Enteral Nutrition of the Very Low Birth Weight (VLBW) Infant

D K L Chan,* *FAMS, MBBS, M Med*

Abstract

Introduction*: Optimal nutrition is critical in the management of the very low birth weight (VLBW) infant. *Methods*: The type of feeding, initiation, route and schedule of feeding, and the rate of increase in feeding volume were reviewed. *Results*: Human milk from the preterm infant's mother is the feeding of choice. When full enteral feeding is established, supplementation of human milk with a multi-nutrient fortifier is required. In VLBW infants having poor weight gain when exclusively fed human milk, feeding of hindmilk is encouraged if the mother expresses large quantities of breast milk. Lactation support is vital for the mother, including appropriate methods of milk collection, storage and transport to the nursery. In mothers who produce no or insufficient human milk, preterm formulas are an alternative feeding, used either alone or in conjunction with human milk. Minimal enteral nutrition using sub-nutritional feedings in the first week of life is advantageous. Intragastric intermittent ("bolus") tube feeding is the route of choice for the infant born at <32 to 34 weeks gestational age. Feeding volume must be advanced cautiously at <20 mL/kg/day. *Conclusion*: Future goals of nutrition research in the VLBW infant must include determining the role and optimal composition of the various nutrients and duration of use.

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Key words: Human milk fortifier, Minimal enteral feeding, Necrotising enterocolitis, Preterm

Introduction

Optimal nutrition is critical in the management of the preterm infant. The fetus *in utero* receives continuous intravenous nutrition that is interrupted when prematurely delivered. Thus, the preterm baby born with a very low birth weight (VLBW) of less than 1500 g presents as a nutritional emergency.

The nutritional goal of extremely premature babies is highly debated and ill defined.[1,2] Management practices recommended for larger and relatively more mature preterm babies cannot be extrapolated to the more immature ones. The Committee on Nutrition of the American Academy of Pediatrics has recommended that the optimal diet for premature infants be designed to provide nutrients to approximate the rate of growth and composition of weight gain for a normal fetus of the same post-conceptional age.[3,4] Furthermore, they recommend maintaining normal concentrations of blood and tissue nutrients. Table I shows enteral intake recommendations for growing preterm infants in stable clinical condition.

In the immediate postnatal period, the preterm infant undergoes extrauterine adaptation to the environment because of change in distribution of body water. During the second week of life, when acute cardiorespiratory problems resolve, growth then usually begins. In this period, nutritional goals are to maintain fluid homeostasis, optimise glucose utilisation and normalise serum electrolyte and mineral concentrations. Parenteral nutrition is initiated almost routinely to support these goals. Nevertheless, enteral nutrition in the form of milk feeds has to be gradually introduced when parenteral nutrition is progressively decreased. Factors that need to be considered when designing a nutritional regimen include rapid fetal growth, immaturity of organ systems and the presence of additional conditions like chronic lung disease that increase energy requirements of the VLBW infant.

The Feeding of Choice—Human Milk

Human milk from the preterm infant's own mother is the feeding of choice.[5] Human milk is a living tissue and not simply an inert medium containing multiple nutrients. It contains live cells (polymorphonuclear leukocytes, macrophages and lymphocytes), secretory IgA, lactoferrin, lysozyme B_{12}, complement and hormones.[6] Human milk has an important role in conferring immunologic and antimicrobial protection. In a prospective, randomised multicentre study of 926 preterm infants with birth weights below 1850 g, confirmed necrotising enterocolitis (NEC) was 6 times commoner in babies exclusively fed formula than in those fed breast milk only and 3 times commoner than in those fed formula plus breast milk.[7]

* *Consultant*
Department of Neonatology
Singapore General Hospital
Address for Reprints: Dr Daisy Chan, Department of Neonatology, Singapore General Hospital, 1 Hospital Drive, Singapore 169608.

TABLE I: COMPARISON OF ENTERAL INTAKE RECOMMENDATIONS FOR PRETERM INFANTS IN STABLE CLINICAL CONDITION

Nutrients per 100 kcal	AAPCON	ESPGAN-CON
Water, mL	–	115-154
Energy, kcal	100	100
Protein, g	2.9-3.3	2.25-3.1
Carbohydrate, g	9-13	7-14
Fat, g	4.5-6.0	3.6-7
Linoleic acid, g	0.4	0.5-1.4
Linolenic acid, g	–	>0.055
C18:2/C18:3	–	5-15
Vitamin A, IU	75-225	270-450
Vitamin D, IU	270	800-1600/d
Vitamin E, IU	>1.1	0.6-10
Vitamin K, µg	4	4-15
Ascorbate, mg	35	7-40
Thiamine, µg	>40	20-250
Riboflavin, µg	>60	60-600
Pyridoxine, µg	>35	35-250
Niacin, mg	>0.25	0.8-5.0
Pantothenate, mg	>0.30	>0.3
Biotin, µg	>1.5	>1.5
Folate, µg	33	>60
Vitamin B_{12}, µg	>0.15	>0.15
Sodium, mg	48-67	23-53
Potassium, mg	66-98	90-152
Chloride, mg	–	57-89
Calcium, mg	175	70-140
Phosphorus, mg	91.5	50-87
Magnesium, mg	–	6-12
Iron, mg	1.7-2.5	1.5
Zinc, µg	>500	550-1100
Copper, µg	90	90-120
Selenium, µg	–	–
Chromium, µg	–	–
Manganese, µg	>5	1.5-7.5
Molybdenum, µg	–	–
Iodine, µg	5	10-45
Taurine, mg	–	–
Carnitine, mg	–	>1.2
Inositol, mg	–	–
Chlorine, mg	–	–

