucking (NNS) measures as predictors of oral feeding performance in comparison to other putative predictors of feeding skills: respiratory support, post-menstrual age (PMA) at birth and the neonatal oral motor assessment score (NOMAS).

Methods This was a prospective, observational study. Cox proportional hazards and non-parametric rank sum tests were used to assess the relationship between NNS and feeding outcome measures. The setting was neonatal intensive care units (NICU) in rural/academic, urban/tertiary centres in the USA. In all, 51 premature infants born between 25 and 34 weeks' PMA, birth weight 1512.3±499.4 g, were included in this study. Interventions were measurement of NNS, standardised feeding advance schedule, performance of NOMAS, and standardised, permissive, oral feeding advance schedule. Main outcome measures were transition time from first to full oral feeding (FOF) and gestational age at FOF.

Results Higher NNS organisation scores predicted shorter transition to FOF ($p<0.05$): infants with a more organised suck pattern reached independent oral feeding 3 days earlier (16 vs 13 day transition) than infants with more chaotic patterns of suck bursts. Consistency of the suck waves also corresponded with feeding milestones: infants with more regular suck wave pressure deflections became competent oral feeders approximately 3 days earlier than those with irregular suck pressure waves. PMA at birth was inversely associated with PMA at FOF. NOMAS measures were not associated with outcome measures.

Conclusions Measures of NNS organisation and suck consistency constitute useful candidate predictors of feeding performance by premature infants. The results accord with previous findings linking PMA at birth with age at independent feeding.

What is already known on this topic

- Prolonged transition from tube to oral feeding is common in tube-fed premature infants.
- Encouragement of non-nutritive sucking, which normally increases in amount and complexity from 28 to 40 weeks' gestation, effectively facilitates oral feeding in premature infants.
- Analysis of non-nutritive sucking patterns in tube-fed premature infants may help to identify problem feeders.

What this study adds

- We developed technology and a method for characterising the development of non-nutritive sucking that nurses can readily apply at the bedside in the neonatal intensive care unit (NICU).
- Non-nutritive sucking descriptors proved to be stable over repeated observations.
- In a prospective study, assessment of non-nutritive sucking prior to introduction of oral feeding correlated with measures of subsequent feeding performance.

INTRODUCTION

American Academy of Pediatrics guidelines suggest that premature infants should demonstrate feeding competence prior to hospital discharge.[1] Although most premature infants begin oral feeding between 32 and 34 weeks' post-menstrual age (PMA), these patients vary widely in the gestational ages at which they attain full oral feeding (FOF).[2] Some infants require less than 1 week to transition to FOF, while others, especially those born more prematurely with a greater number of complications, require weeks of combined tube and oral feeding before they reach this developmental milestone.[3] A significant subset of 'delayed feeders' (premature infants who only acquire independent oral feeding beyond term equivalent) require a higher degree of support and longer stays in the neonatal intensive care unit (NICU).

While objective stages of feeding by premature infants have been characterised,[4] the timescale for progression through these stages is not well understood. It would be helpful to prospectively identify those infants at risk for delayed oral feeding, as it is these infants who stand to benefit most from interventions aimed at feeding skills. While there has been discussion concerning the desirability of a valid, predictive, feeding assessment for premature infants,[5] no such instrument has been identified to date.

The decision that an infant is ready for oral feeding trials depends upon infant characteristics, including PMA and respiratory status. In addition, nurses in our NICUs often assess the quality of non-nutritive sucking (NNS; sucking without swallowing) to estimate feeding readiness. Quantitative evidence for this practice is lacking. A physical score of the rhythmicity of NNS as an ingestive behaviour has potential as a reliable indicator of feeding skills, as it may integrate the sundry patient characteristics (degree of prematurity, severity of respiratory disease, growth and nutritional status, medical complications) that ostensibly influence oral motor development. The utility of a score of actual feeding behaviour, whether nutritive or non-nutritive, depends on its predictive value and on ease of implementation and reliability (ie, different scorers should tend to arrive at consistent results). A few studies have examined the Neonatal Oral Motor Assessment Score (NOMAS) for this purpose. Reports differ as to the reliability of the NOMAS scale,[6 7] an instrument that has been widely used since its introduction to neonatology researchers 15 years ago.[8]

The beneficial effects of NNS enhancement (ie, promoting pacifier use) on feeding skills suggest the possibility of a quantitative relationship between NNS and feeding skills.[9] The advent of new methods of stimulating NNS that impact positively upon feeding, such as rhythmic orocutaneous stimulation,[10] or oral stimulation[11 12] also support the possibility of a predictive, quantitative relationship between NNS and feeding milestones.[13] However, rigorous, prospective, observational studies have not formally addressed the relationship between NNS measures and feeding outcome.

