Prebiotic Supplementation in Full-term Neonates

A Systematic Review of Randomized Controlled Trials

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Objective: To systematically review randomized controlled trials evaluating the efficacy and safety of prebiotic supplementation in full-term neonates.

Data Sources: Cochrane Central Register of Controlled Trials, MEDLINE, EMBASE, and CINAHL databases and proceedings of relevant conferences.

Study Selection: Eleven of 24 identified trials (n=1459) were eligible for inclusion.

Intervention: Trials comparing formula milk supplemented with or without prebiotics, commenced at or before age 28 days and continued for 2 weeks or longer.

Main Outcome Measures: Stool colony counts (bifidobacteria, lactobacilli, and pathogens), pH, consistency, frequency, anthropometry, and symptoms of intolerance.

Results: Six trials reported significant increases and 2 reported a trend toward increases in bifidobacteria counts after supplementation. Meta-analysis estimated significant reduction in stool pH in infants who received prebiotic supplementation (weighted mean difference, −0.65; 95% confidence interval, −0.76 to −0.54; 6 trials). Infants who receive a supplement had slightly better weight gain than did controls (weighted mean difference, 1.07 g; 95% confidence interval, 0.14–1.99; 4 trials) with softer and frequent stools similar to breastfed infants. All but 1 trial reported that prebiotic supplementation was well tolerated. In that trial, diarrhea (18% vs 4%; P = .008), irritability (16% vs 4%; P = .03), and eczema (18% vs 7%; P = .046) were reported more frequently by parents of infants who received prebiotic supplements.

Conclusions: Prebiotic-supplemented formula is well tolerated by full-term infants. It increases stool colony counts of bifidobacteria and lactobacilli and results in stools similar to those of breastfed neonates without affecting weight gain. Larger trials with long-term follow-up are needed to determine whether these short-term benefits are sustained.


BACTERIAL COLONIZATION of the sterile neonatal gut starts immediately after birth and consists predominantly of bifidobacteria and lactobacilli. These pioneer bacteria modulate gene expression in host epithelial cells, create a favorable permanent habitat for themselves, and prevent growth of harmful bacteria. Early colonization is thus a critical determinant of the permanent gut flora that may beneficially affect the individual’s health throughout life by preventing conditions such as colon cancer, inflammatory bowel disease, allergic diseases, diabetes, and obesity.1,2

Human milk contains various “oligosaccharide prebiotics” that promote the beneficial gut flora, making breastfeeding very important especially in the first month of life.1,6 However, breastfeeding may not be possible for various reasons. Formula feeding at such a critical stage of development may result in failure to develop normal gut flora and colonization with potential pathogens such as staphylococci and Escherichia coli.7,8 Supplementation of formula milk with prebiotic oligosaccharides such as galactose oligosaccharide (GOS) and fructose oligosaccharide (FOS) is therefore being explored to overcome this problem.10,11

Prebiotic oligosaccharides are short-chain carbohydrates with a degree of polymerization between 2 and 60 and are nondigestible by human or animal digestive systems. The defining property of prebiotics is their ability to selectively stimulate the growth of bifidobacteria and lactobacilli in the large intestine.12 The prebiotic oligosaccharides in turn are fermented by the gut flora, resulting in the release of hydrogen and carbon dioxide gas and short-chain fatty acids such as butyrate. The short-chain fatty acids reduce the pH of the stools, resulting in more acidic
stools, which in turn leads to a mild laxative effect with softening and increased frequency of stools. This could be beneficial in preventing the constipation that is frequently observed in formula-fed infants. In addition, the acidic pH prevents growth of pathogens, promotes further growth of healthy organisms, and promotes integrity of colonic epithelial cells. The immediate adverse effects of prebiotics are abdominal pain, regurgitation, and flatulence, which are related to excessive gas production in the gut. These adverse effects can result in failure to adhere to treatment and hence limit the short-term as well as long-term potential benefits of prebiotics.

A narrative review by Fanaro et al. reported that a prebiotic mixture specifically stimulates the growth of bifidobacteria and lactobacilli and reduces the growth of pathogenic bacteria. They also concluded that prebiotic supplementation results in changes in stool pH and short-chain fatty acid levels that are similar to those of breastfed infants. However, these conclusions were based on the results of 6 trials (of which only 3 were randomized controlled trials [RCTs]) in a neonatal population. A Cochrane review studied the effect of prebiotic supplementation for the prevention of allergic disease and food hypersensitivity in infants. Only 2 of the 7 studies included in the review reported on allergic disease outcome. Meta-analysis of these studies found no significant difference in eczema, but significant heterogeneity was detected. There was insufficient evidence to determine the role of prebiotic supplementation of infant formula for the prevention of allergic disease and food hypersensitivity. This review did not evaluate the effect of prebiotic supplementation on intestinal bacterial flora, which is a prerequisite for the potential benefits of prebiotics.

Considering the significance of gut colonization in the early neonatal period and the recently published RCTs in this population, we undertook this systematic review to determine the effectiveness of prebiotic supplementation on gut colonization with normal and pathogenic bacteria, the physical characteristics of stool, and growth as measured by anthropometry in full-term neonates.