AAPCON: American Academy of Pediatrics, Committee on Nutrition; ESPGAN-CON: European Society of Paediatric Gastroenterology and Nutrition, Committee on Nutrition of the Preterm Infant

Nutritionally, the protein quality of human milk is particularly suited to the VLBW infant.[8] Human milk contains 30% casein and 70% whey, in contrast to cow's milk, which contains 82% casein and 18% whey. Clinical studies showed that whey-predominant milks were digested more easily, promoted faster gastric emptying[9] and produced lower plasma amino acid concentrations of phenylalanine and tyrosine[10] than casein-predominant milks. Casein-predominant milks however, were associated with more frequent and prolonged metabolic acidosis.[11] Human milk contains lipases that are activated by bile salts in the duodenum and improve fat digestion and absorption.[12] Oligosaccharides in human milk aid in host defense because their structure mimics specific bacterial antigen receptors.[6]

Preterm human milk has been associated with promotion of cognitive development. In a multicentre trial of 300 premature infants weighing <1850 g at birth, those infants receiving human milk during their hospitalisation had an 8.3 point advantage in intelligence test scores at 7½ to 8 years compared to those who never received human milk.[13] This occurred even after adjusting for differences between groups in maternal social class and educational status, illness severity, gender and duration of breast-feeding. It was suggested that the presence of long-chain polyunsaturated fatty acids, present in human but not formula milk, accounted for the developmental benefit of human milk.[13]

Apart from nutritional advantages, human milk may be beneficial in infants having a family history of atopy (in first degree relatives). One randomised trial showed that preterm infants who had a family history of atopy and were fed exclusively human milk, developed less allergic reactions at 18 months, notably eczema, (odds ratio 3.6; 95% confidence intervals 1.4 to 9.1) than those fed preterm formula.[14]

Nevertheless, clinical studies have shown that non-fortified human milk often fails to meet estimated nutrient needs of the growing preterm infant for protein, calcium, phosphorus, magnesium, sodium, copper, zinc, vitamins B_2, B_6, C, D, E and K, and folic acid.[1,5]

Unlike formula milk, the composition of human milk varies within a single feeding (or milk expression) itself[15] and during the course of lactation.[16] Human milk expressed at the beginning of a feeding (the foremilk) contains less fat and therefore less energy content than that at the end of a feeding (the hindmilk).[15] Milk from mothers of preterm infants during the first 2 weeks after delivery contains higher levels of protein, fat and sodium, but lower concentrations of lactose, calcium and phosphorus, compared with milk from mothers of term infants.[17-20] These differences may be due to the lower daily volume of milk produced by mothers of preterm infants.[21] The amount of protein in preterm milk in the first 2 to 3 weeks of life may be sufficient to match the infants' needs when fed at 180 to 200 mL/kg/day but becomes inadequate by the end of the first month of life. Preterm infants fed unsupplemented human milk on a long-term basis developed complications of hypoproteinemia at 8 to 12 weeks,[22] hyponatremia at 4 to 5 weeks,[23] osteopenia at 4 to 5 months,[24] and zinc deficiency at 2 to 6 months.[25]

Fat forms the major energy source (nearly 50% of

calories) but is the most variable nutrient component in human milk. The fat content of human milk varies widely from mother to mother and declines during the day. One disadvantage of expressed human milk over breast-feeding is the adherence of separated milk fat on standing to collection bottles and possibly feeding tubes.[26,27] This deprives the infant of additional calories from fat.

Preterm human milk is therefore recommended for VLBW infants because it protects against necrotising enterocolitis. It leads to better gastric emptying, enhanced fat absorption, improved cognition and reduced allergies for those with a family history of atopy. However, it is likely to give rise to specific nutritional inadequacies when given long-term without supplementation, especially after the first month of life.

Fortification of Human Milk

To correct the inadequacies of preterm human milk, commercial infant formula manufacturers have developed multi-nutrient fortifiers for the preterm infant.[28] These commercial human milk fortifiers (HMF) generally contain carbohydrate that is predominantly or exclusively glucose polymers and whey-predominant cows' milk protein. Minerals and vitamins are included in such fortifiers. Human milk fortification has definite nutritional advantage.[29] Compared to infants exclusively fed unfortified preterm milk, several studies showed that addition of HMF to preterm milk resulted in greater protein and mineral intake,[30-32] leading to short-term increase in weight gain and linear growth.[30] Balance data demonstrated that use of fortified human milk resulted in net nutrient retention that approached or was greater than expected intrauterine accretion rates.[33]

There are insufficient data to evaluate long-term neurodevelopmental outcome.[29] A multicentre study evaluated the neurodevelopment of 275 preterm infants with birth weights <1850 g randomised to either a multi-nutrient fortifier or a control supplement of phosphate/vitamins for 39 days.[34] They found that infants randomised to the multi-nutrient fortifier showed no neuro-developmental advantage at 18 months old when compared to those given the control supplement.

Concerns have been raised regarding the effect of cow's milk protein in fortifiers on feeding tolerance and gastric emptying rate.[35] However, recent data suggested that feeding tolerance does not change after HMF is added.[36] A disadvantage of adding multi-nutrient fortifier lies in the inability to adjust individual nutrients according to the infant's particular needs, so that addition of a fixed nutrient supplement could still fail to meet the estimated requirement in some infants. Concerns have also been expressed over the levels of minerals included in human milk fortifiers, since insoluble calcium soaps may be formed by the reaction of minerals in fortifiers with the long chain fatty acids.[37] This may result in slower weight gain due to poorer fat absorption.