As with oral feeding patterns, NNS behaviour shows characteristic developmental patterns, increasing in complexity and organisation with advancing maturity.[14] At a neuroanatomical and neurophysiological level, this maturation parallels increasing coordination of interconnected 'central pattern generators' that mediate breathing, sucking and swallowing.[15] Considering that NNS behaviour depends on a common neural substrate with nutritive sucking (NS), it appears likely that NNS patterns develop in parallel with NS and could therefore predict oral feeding skills.

The NICU environment offers opportunities to assess NNS patterns prior to patients' initial oral feeding experiences. For the present study, we developed technology that NICU nurses can use to analyse and record NNS patterns. We developed and validated an NNS organisation score that corresponds to reported developmental patterns associated with nutritive sucking.[4] In a prospective, observational study of 51 tube-fed, premature infants, we tested the hypothesis that NNS measures would correlate with subsequent feeding performance when obtained before initiation of oral feeding (IOF). We also compared the predictive value of NNS measures to that of variables believed to relate to feeding skills and feeding readiness: duration of respiratory support, PMA at birth and the NOMAS.

METHODS

Study population

For this prospective observational cohort study, patients were recruited from NICUs at a smaller, rural academic hospital (Fletcher Allen Health Care, Burlington, Vermont, USA) and a larger, urban hospital (Pennsylvania Hospital, Philadelphia, Pennsylvania, USA). Informed consent was obtained from parents after the nature of the study was explained. All procedures were approved by Institutional Review Boards at both institutions.

The study patients consisted of 51 premature infants born between 25 and 34 weeks' PMA (table 1). Participants with orofacial anomalies, neurological problems, or those undergoing major procedures were excluded. Observations were only performed on participants who were breathing comfortably in room air with no respiratory support or with nasal cannula (room air) only. Recorded clinical characteristics included aspects of respiratory support and occurrence of medical complications of prematurity.

Table 1 Baseline characteristics (n=51)

Characteristic	Value
Male/female	16/35
PMA at birth, weeks	30.7±2.1*
Birth weight, g	1512.3±499.4*
Maternal age, years	29.2±7.2*
5-min Apgar score	9 (6, 9)†
Number of days on ventilator	1 (0–2)†
Number of days on oxygen	0 (0–7)†
Number of days on CPAP	2 (0–7)†
Number of days on ventilator, oxygen, CPAP	5 (1–14)†

*Mean±SD.
†Median and range.
CPAP, continuous positive airway pressure; PMA; post-menstrual age.

Study outcomes

Feeding milestones and outcome measures included (1) PMA at IOF, (oral consumption of at least 5 ml milk); (2) PMA at FOF (infant orally consuming at least 100 ml/kg/day and absence of tube feeding for 48 h); (3) PMA at successful oral feeding (SOF; participant consumes >15 ml or g/kg at each of three feedings within a 24 h period); (4) early transition time (number of days required to progress from IOF to SOF); and (5) transition time (days from IOF to FOF).

NNS measurement

NNS observations were performed prior to IOF when participants were an average of 32.7±0.1 weeks' PMA. Between 5 and 9, 10-min NNS observations were performed concurrent with or immediately prior to tube feedings. These observations were performed at intervals varying from 3 h to 24 h over a period of less than 72 h, on participants who had prior experience with pacifiers. Participants may also have been receiving intravenous fluids, but had not undergone intravenous placement or other procedures within 24 h of the observation and were receiving the majority of their fluids enterally.

NNS measures were performed regardless of behaviour state. Considering that level of arousal may influence NNS burst behaviour,[14] behaviour state was recorded at the start of the observation using a modification of Brazelton's scale (table 2).[16] To assess agreement between observers at both study sites, observers at each site jointly reviewed criteria and then separately scored a series of five videotapes. Scores agreed on 80% of these videotaped participants and were within one point (on a six-point scale) on all tapes.