**METHODS**

We followed guidelines from the Cochrane neonatal review group, the Quality of Reporting of Meta-analyses statement, and the Centre for Reviews and Dissemination group for undertaking and reporting this systematic review and meta-analysis. To be included in this review, the trials had to meet the following criteria.

Only randomized and quasi-randomized trials were included. Case series, retrospective trials, crossover trials, and uncontrolled trials were not eligible. Trials involving full-term neonates were eligible for inclusion. Trials were excluded if the postnatal age at randomization was greater than 28 days. Trials on preterm neonates (<37 weeks at birth) were excluded because their physiology and nutritional requirements are different from those of full-term neonates.

Trials comparing formula milk supplemented with prebiotics vs placebo or unsupplemented formula milk were eligible for inclusion. The prebiotics could be GOS, FOS, or both. The supplementation should have commenced within 28 days of life and continued for at least 2 weeks. Trials comparing a combination of prebiotics and probiotics vs controls were excluded. Trials in which the intervention formula had different composition than the control formula (apart from prebiotics) were excluded.

Trials with at least 1 of the following outcome measures were included: stool characteristics such as pH, consistency, and frequency; stool colony count of bifidobacteria and lactobacilli; stool colonization with enteric pathogenic bacteria such as *E. coli*; weight gain during the first 12 months of life; and symptoms of intolerance such as excessive vomiting, diarrhea, regurgitation, and excessive irritability.

**IDENTIFICATION AND ASSESSMENT OF TRIALS**

The Cochrane Central Register of Controlled Trials (CENTRAL, the Cochrane library, issue 2, 2008), PubMed (1966 to May 2008), EMBASE (1980 to May 2008), and CINAHL databases, as well as proceedings of the pediatric academic society meetings (published in Pediatric Research from 1980) and pediatric gastroenterology conferences (from 1980 onward) were searched. PubMed was searched by means of the following Medical Subject Headings words: oligosaccharides AND infant formula AND infant OR infant, newborn. The search was repeated using the text word prebiotic instead of oligosaccharides. Finally, the search was repeated with the text word inulin. Related articles of the included trials were searched on PubMed fortnightly until May 2008 to identify any additional trials.

In addition, the reference lists of identified trials and key review articles were searched. No language restrictions were applied. Two of us (S.R. and R.S.) searched the literature independently and assessed the eligibility of trials for inclusion in the review. Any differences were resolved by discussion with the third reviewer (S.P.).

The methodologic quality of the included trials in terms of internal validity was assessed by the 2 reviewers (S.R. and R.S.), using the Jadad scoring system. In the event of disagreement, consensus was reached by discussion with the third reviewer (S.P.).

The 2 reviewers (S.R. and R.S.) independently extracted the data. Inconsistencies were resolved by discussion among all 3 reviewers. All authors of studies were contacted to provide additional information and clarification regarding the data and methods of their trials.

**STATISTICAL ANALYSIS**

Meta-analysis was done with Review Manager 4.3 software (http://www.cc-ims.net/RevMan). Weighted mean difference and 95% confidence interval were calculated. Heterogeneity was estimated by the I² statistic. A fixed-effects model was used. The results were also cross-checked by using the random-effects model. Funnel plots were used to identify the possibility of publication bias.

**RESULTS**

**TRIAL SELECTION**

Searching PubMed by using the search term oligosaccharides returned a total of 45 relevant articles. Replacing it with the text word prebiotics returned a total of 37 relevant articles. Replacing the word with inulin returned 3 articles. After removing the overlapping articles, a total of 55 potentially relevant articles were identified. Careful scrutiny of these 55 publications and additional articles obtained by searching related articles on PubMed.
and other databases produced a total of 13 articles that were eligible for inclusion.20-32

Of these 13 articles, 2 were different publications from the same trial.21,22 They were considered as a single trial and referred to as “Bakker-Zierikzee et al21,22” (and as “Bakker-Zierikzee et al21,22 2005A” in the tables). Similarly, 2 others were different publications from the same RCT25,30 and were considered as a single trial and referred to as “Moro et al29,30” in this review (and as “Moro et al29,30 2002” in the tables). A total of 11 trials were finally included in the review (Figure 1). Thirteen RCTs33-45 were excluded for reasons given in Table 1.

**SUMMARY OF FINDINGS**

**Methodologic Quality**

The reviewers agreed on all of the methodologic assessments. Authors were contacted for clarifications and/or additional data given the inadequate reporting in individual trials included in the review. Authors of Alliet et al,20 Costalos et al,26 Decsi et al,27 and Zeigler et al32 provided the needed data. The first author of Bakker-Zierikzee et al21,22 and Bakker-Zierikzee et al23 advised us to contact a coauthor, who did not respond to our 3 requests. There was no response from the remaining authors. The details of the quality of individual trials are presented in Table 2.