Currently, manufacturers recommend addition of fortifier when the infant achieves full enteral feeding at milk volumes of over 100 mL/kg/day. In many neonatal units, fortification of human milk is continued until the preterm infant achieves a certain minimum body weight (for example, 1800 g) or until hospital discharge. Future research should be directed toward comparison between different proprietary preparations and evaluating both short- and long-term outcome in search of the "optimal" composition and duration of use of fortifier.[29] Research is also needed to study the optimum level of minerals that could be included in fortifiers without affecting fat absorption.

The Alternative Feeding—Commercial Preterm Formulas

For mothers who produce no or insufficient breast milk, commercial preterm infant formulas have been developed to meet the nutritional requirements of the growing preterm infant. These preterm formulas can be used alone or in conjunction with the mother's milk. Most preterm formulas have an energy content of about 80 kcal/100 mL (24 kcal/oz) instead of the 65 to 70 kcal/100 mL (20 kcal/oz) found in term formula or term breast milk. They characteristically contain carbohydrate blends of lactose and glucose polymers (maltodextrins), whey-predominant cow's milk protein and fat blends containing medium-chain triglycerides and polyunsaturated long-chain triglycerides. Compared with standard term formulas, preterm formulas have increased levels of sodium, calcium, phosphorus, copper and zinc.

The preterm infant has difficulty digesting lactose in the first few days of life due to low intestinal lactase activity.[38] However, alpha-glycosidase enzymes for digesting glucose polymers are active, so glucose polymers are well-tolerated.[39] Most preterm formulas therefore contain blends of lactose and glucose polymers. Taurine is present in human milk and added to most preterm formulas. Taurine is presumably important in infant nutrition, although no definite functional benefits have been found from its addition to preterm formulas.[40,41]

Preterm infants have low lingual lipase and pancreatic lipase activity. The inclusion of medium chain triglycerides in preterm formulas is an advantage because their digestion and absorption is not dependent on bile salt levels that are low in the premature infant.[42] The fat blend in preterm formulas meets the estimated essential fatty acid requirement of at least 3% of total calories in the form of linoleic acid and linolenic acid.[4]

Long-term cognitive benefits have been reported from

feeding to preterm babies a preterm formula compared to standard term formula. In a large randomised intervention trial, preterm babies fed preterm formula either as sole or supplementary diet for the first 4 weeks showed better mental and psychomotor development indices when assessed at 18 months post-term than those fed a term formula.[43] The same group of infants was subsequently re-assessed at 7½ to 8 years old.[44] Boys previously fed the standard term formula had a 12.2 point disadvantage (95% confidence interval 3.7 to 20.6; P <0.01) in verbal intelligence quotient (IQ) scores. The authors concluded that the cognitive function of preterm infants, especially in males, was vulnerable to suboptimal early nutrition.[44]

Although preterm formulas were designed for use at full strength, some neonatal units initiate feeding with half-strength formula but at double the feeding volume in order to provide the same caloric content. While a small study has shown better feeding tolerance with half-strength compared to full-strength formula,[45] there are concerns over the double feeding volume (up to 250 mL/kg/day) required.

Several randomised controlled studies have compared the feeding of exclusive preterm formula to that of fortified human milk for preterm infants.[46,47] Infants fed fortified human milk have slower weight gain but a lower incidence of NEC and late-onset sepsis than those fed preterm formula. There was no difference in feeding tolerance between groups.[46]

Soy-based formulas have no place in the feeding of preterm infants because of lower protein, calcium and phosphorus absorption, resulting in poorer weight gain, lower serum albumin and calcium levels.[48] Soy formulas contain phytate that may reduce trace mineral availability and may have high levels of aluminium.[49]

Preterm formulas are acceptable as an alternative feeding for the preterm infant whose mother produces no or insufficient breast milk. Research is needed to clearly define the role and optimal composition of various nutrients in preterm formulas.

Supplementation of Commercial Preterm Formulas

The recommended oral intakes of vitamin A, thiamin, riboflavin, niacin, pyridoxine, pantothenic acid, B_{12} and biotin by VLBW infants are the same as those recommended for term infants.[50] Once enteral feedings are established, the Committee on Nutrition of the American Academy of Pediatrics recommends that daily multivitamin supplements be considered, after taking into account the vitamin content of non-supplemented formula.[4] Due to instability of folic acid in solutions, the liquid multivitamin drops for infants do not contain folic acid. The Committee on Nutrition of the American Academy of Pediatrics suggests that the recommended daily allowance (RDA) for folic acid be added to the multivitamin preparation in the hospital pharmacy.[4]

There is no clear indication for iron supplementation in premature infants. However, iron supplementation is definitely indicated before preterm infants reach 2 months old.[5] Iron should be provided at 2 to 4 mg/kg/day and continued for a year.[5] Preterm infants fed human milk should receive ferrous sulphate supplementation, whereas formula-fed infants may receive sufficient iron in iron-fortified formulas. When recombinant human erythropoietin is used in preterm infants to prevent anaemia of prematurity, iron supplementation up to 6 mg/kg/day is important, because active erythropoiesis requires additional iron as substrate.[51] Like multivitamin supplements, the preterm infant may be fed oral medications like caffeine citrate and theophylline once enteral feedings are established.

Method of Feeding

The method of feeding selected for each preterm infant is based on birth weight, gestational age, physiologic stability and experience of the hospital nursing staff. Specific feeding decisions that must be made by the clinician include the age at which to initiate feeding, the route of delivering feeds and the rate of increase in feeding volume.