To measure and record NNS, pacifiers (Hawaii Medical, Pembroke, Massachusetts, USA) were instrumented with a pressure transducer so that sequences of compressions due to sucking activity could be recorded directly on to a laptop computer equipped with a data acquisition card as described previously.[17] We confirmed the validity of these compression wave tracings by comparing scores based on visual review of a videotape with scoring of a 10 min tracing in two cases (>95% agreement in total suck count).

Each 10-min record of pressure changes was stored as a digital file for later, blinded assessment of NNS. The baseline was corrected by subtraction of the mean. The sampling rate was

Table 2 Behaviour state scoring criteria

State	Description
1	Deep sleep, regular breathing, eyes closed, quiet facial expression
2	Light sleep; rapid eye movements, irregular breathing; mouthing movements
3	Drowsy, semi-awake, eyes open or closed or fluttering, activity variable with occasional startles, some fussing vocalisation or facial grimacing
4	Quietly awake/alert, animated facial expression; may appear focused
5	Actively awake and aroused, fussing; eyes may or may not be open, motor arousal, distressed facial expression or grimacing
6	Highly aroused, agitated, upset and/or crying, intense upset with intense grimace and cry face, cry may be strained, weak or absent

Table 3 Non-nutritive sucking (NNS) ordinal scoring system

Score	Criteria
Suck consistency score (if burst score >0)	
0	Jagged, differently shaped, or inconsistently spaced suck waves; a neat-appearing group of sucks is the exception
1	Odd shaped, some irregular spacing OR irregular amplitude of suck waves (suck peaks not in a smooth 'up and down' pattern)
2	Very uniform appearance to suck waves
Burst organisation score	
0	No sucks, ±noise
1	Recognisable sucks, no bursts
2	One or more bursts, not occurring in regularly spaced 'trains'
3	Trains of three or more bursts taking up <50% of tracing; bursts are well formed/organised, evenly spaced
4	Dense, regular bursts throughout/ burst trains >50% of tracing

50 Hz. The peak detector algorithm first determined all local maxima for the 10 min period. The remaining peaks were validated for minimum duration of 0.3 s and maximum frequency of 3 Hz. This parameter was calculated to maximise the sensitivity of the algorithm, based on earlier observations that the frequency of NNS events in premature infants tends to average near 1.7 sucks/s,[14] and that superimposed tremor events occur at >5 Hz.[18] Two or more peaks lying no more than 1 s apart were counted as bursts.

NNS statistics included continuous and ordinal measures. The continuous NNS measures, derived via computer algorithm programmed in Matlab (Mathworks, Natick, Massachusetts, USA), included total number of sucks, suck bursts (defined as a sequence of two or more sucks whose peaks lie no more than 1 s apart), average number of sucks per burst and average of the maximum length of bursts for each 10 min observation. Because variation in amplitude of NNS waves led to frequent missed NNS events in some of the records, a scorer who was blind to study outcome measures adjusted the threshold so as to capture all NNS burst events. The results from 2 different scorers on 10 different 10 min tracings showed >90% agreement, and this level of agreement was deemed a satisfactory level of interobserver reliability.

The two ordinal measures (suck score, burst score) were designed to assess features of morphology and organisation of NNS that have previously been described as part of a developmental sequence in rhythmicity of feeding behaviour and consistency of the suck wave deflections (see table 3).[4] The suck consistency score (0–2) emphasised regularity of individual suck wave deflections, while the burst organisation score (0–4) abstracted more derivative features of bursts (the degree to which suck waves aggregated into bursts and sequences of bursts; see figure 1). After iteratively refining and clarifying