Initiation of Feeding—"Minimal Enteral Feeding"

The decision to start feeding a preterm infant is usually dependent on signs of "gut readiness". Signs of intestinal obstruction are an absolute contraindication to commence feeding. The absence of bilious intragastric aspirates, abdominal distension, abdominal masses or gastro-intestinal bleeding and the passage of stools often signify that the gut is ready to receive feeds.[52] The initiation of feeding is often delayed by the presence of factors known to be associated with bowel ischaemia (due to prolonged hypoxia, hypotension, polycythemia or haemodynamically significant patent ductus arteriosus) because of concerns over precipitating necrotising enterocolitis.[52] However, one study showed no increased risk of NEC among preterm infants receiving early (within the first 2 weeks) as compared to delayed oral feedings.[53] Others delay the initiation of feeding when an umbilical arterial catheter is in place. In a recent large study evaluating feeding strategies in preterm infants of gestational age 26 to 30 weeks, there was no association between the use of umbilical arterial catheters and feeding tolerance or NEC.[54] We believe that infants can be fed while umbilical arterial catheters are *in situ*, so long as they remain stable physiologically, but catheters must be removed when they are no longer required.

In most VLBW infants, parenteral nutrition is initiated almost routinely in the first few days of life to supply the majority of the preterm infants' needs. Simultaneously, enteral feedings that are of small volume and nutritionally

insignificant are commenced. This concept of "minimal enteral feeding" or "trophic feeding" has gradually evolved since the 1980s.[55] Feeding volumes varying from 12 to 24 mL/kg/day have often been used for such "gastrointestinal priming".

The physiologic effects of early enteral nutrition are summarised in Table II. The presence of intraluminal food stimulates growth of the intestinal mucosa. Prolonged starvation produces intestinal mucosal thinning, villus shortening, DNA and protein content loss and reduced enzymatic activity.[56] Infants who received early enteral nutrition displayed greater migrating motor activity that is responsible for the forward movement of nutrients.[57,58] Minimal enteral feeding stimulated normal postnatal gut hormone surges within days, even with feed volumes (12 mL/kg body weight) that would have no nutritional benefit.[59,60] Significantly higher levels of gastrin, enteroglucagon, motilin, neurotensin, gastric inhibitory peptide, pancreatic polypeptide and peptide YY were found in enterally fed preterm infants.[57,61,62]

Clinical benefits of early enteral nutrition have been identified in several randomised controlled trials of VLBW infants (Table II). A randomised trial showed that 19 VLBW infants who received small feeds for the first 9 postnatal days established full enteral feeding earlier and had less indirect hyperbilirubinaemia, cholestatic jaundice and osteopenia than 20 controls.[63] Other studies showed that early enteral feeding was associated with less gastric residuals,[64] a shorter course of parenteral nutrition,[64] fewer days of feeding intolerance[57] and faster weight gain[57] than late feeding. Recently, early gastrointestinal priming was associated with better calcium and phosphorus retention, higher serum calcium, alkaline phosphatase activity and shorter intestinal transit times.[54]

Minimal enteral nutrition is clearly beneficial for the preterm infant in view of its effect on intestinal mucosal growth, maturation of motor activity and postnatal gut hormone surge. This is translated clinically into less jaundice, a shorter time to achieve full enteral feeding and improved weight gain, resulting in a shorter duration of hospitalisation.[54]

TABLE II: BENEFITS OF EARLY ENTERAL NUTRITION

Physiologic Benefits:
· Growth of intestinal mucosa
· Greater migrating motor activity for peristalsis
· Stimulation of gut hormone surge, including that of gastrin, enteroglucagon, motilin, neurotensin, gastric inhibitory peptide, pancreatic polypeptide and peptide YY
Clinical Benefits:
· Shorter time to full enteral feeding
· Better feeding tolerance, less gastric residuals
· Better weight gain
· Less indirect hyperbilirubinemia and cholestatic jaundice
· Better calcium and phosphorus retention and lower serum alkaline phosphatase levels
· Less osteopenia

Route of Feeding Delivery

The route for enteral feeding is determined by the infant's ability to coordinate sucking, swallowing and breathing, which appear at about 32 to 34 weeks' gestation.[5] Vigorous preterm infants who are born at more than 32 to 34 weeks may be allowed to suck from the teat or nipple. Those who are less mature, very hypotonic or critically ill will require feeding by tube to conserve energy and avoid the risk of aspiration.

Tube feeding may be accomplished with intragastric or transpyloric tubes. Intragastric tube feeding, by the nasogastric or orogastric route, is the most commonly used method in many neonatal intensive care units. The advantage of intragastric feeding is that it utilises the digestive capability of the stomach, can be performed intermittently and hence requires less supervision. Furthermore, as fat digestion in the newborn depends mostly on lingual lipase, which is most active in an acid medium, intragastric feeding would theoretically allow better fat digestion and absorption.[65] Complications of intragastric tubes include misplacement in the trachea, perforation of oesophagus or stomach, mucosal irritation and vagal bradycardia during placement. These complications occur infrequently with careful placement. There is little difference between nasogastric and orogastric tube feeding. However, a small, randomised trial showed that nasogastric tubes were associated with increased airway resistance, periodic breathing and central apnoea.[66] In our unit, orogastric tubes are placed because they are easily inserted and secured when nasal prongs or nasal endotracheal tubes are in use.

Transpyloric feeding is not routinely recommended for preterm infants. In transpyloric feeding, the tube is inserted into the duodenum (nasoduodenal) or jejunum (nasojejunal) and feedings given by continuous infusion.[67] Disadvantages of transpyloric feeding include the risk of intestinal perforation and strictures,[68] as well as the greater incidence of steatorrhoea due to relative inactivity of lingual lipase in the alkaline medium of the intestine.[69] Furthermore, transpyloric feeding may theoretically predispose the preterm infant to the risk of NEC by altering gut flora and luminal pH.[70] One randomised trial showed that the mortality risk increased by 15% when transpyloric feeding was compared to intragastric feeding.[71] Another randomised trial showed that transpyloric feeding had no nutritional benefits over bolus nasogastric and continuous nasogastric feeding and instead resulted in more radiation exposure

and an increased incidence of gastric bleeding.[72] For these reasons, it should be reserved only for selected infants with pylorospasm, delayed gastric emptying or severe symptomatic gastro-oesophageal reflux.

Gastrostomy feeding may be considered in infants who are unable to suck for several months. The gastrostomy tube is placed directly through the abdominal wall into the stomach. The advantage of gastrostomy feeding is that it reduces the risk of developing a palatal groove and negative oral stimulation associated with feeding tube insertion. Nevertheless, it subjects the infant to anaesthesia and surgery. In a randomised trial comparing gastrostomy and conventional feeding, gastrostomy feeding was shown to result in a significantly higher death rate than conventional feeding.[73]

VLBW infants receiving naso or orogastric or gastrostomy feeding may be fed on an intermittent ("bolus") or continuous schedule. In intermittent feeding, the bolus feed is placed in a syringe devoid of its plunger and allowed to drip by gravity (10 to 15 cmH_2O pressures) over 15 to 20 minutes every 2 to 3 hours. Intermittent feeding is more physiological as it simulates the feeding pattern that the infant eventually has when advanced to bottle- or breast-feeding just before hospital discharge. Intermittent feeding is generally easy to administer and does not require the use of costly infusion pumps.

Continuous feeding, on the other hand, is associated with the risk of bacterial contamination when milk is warmed or remains at room temperature for 12 to 24 hours.[74] Changing the delivery syringe, tubing and milk every 4 to 6 hours may reduce the risk of contamination in continuous feeding. When the syringe containing the feed is placed horizontally in the infusion pump, the fat portion of the milk rises to the top, leading to delivery of milk with low fat content.[75,76] This can be avoided by gently agitating the syringe every hour or inclining it at an angle of 25° to 40° in the infusion pump with the nozzle directed upwards.[75,76] Continuous feeding gives rise to significant fat losses compared to bolus feeding, due to fat adherence to the tubing especially at low flow rates.[27,75] Additional measures to reduce fat losses include complete emptying of the syringe at the end of each feed and use of shorter feeding and connecting tubes. A theoretical concern with continuous feeding is the prolonged duration of exposure of the milk to ambient light in the neonatal unit, which may result in photo-degradation of riboflavin and vitamin A.[77]

Two prospective randomised trials comparing continuous and intermittent feeding schedules in low birth weight infants showed no differences between groups in the number of days to regain birth weight, number of days to full enteral feeding and number of days to discharge.[78,79] On the other hand, in a recent large randomised feeding trial of premature infants, intermittent feeding caused significantly less feeding intolerance and better weight gain than continuous feeding, even when both groups of infants received iso-caloric formula.[54]

Tube feeding bypasses the "cephalic phase" of feeding. The potential benefit of non-nutritive sucking on a pacifier while being tube-fed has been investigated in 13 randomised trials.[80] Non-nutritive sucking was shown to decrease significantly the length of stay of preterm infants. However, it had no consistent benefit on weight gain, energy intake, heart rate, oxygen saturation, intestinal transit time or the age at full oral feeds.[80] No negative outcomes were reported in any study.

The feeding route of choice for VLBW infants is intragastric tube feeding. Intermittent (bolus) feeding is preferable to continuous feeding because it is more physiological, easier to administer, may result in less feeding intolerance and gives rise to less fat loss from adherence to the tubing.

Rate of Increase in Feeding Volume

In most VLBW babies, the volume of feeds is increased gradually each day if the baby remains physiologically stable and shows no signs of feeding intolerance. To monitor feeding tolerance, gastric contents are aspirated and examined before each bolus feeding or every 2 to 4 hourly if using continuous feeding infusion. Feeding intolerance (gastric residual volumes exceeding 20% of previous feed volumes, abdominal distention, decreased bowel sounds, tenderness) is commonly associated with rapid advancement of feeding volume. Several retrospective case-control studies have shown that infants who developed NEC were more likely to have received larger daily increments in feeding volume when compared to controls.[81-83] In one study, the group in whom NEC developed had received an average daily increase in feeding volume of 28 mL/kg/day, compared to that in the control group without NEC of 17 mL/kg/day.[84] Based on these reports, it would be prudent to advance feeds cautiously at no more than 20 mL/kg/day.

Monitoring Adequacy of Nutrition

Whether the VLBW infant receives enteral and/or parenteral nutrition, it is important to monitor growth regularly, including measurements of daily weight, weekly crown-heel length and weekly occipital-frontal circumference. Following the expected weight loss of 10% to 15% of birth weight in the first 2 weeks of life due to change in body water, the infant will subsequently gain weight. The appropriately growing preterm infant should gain weight at the rate of 15 to 20 g/kg/day.[85]

Nutritional status may be assessed by periodically

measuring the blood glucose, serum urea and creatinine, total protein and albumin, serum electrolytes, serum calcium, phosphorus and magnesium, serum alkaline phosphatase and a full blood count.

Post-Discharge Nutrition

Traditionally, preterm infants fed preterm formula in hospital are often changed to term formula when a certain minimal weight (usually 1800 g) has been achieved or before hospital discharge. To evaluate the importance of post-discharge nutrition, randomised trials have utilized a specially designed "follow-on preterm formula" or "preterm discharge formula" that is intermediate in composition between preterm and term formula. It has an increased energy content of 72 kcal/100 mL, a 24% higher protein content compared to term formula and higher content of calcium, phosphorus, zinc and copper. Use of this "preterm discharge formula" to a postnatal age of 9 months was shown to result in greater linear growth, weight gain and bone mineral content than use of term formula.[86,87] Research is needed to determine the optimal duration of use of such "preterm discharge formulas".