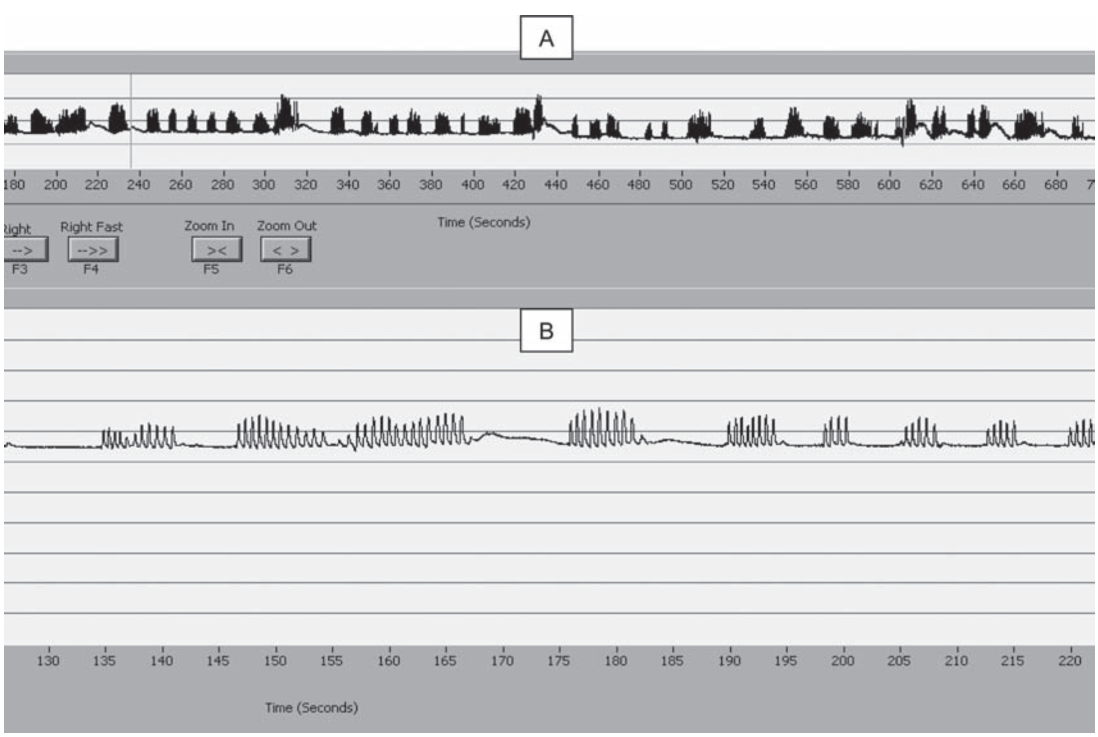

Figure 1 Example of a non-nutritive sucking (NNS) recording. A. Upper tracing shows the entire 10 min period. This example would be scored a '4' because of the presence of regular trains of bursts present for >50% of the record. B. Lower tracing shows a 60 s sample of the record, so that consistency of individual suck waves can be appreciated. This sample was scored as 2 because of the consistent, 'crescendo–decrescendo' appearance of individual suck waves.

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criteria, reliability of these scores was established by reviewing the precise criteria with NICU nurses at both study sites (n=17) and then presenting them with a series of 10 NNS tracings. Nurses reliably assigned ordinal NNS suck consistency and burst organisation scores using these scoring criteria (Cronbach α=0.98 for the suck score, 0.99 for the burst score).

Feeding advance and tracking

To minimise the influence of arbitrary decisions on feeding outcomes, a standardised feeding advance protocol was reviewed daily with participants' nurses. The advance protocol was designed so as to provide participants with relatively uniform oral feeding opportunities and to permit advance through oral feeding 'levels' depending on infant cues (see below). Oral feeding attempts (a milk volume of 5 ml for bottle-fed infants) were initiated 72 h after participants reached a PMA of 32 weeks.

Infant cue-based feeding advance was standardised and administered as follows. Minimum 5-min feeding trials were initiated when participants were awake and when participants were at least 32 weeks' corrected PMA. Infants who had consumed 5 ml orally were initially offered opportunities to feed orally three times (level 1). Level 2 (feeding trial every 6 h; 4× per day) began as early as the second day of feeding, once participants consumed at least 10 ml/kg/feeding at level 1 without signs of distress (as defined later). As early as the third day of feeding participants advanced to oral feeding trials every 3 h (level 3). Feeding trials were terminated if signs of feeding intolerance (tachypnoea, regurgitation, cyanosis, head turning, fending/protest gestures) appeared. Participants advanced to the next level once they orally consumed at least 10 ml/kg/feeding without showing signs of intolerance. If signs of intolerance appeared before the infant consumed 10 ml/kg, the participant was not advanced to the next level. Breastfed participants were weighed immediately prior to/post feeding attempts to document intake using an Olympus infant scale accurate to ±1 g.