Like formula-fed infants, preterm infants receiving fortified human milk in hospital often continue to receive human milk without fortification when a certain minimal weight (usually 1800 g) has been achieved or before hospital discharge. One study reported that ex-preterm infants who were initially fed fortified human milk in hospital but exclusively fed human milk after discharge had lower bone mineral content, lower phosphorus, higher alkaline phosphatase than formula-fed babies at 16 and 25 weeks postnatally.[88] Growth was otherwise similar. Calcium supplementation may possibly be necessary in some preterm infants who are exclusively breast-fed after hospital discharge.

Conclusion

Optimal parenteral and enteral nutrition is critical in the management of the VLBW infant. Future goals of nutrition research in the VLBW infant must include determining the role and optimal composition of various nutrients required by the VLBW infant and the duration of use, so as to promote appropriate growth and development comparable to that of the fetus at the same post-conceptional age.

REFERENCES

1. Tsang R C, Lucas A, Uauy R, Zlotkin S, editors. Nutritional Needs of the Preterm Infant: Scientific Basis and Practical Guidelines. Baltimore, MD: Williams & Wilkins, 1993.
2. Committee on Nutrition of the Preterm Infant, European Society of Paediatric Gastroenterology And Nutrition (ESPGAN). Nutrition and Feeding of Preterm Infants. Oxford, England: Blackwell Scientific Publications, 1987.
3. American Academy of Pediatrics, Committee on Nutrition. Nutritional needs of low birth weight infants. Pediatrics 1977; 60:519-30.
4. American Academy of Pediatrics, Committee on Nutrition. Nutritional needs of low birth weight infants. Pediatrics 1985; 75:976-86.
5. American Academy of Pediatrics, Nutrition Committee: Nutritional Needs of Preterm Infants. In: Pediatric Nutrition Handbook. 4th ed. Evanston, IL: American Academy of Pediatrics, 1998.
6. Schanler R J. Human milk for preterm infants: Nutritional and immune factors. Semin Perinatol 1989; 13:69-77.
7. Lucas A, Cole T J. Breast milk and neonatal necrotizing enterocolitis. Lancet 1990; 336:1519-23.
8. Schanler R J. Suitability of human milk for the low birth weight infant. Clin Perinatol 1995; 22:207-22.
9. Cavell B. Gastric emptying in infants fed human milk or infant formula. Acta Paediatr Scand 1981; 70:639-41.
10. Rassin D K, Gaull G E, Raiha N C, Heinonen K. Milk protein quantity and quality in low birth weight infants. IV. Effects on tyrosine and phenylalanine in plasma and urine. J Pediatr 1977; 90:356-60.
11. Raiha N C, Heinonen K, Rassin D K, Gaull G E. Milk protein quantity and quality in low birth weight infants. I. Metabolic responses and effects on growth. Pediatrics 1976; 57:659-84.
12. Jensen R G, Jensen G L. Specialty lipids for infant nutrition. I. Milks and formulas. J Pediatr Gastroenterol Nutr 1992; 15:232-45.
13. Lucas A, Morley R, Cole T J, Lister G, Leeson-Payne C. Breast milk and subsequent intelligence quotient in children born preterm. Lancet 1992; 339:261-4.
14. Lucas A, Brooke O G, Morley R, Cole T J, Bamford M F. Early diet of preterm infants and development of allergic or atopic disease: randomised prospective study. BMJ 1990; 300:837-40.
15. Hytten F E. Clinical and chemical studies in human lactation, II: variations in major constituents during a feeding. BMJ 1954; I:176-9.
16. Hytten F E. Clinical and chemical studies in human lactation, IV: trends in milk composition during the course of lactation. BMJ 1954; I:249-53.
17. Atkinson S A, Anderson G H, Bryan M H. Human milk: comparison of the nitrogen composition in milk from mothers of premature and full-term infants. Am J Clin Nutr 1980; 33:811-5.
18. Gross S J, David R J, Bauman L, Tomarelli R M. Nutritional composition of milk produced by mothers delivering preterm. J Pediatr 1980; 96:641-4.
19. Anderson G H, Atkinson S A, Bryan M G. Energy and macronutrient content of human milk during early lactation from mothers giving birth prematurely and at term. Am J Clin Nutr 1981; 334:258-65.
20. Lemons J A, Moye L, Hall D, Simmons M. Differences in the composition of preterm and term human milk during early lactation. Pediatr Res 1982; 16:113-7.
21. Lucas A, Hudson G J. Preterm milk as a source of protein for low birth weight infants. Arch Dis Child 1984; 59:831-6.
22. Ronnholm K A, Sipila I, Siimes M A. Human milk protein supplementation for the prevention of hypoproteinemia without metabolic imbalance in breast milk-fed, very low birth weight infants. J Pediatr 1982; 101:243-7.
23. Engelke S C, Shah B L, Vasan U, Raye J R. Sodium balance in very low birth weight infants. J Pediatr 1978; 93:837-41.
24. Greer F R, Steichen J J, Tsang R C. Calcium and phosphate supplements in breast milk-related rickets: results in a very low birth weight infant.

Am J Dis Child 1982; 136:581-3.