Additional variables that were considered as potential predictors of feeding outcome included (1) NOMAS scores; (2) feeding efficiency (volume consumed in the first 5 min of bottle feeding); (3) PMA at birth; (4) duration of respiratory support (see table 1 for descriptors of respiratory support; number of days on ventilator, days on oxygen without mechanical ventilation, days on continuous positive airway pressure (CPAP)). NOMAS scoring was performed by NOMAS-certified feeding therapists/NICU nurses within 72 h after the infant successfully initiated oral feeding. Subscores of the NOMAS comprise 10 dichotomous assessments of nutritive suck organisation (suck rhythm) and 8 assessments of nutritive suck function (lip seal, tongue and jaw movement).[8] Consistency in NOMAS scoring was confirmed by the NOMAS certification process, which requires 100% agreement in diagnosis of normal versus disorganised versus dysfunctional sucking pattern and 85% agreement in scoring 28 attributes for 5 different 2 min observations of infant feeding. Study raters had >80% agreement on each of 5, 2 min, infant feeding videotapes and were blind to the NNS assessment and feeding outcome measures. Considering that feeding efficiency (volume consumed per unit time) has been suggested as a predictor of feeding skills,[19] timed feeding measures were performed within 72 h of the first day that the participant consumed 10 ml/kg by mouth twice within a 24 h period.

Analysis

Data were described with means, SDs, medians and ranges. A Kruskal–Wallis non-parametric rank sum test was used to examine the relationship of ordinal NNS measures to feeding milestones and to behavioural state. For these non-parametric analyses, participants were divided according to the median value of the NNS score of interest. The non-parametric analysis was used to deal with non-normality and unequal variances in the outcome measures. Cox proportional hazard regression was used to test the relationship of continuous NNS measures, and patient characteristic variables, respectively, to feeding outcome measures. Statistical significance was defined as $p<0.05$ for the primary analysis relating number of NNS bursts to age at SOF. Secondary analyses relating other NNS descriptors to feeding outcome measures, including those yielding values of p lying between 0.05 and 0.10, were noted as statistical trends.

Consistency of NNS variables was assessed using the Cronbach α, a measure of internal consistency based on the average correlation among items; and by intraclass correlation. In order to further elucidate the impact of testing conditions on NNS measures, we used repeated measures analyses of variance to examine differences in NNS measures (1) according to behaviour state score at the time of the observation and (2) between observations that were performed prior to versus concurrent with tube feeding.

RESULTS

Feeding outcome data

Though oral feeding was offered to participants soon after 32 weeks' PMA, participants still took several days or weeks to initiate oral feeding (mean 33.3 weeks±0.8 weeks, range 32.0–36.3 weeks). Participants achieved SOF at a median age of 34.5±1.1 (range 32.9–38.1) weeks and FOF at a median PMA of 35.3 weeks (interquartile range from 34.9 to 36.0 weeks). Transition time (days from IOF to FOF) required 15.8±6.6 days (range 5.0–38.0), while transition time to SOF required 8.7±6.0 days (range 2.0–32.0).

PMA at birth, respiratory support and feeding outcomes

Cox proportional hazard regression models indicated that PMA at birth was significantly associated with PMA at FOF (HR=1.2; 95%; p value <0.01), though it was not significantly associated with PMA at SOF (SOF) (HR=1.12; p=0.10). The relationship between PMA at birth and transition time (number of days from IOF to FOF was statistically significant (HR=1.21, p=0.025). There was no statistical association between PMA at birth and number of days from IOF to SOF (HR=1.08, p=0.34). The number of days on ventilator correlated with age at SOF (HR=0.93, p=0.04).

NOMAS/feeding efficiency

Neither feeding efficiency nor NOMAS measures were significantly associated with outcome measures in a univariate Cox proportional hazard models.

NNS measures and feeding milestones measures

Overall descriptive statistics for ordinal and continuous NNS variables are presented in table 4. There was no evidence that any of the NNS measures varied significantly over the 5–9 10-min observational periods, and comparison of NNS during pre-tube feeding observations to observations performed concurrent with tube feeding revealed no significant differences in any NNS variable. Therefore, the average for infant scores over the 5–9 10-min observational periods was used in calculating

Table 4 Quantitative and ordinal non-nutritive sucking (NNS) measures

NNS measure	Mean±SD	Median	Range (min–max)
Number of sucks	132.2±63.3	124.3	(13–293)
Number of bursts	25.0±10.5	22.8	(5–54)
Number of sucks per burst	4.8±1.4	4.7	(2–8)
Peak number of sucks per burst	11.2±4.6	11.2	(3–22)
Suck consistency	1.0±0.4	1.0	0–2
Burst Score	2.9±0.6	3.0	0–4