25. Zlotkin S H. Assessment of trace element requirements (zinc) in newborns and young infants including the infant born prematurely. In: Chandra R K, editor. Trace Elements in Nutrition of Children-II. New York: Raven Press, 1991; 23:49-64.
26. Mehta N R, Hamosh M, Bitman J, Wood D L. Adherence of medium chain fatty acids to feeding tubes during gavage feeding of human milk fortified with medium chain triglycerides. J Pediatr 1988; 112:474-6.
27. Stocks R J, Davies D P, Allen F, Sewell D. Loss of breast milk nutrients during tube feeding. Arch Dis Child 1985; 60:164-6.
28. Schanler R J. The role of human milk fortification for premature infants. Clin Perinatol 1998; 25:645-57.
29. Kuschel C A, Harding J E. Multicomponent fortified human milk for promoting growth in preterm infants. Cochrane Database Syst Rev 2000; (2):CD000343.
30. Ehrenkranz R A, Gettner P A, Nelli C M. Nutrient balance studies in premature infants fed premature formula or fortified preterm human milk. J Pediatr Gastroenterol Nutr 1989; 8:58-67.
31. Raschko P K, Hiller J L, Benda G I, Buist N R, Wilcox K, Reynolds J W. Nutritional balance studies of VLBW infants fed their mothers' milk fortified with a liquid human milk fortifier. J Pediatr Gastroenterol Nutr 1989; 9:212-8.
32. Greer F R, McCormick A. Improved bone mineralization and growth in premature infants fed fortified own mother's milk. J Pediatr 1988; 112:961-9.
33. Schanler R J, Abrams S A. Postnatal attainment of intrauterine macromineral accretion rates in low birth weight infants fed fortified human milk. J Pediatr 1995; 126:441-7.
34. Lucas A, Fewtrell M S, Morley R, Lucas P J, Baker B A, Lister G, et al. Randomized outcome trial of human milk fortification and developmental outcome in preterm infants. Am J Clin Nutr 1996; 64:142-51.
35. Metcalf R, Dilena B, Gibson R, Marshall P, Simmer K. How appropriate are commercially available human milk fortifiers? J Paediatr Child Health 1994; 30:350-5.
36. Moody G J, Schanler R J, Lau C, Schulman R J. Feeding tolerance in premature infants fed fortified human milk. J Pediatr Gastroenterol Nutr 2000; 30:408-12.
37. Boehm G, Muller D M, Senger H, Borte M, Moro G. Nitrogen and fat balances in very low birth weight infants fed human milk fortified with human milk or bovine milk protein. Eur J Pediatr 1993; 152:236-9.
38. Maclean W C Jr, Fink B B. Lactose malabsorption by premature infants: Magnitude and clinical significance. J Pediatr 1980; 97:383-8.
39. Cicco R, Holzman I R, Brown D R, Becker D J. Glucose polymer tolerance in premature infants. Pediatrics 1981; 67:498-501.
40. Gaull G E, Rassin D K, Raiha N C, Heinonen K. Milk protein quantity and quality in low birth weight infants. III. Effects on sulphur amino acids in plasma and urine. J Pediatr 1977; 90:348-55.
41. Jarvenpaa A L, Raiha N C, Rassin D K, Gaull G E. Feeding the low birth weight infant, I: taurine and cholesterol supplementation of formula does not affect growth and metabolism. Pediatrics 1983; 71:171-8.
42. Hamosh M. Lipid metabolism in premature infants. Biol Neonate 1987; 52:50-64.
43. Lucas A, Morley R, Cole T J, Gore S M, Lucas P J, Crowle P, et al. Early diet in preterm babies and developmental status at 18 months. Lancet 1990; 335:1477-81.
44. Lucas A, Morley R, Cole T J. Randomized trial of early diet in preterm babies and later intelligence quotient. BMJ 1998; 317:1481-7.
45. Currao W J, Cox C, Shapiro D L. Diluted formula for beginning the feeding of premature infants. Am J Dis Child 1988; 142:730-1.
46. Schanler R J, Schulman R J, Lau C. Feeding strategies for premature infants: Beneficial outcomes of feeding fortified human milk versus preterm formula. Pediatrics 1999; 103:1150-7.
47. Schanler R J, Schulman R J, Lau C. Growth of premature infants fed fortified human milk. Pediatr Res 1997; 41:240A.
48. Namde S P, Prinsloo J G, Hampt C E. Comparison between a humanised cows' milk and a soy product for premature infants. S Afr Med J 1979; 55:982-6.
49. Bishop N, McGraw M, Ward N. Aluminium in infant formulas. Lancet 1989; 863:490,565.
50. American Academy of Pediatrics, Committee on Nutrition: Commentary on breast-feeding and infant formulas, including proposed standards for formulas. Pediatrics 1976; 57:278-89.
51. Shannon K M, Mentzer W C, Abels R I, Freeman P, Newton N, Thompson D, et al. Recombinant human erythropoietin in infants with anemia of prematurity: results of a placebo-controlled pilot study. J Pediatr 1991; 118:949-55.
52. La Gamma E F, Browne L E. Feeding practices for infants weighing less than 1500 g at birth and the pathogenesis of necrotizing enterocolitis. Clin Perinatol 1994; 21:271-302.
53. La Gamma E F, Ostertag S G, Birenbaum H. Failure of delayed oral feedings to prevent necrotizing enterocolitis. Am J Dis Child 1985; 139:385-9.
54. Schanler R J, Schulman R J, Lau C, Smith O, Heitkemper M M. Feeding strategies for premature infants: Randomized trial of gastrointestinal priming and tube-feeding method. Pediatrics 1999; 103:434-9.
55. Berseth C L. Minimal enteral feedings. Clin Perinatol 1995; 22:195-205.
56. Brown H O, Levine M L, Lipkin M. Inhibition of epithelial cell renewal and migration induced by starvation. Am J Physiol 1963; 205:868-72.
57. Berseth C L. Early feeding enhances maturation of the preterm small intestine. J Pediatr 1992; 120:947-53.
58. Berseth C L, Nordyke C. Enteral nutrients promote postnatal maturation of intestinal motor activity in preterm infants. Am J Physiol 1993; 264:G1046-G1051.
59. Lucas A, Bloom S R, Aynsley-Green A. Postnatal surges in plasma gut hormones in term and preterm infants. Biol Neonate 1982; 41:63-7.
60. Lucas A, Bloom S R, Aynsley-Green A. Gut hormones and 'minimal enteral feeding'. Acta Paediatr Scand 1986; 75:719-23.
61. Berseth C L, Nordyke C K, Valdes M G, Furlow B L, Go V L. Responses of gastrointestinal peptides and motor activity to milk and water feedings in preterm and term infants. Pediatr Res 1992; 31:587-90.
62. Lucas A, Bloom S R, Aynsley-Green A. Metabolic and endocrine consequences of depriving preterm infants of enteral nutrition. Acta Paediatr 1983; 72:245-9.
63. Dunn L, Hulman S, Weiner J, Kliegman R. Beneficial effects of early hypocaloric enteral feeding on neonatal gastrointestinal function: Preliminary report of a randomized trial. J Pediatr 1988; 112:620-2.
64. Slagle T A, Gross S J. Effect of early low-volume enteral substrate on subsequent feeding tolerance in very low birth weight infants. J Pediatr 1988; 113:526-31.
65. Alemi B, Hamosh M, Scanlon W, Salzman-Mann C, Hamosh P. Fat digestion in very low birth weight infants: effect of addition of human milk to low birth weight formula. Pediatrics 1981; 68:484-9.
66. Van Someren V, Linnett S J, Stothers J K, Sullivan P G. An investigation into the benefits of resiting nasoenteric feeding tubes. Pediatrics 1984; 74:379-83.
67. Rhea J W, Kilby J O. A naso-jejunal tube for infant feeding. Pediatrics 1970; 46:36-40.