Table 5 Feeding milestones by non-nutritive sucking (NNS) groupings

	No. of sucks		No. of bursts		No. of sucks per burst		Peak no. of sucks per burst		Consistency		Burst organisation	
Transition time (days from IOF to FOF)												
Mean	15.6	15.9	15.7	15.8	16.3	15.2	15.3	15.6	17.0	14.4	18.4	13.3
SD	6.0	7.1	5.2	7.7	7.7	5.3	7.4	5.8	5.9	7.0	7.2	5.0
Median	14.5	16.0	15.0	15.0	14.0	16.0	14.0	16.5	16.0	13.0*	16.0	13.0**
Min	6.0	5.0	7.0	5.0	6.0	5.0	6.0	5.0	8.0	5.0	11.0	5.0
Max	29.0	38.0	29.0	38.0	38.0	28.0	38.0	29.0	29.0	38.0	38.0	23.0
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Age at SOF (GA in weeks)												
Mean	34.5	34.6	34.5	34.6	34.8	34.4	34.6	34.5	34.7	34.4	34.8	34.3
SD	1.0	1.3	1.0	1.3	1.2	1.2	1.1	1.2	0.9	1.4	1.2	1.1
Median	34.3	34.2	34.2	34.4	34.4	34.1*	34.4	34.1	34.6	34.1**	34.4	34.1
Min	33.1	32.6	33.1	32.9	33.1	32.9	33.1	32.9	33.1	32.9	33.1	32.9
Max	38.0	38.1	38.0	38.1	38.0	38.1	38.0	38.1	36.9	38.1	38.0	38.1
Number of days from IOF to SOF												
Mean	8.0	9.3	8.0	9.4	9.3	8.1	8.3	9.0	9.4	7.9	10.4	7.1
SD	4.9	6.9	4.6	7.2	6.9	5.2	6.5	5.7	5.6	6.4	7.2	4.3
Median	7.0	8.0	7.0	7.0	7.0	7.0	6.0	7.0	7.0	6.0	8.0	6.0*
Min	2.0	2.0	3.0	2.0	2.0	3.0	2.0	3.0	4.0	2.0	4.0	2.0
Max	24.0	32.0	24.0	32.0	32.0	24.0	32.0	24.0	24.0	32.0	32.0	20.0

Kruskal–Wallis rank sum test: *p<0.10; **p<0.05.
FOF, full oral feeding; GA, ;IOF, initiation of oral feeding; SOF, successful oral feeding.

the descriptive statistics and for comparison to feeding outcome measures.

The average behavioural state across observations for individual participants was correlated to the corresponding average of continuous NNS measures: sucks (r=0.330, p=0.018), average bursts (r=0.396, p=0.004) and average suck consistency (r=0.368, p=0.008) were increased when behaviour scores reflected increased participant wakefulness/arousal. However, when the behaviour state measure (mean=3.0±0.6; median=3.0; min=2.0; max=4.8) was divided at the median, none of the ordinal NNS measures differed statistically between infants with behavioural states less than versus above the median value.

Table 5 relates continuous and ordinal NNS measures to feeding milestones. For each NNS measure, the left-hand column shows feeding outcome results for those in the lower 50th percentile, while the right-hand column shows feeding performance in participants in the upper 50th percentile. A higher NNS organisation score was associated with shorter transition time from initiation to FOF (median 13 vs 16 days, p<0.05), while a higher NNS consistency score showed a trend to shorter transition time (median 13 vs 16 days, p <0.10), and a higher NNS organisation score showed a trend in its relationship to number of days from IOF to SOF (median 6 vs 8 days, p <0.10). A high NNS consistency score was significantly associated with a lower PMA at SOF (34.1 vs 34.6 weeks' PMA, p <0.05). With the exception of the relationship of number of sucks per burst with PMA at SOF (p<0.10), continuous NNS measures were not related to feeding milestones.

DISCUSSION

By prospectively measuring NNS before IOF in a group of premature infants, this study aimed to improve understanding of the relationship between NNS and oral feeding performance. Infants showing more mature patterns of NNS (burst organisation, suck consistency) showed more advanced oral feeding skills, reflected in shorter transition time to oral feeding and younger age at SOF. These findings are in accord with other observations that associate emergence of more organised sucking patterns with oral feeding.[19] Measures of NNS burst organisation and suck wave consistency may therefore constitute useful predictors of feeding performance by premature infants.