68. Chen J W, Wong P W. Intestinal complications of naso-jejunal feeding in low birth weight infants. J Pediatr 1974; 85:109-10.

69. Roy R N, Pollnitz R P, Hamilton J R. Impaired assimilation of naso-jejunal feeds in healthy low birth weight newborn infants. J Pediatr 1977; 90:431-4.

70. Challacombe D. Letter: Bacterial microflora in infants receiving naso-jejunal tube feeding. J Pediatr 1974; 85:113.

71. Steer P A, Lucas A, Sinclair J C. Feeding the low birth weight infant. In: Sinclair J C, Bracken M B, editors. Effective Care of the Newborn Infant. Oxford: Oxford Univ Press, 1992:94-140.

72. Macdonald P D, Skeoch C H, Carse H, Dryburgh F, Alroomi L G, Galea P, et al. Randomized trial of continuous naso-gastric, bolus naso-gastric and trans-pyloric feeding in infants of birth weight under 1400g. Arch Dis Child 1992; 67:429-31.

73. Vengusamy S, Pildes R S, Raffensperger J F, Levine H D, Cornblath M. A controlled study of feeding gastrostomy in low birth weight infants. Pediatrics 1969; 43:815-20.

74. Schreiner R, Eitzen H, Gfell M, Kress S, Gresham E L, French M, et al. Environmental contamination of continuous drip feedings. Pediatrics 1979; 63:232-7.

75. Greer F, McCormick A, Loker J. Changes in fat concentration of human milk during delivery by intermittent bolus and continuous mechanical pump infusion. J Pediatr 1984; 105:745-9.

76. Narayanan I, Singh B, Harvey D. Fat loss during feeding of human milk. Arch Dis Child 1984; 59:475-7.

77. Bates C J, Liu D S, Fuller N J, Lucas A. Susceptibility of riboflavin and vitamin A in breast milk to photodegradation and its implications for the use of banked breast milk in infant feeding. Acta Paediatr Scand 1985; 74:40-4.

78. Silvestre M A A, Morbach C A, Brans Y W, Sankaran S. A prospective randomized trial comparing continuous versus intermittent feeding methods in very low birth weight neonates. J Pediatr 1996; 128:748-52.

79. Akintorin S M, Kamat M, Pildes R S, Kling P, Andes S, Hill J, et al. A prospective randomized trial of feeding methods in very low birth weight infants. Pediatrics 1997;100(4). Available from: URL: http://www.pediatrics.org/cgi/content/full/100/4/e4.

80. Pinelli J, Symington A. Non-nutritive sucking for promoting physiologic stability and nutrition in preterm infants. Cochrane Database Syst Rev 2000; 2:CD001071.

81. Covert R F, Neu J, Elliott M J, Rea J L, Gimotty P A. Factors associated with age of onset of necrotizing enterocolitis. Am J Perinatol 1989; 6:455-60.

82. Goldman H I. Feeding and necrotizing enterocolitis. Am J Dis Child 1980; 134:553-5.

83. McKeown R E, Marsh T D, Amarnath U, Garrison C Z, Addy C L, Thompson S J, et al. Role of delayed feeding and of feeding increments in necrotizing enterocolitis. J Pediatr 1992; 121:764-70.

84. Anderson D M, Kliegman R M. The relationship of neonatal alimentation procedures to the occurrence of endemic necrotizing enterocolitis. Am J Perinatol 1991; 8:62-7.

85. Pauls J, Bauer K, Versmold H. Postnatal body weight curves for infants below 1000 g birth weight receiving early enteral and parenteral nutrition. Eur J Pediatr 1998; 157:416-21.

86. Lucas A, Bishop N J, King F J, Cole T J. Randomized trial of nutrition for preterm infants after discharge. Arch Dis Child 1992; 67:324-7.

87. Bishop N J, King F J, Lucas A. Increased bone mineral content of preterm infants fed with a nutrient enriched formula after discharge from hospital. Arch Dis Child 1993; 68:573-8.

88. Abrams S A, Schanler R J, Garza C. Bone mineralization in former very low birth weight infants fed either human milk or commercial formula. J Pediatr 1988; 112:956-60.