NNS follows a developmental pathway featuring increasing regularity of the suck wave, increasing length of sucking bursts and increasing consistency in the intervals between sucks within a burst.[14] Over 20 years ago it was suggested that NNS maturation may 'signal … sensory-motor integration' of oral motor skills.[20] Published reports have not provided a rigorous test of this hypothesis. Speculations that NNS could not provide a useful indicator of oral feeding skills have been based on observations of fewer than 10 participants.[21 22] Meanwhile, NNS is routinely facilitated in premature infants on the well founded observation that stimulation of NNS accelerates oral feeding milestones.[9]

In order to identify variability in NNS measures not merely due to PMA of the participant, we obtained NNS measures shortly after participants reached 32 weeks' PMA. To minimise the effect of oral experience on the NNS measures, all infants were studied before they had initiated oral feeding. In addition, multiple NNS 'samples' were obtained so as to minimise arbitrary influences of arousal level, digestive or appetitive factors on the NNS score. However, statistical testing showed negligible intraindividual variability of sequential NNS measures; NNS measures did not vary over the course of the observations. While continuous measures were influenced by behaviour state, the ordinal NNS measures that were predictive of feeding skills were less affected by behaviour state at the time of the observation. A relatively brief sample, allowing assessment of the ordinal measures described here (measures of organisation and suck consistency) may therefore be sufficient to predict feeding outcomes.

Infants born at a younger PMA tended to be those with a more advanced PMA at FOF. This finding accords with earlier results showing that PMA at birth inversely correlates with PMA at which premature infants attain the developmental milestone of FOF.[4 23] Delay in independent oral feeding by more prematurely born infants may reflect the fact that the most prematurely born infants are patients who are more ill, are also those who undergo the greatest deprivation in terms of feeding experience, and therefore experience the greatest difficulty with reaching oral feeding milestones.[23]

The problem of identifying 'problem feeders' among premature infants who are just initiating oral feeding is a complex one. Our focus on participants who were breathing without respiratory support by 34 weeks necessarily excluded infants with more severe respiratory complications of prematurity. Within this context, the broad inclusion criteria for PMA at birth intentionally included infants who would show a wide range of feeding ability. While the approach and findings described here can guide strategies for future studies, a relatively small sample size, comprising participants with a relatively mild respiratory course, limits generalisability of our findings. We did not calibrate the pressure transducer system to permit absolute pressure measurements, or control for possible effects of warming/expansion during the recordings. Temperature change or occasional mouthing movements might therefore have impacted the recordings, though these possible effects should not bias the overall results. A central assumption of our approach is that, compared to measurement of absolute forces, the pattern of rhythmic movements will provide the best indication of the maturation of central pattern generators that underlie feeding. One study of the effect of NNS stimulation on feeding skills indicated that decreased variability of the sucking rhythm, itself a developmental attribute of NNS, corresponds with the emergence of feeding skills.[24] More longitudinal studies of NNS such as this one will likely elucidate which aspects of this behaviour relate most closely to oral feeding competence in premature newborns. Finally, while our findings suggest that measures of NNS maturity can predict participants' intrinsic feeding ability, they must be interpreted in light of the possibility of type 1 (false positive) errors related to multiple comparisons. The method used here may also be useful in future studies aimed to assess the predictive value of NNS measures in higher risk patients, such as those with severe respiratory, neurological, or gastroenterological complications of prematurity.

A difficult methodological issue in feeding research is that of maintaining equal 'access' to feeding opportunities, and the possibility of unequal exposure to oral feeding experience. We attempted to mitigate this problem by specifying a permissive feeding advance schedule. The infant cue-based feeding strategy used in this study allowed participants to demonstrate their maximal oral feeding ability.[25] Extrinsic influences particular for each patient (nursing practice, parental involvement and so on) may yet influence feeding outcomes.

In this study, scores of actual feeding trials (NOMAS, NOMAS subscores and timed feeding trials) that were made early in the feeding advance did not correspond ultimately with the pace or age at acquisition of feeding milestones. This finding is somewhat surprising, considering that these standardised observations comprise participants' suck-swallow-breath coordination skills. Perhaps because they do not focus on key features of the maturation of feeding behaviour, these performance scores were poor predictors of infants' feeding ability. Although multiple feeding performance scores were obtained, the only physical measures corresponding to feeding outcome measures in our study were burst organisation and suck consistency. These results suggest that assessment of NNS maturation can predict which premature infants will experience feeding difficulty.

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