**Trial Characteristics**

Eleven RCTs (n=1459) were included in the review. Nine were considered to be of good quality, with Jadad scores of 3 or more. On the basis of the information from the publications, the Jadad scores were assessed to be less than 3 in 2 RCTs.23,24 The supplementation was with GOS in 2 trials (Bakker-Zierikzee et al23 and Ben et al24), GOS-FOS and acidic oligosaccharide in 1 trial (Fanaro et al28), FOS in 1 trial (Bettler and Euler25), a combination of polydextrose, GOS, and lactulose in 1 trial (Ziegler et al32), and GOS-FOS in the remaining 6 trials. The sample size in individual trials ranged from 34 to 297. The concentration of prebiotics ranged from 0.15 to 0.8 g/dL. Four trials had a group of breastfed infants as a reference group (Bakker-Zierikzee et al21,22 Bakker-Zierikzee et al23 and Ben et al24 and Decsi et al27). The duration of supplementation varied from 2 weeks to 6 months. Outcomes assessed varied in individual trials and included stool characteristics; stool bifidobacteria, lactobacilli, and pathogenic bacterial colony counts/pH/fatty-acid profile/IgA/short-chain fatty acid levels; symptoms of intolerance (regurgitation, diarrhea, and excessive crying); anthropometry; allergy; plasma lipid profile; and calcium absorption at different times after supplementation during the trial period. The trial characteristics are shown in Table 3.

**OUTCOMES OF INTEREST**

**Stool Colonization With Bifidobacteria and/or Lactobacilli**

Nine of the 11 trials evaluated the effect of prebiotic supplementation on the colony counts of bifidobacteria in the stools (Table 3 and Table 4). The stools were analyzed at various time intervals (1 week to 6 months) after the supplementation was commenced. Bakker-Zierikzee et al21,22 Bakker-Zierikzee et al23 and Costalos et al26 reported the colony counts of bifidobacteria as a percentage of the total bacterial counts. All other trials presented the data as actual colony counts per gram of stool. Six trials20,24,27-29,31 demonstrated significantly higher levels of bifidobacteria after supplementation with prebiotics. Two trials (Bakker-Zierikzee et al21,22 and Costalos et al26) reported that, although not statistically significant, the prebiotic-supplemented group had a higher percentage of bifidobacteria in the total bacterial count at all ages during the study period. Bakker-Zierikzee et al21 did not find any significant differences between the 2 groups.

Meta-analysis was not possible because of significant heterogeneity in the methods for measuring and reporting colony counts and the timing of estimation. Even after gathering additional information from the trial authors, few data were available in a format that could be combined.

Three trials (Fanaro et al28 Moro et al29,30 and Moro et al31) also evaluated the effect on lactobacilli colony counts. Fanaro et al28 and Moro et al29,30 demonstrated higher levels of lactobacilli in the stools after supplementation with prebiotics, whereas Moro et al31 found no difference in lactobacilli counts between the 2 groups.

**Stool Colonization With Pathogenic Bacteria**

Alliet et al,20 Ben et al,24 Costalos et al,26 Decsi et al,27 Fanaro et al28 and Moro et al29,30 reported this outcome...
(Table 5). Effects of prebiotic supplementation on enteric pathogens such as *E. coli*, *Klebsiella* species, *Clostridia*, enterococci, etc, were studied. Costalos et al²⁶ showed a trend toward reduction in pathogenic bacteria in the prebiotic-supplemented groups. The data provided by Alliet et al²⁰ and Decsi et al²⁷ suggested a reduction in pathogenic bacteria in the prebiotic group. However Ben et al,²⁴ Fanaro et al,²⁸ and Moro et al²⁹,³⁰ did not find significant differences between prebiotic and control groups.

### Stool pH

Eight trials (Alliet et al,²⁰ Bakker-Zierikzee et al,²¹,²² Bakker-Zierikzee et al,²³ Ben et al,²⁴ Costalos et al,²⁶ Decsi et al,²⁷ Fanaro et al,²⁸ and Moro et al²⁹,³⁰) evaluated the effect of prebiotic supplementation on stool pH. All except Costalos et al²⁶ reported that prebiotic supplementation resulted in a significantly lower stool pH compared with controls. Pooling of the available data from 6 trials estimated a statistically significant reduction in stool pH in the prebiotic-supplemented group (weighted mean difference, −0.65; 95% confidence interval, −0.76 to −0.54) (Figure 2). However, significant statistical heterogeneity was noted between the trials for this outcome (I²=81%; P<.001).

### Stool Consistency

Costalos et al,²⁶ Fanaro et al,²⁸ Ziegler et al,³² Moro et al,²⁹,³⁰ and Moro et al,³¹ assessed the stool consistency after...
<table>
<thead>
<tr>
<th>Trial et al.</th>
<th>Year</th>
<th>Intervention</th>
<th>Outcomes Assessed</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alliet et al.</td>
<td>2007</td>
<td>GOS-lcFOS, 0.6 g/dL (n = 86)</td>
<td>Fecal pH, stool characteristics, serum cholesterol and triglyceride levels at ages 8 and 26 wk</td>
<td>No difference in weight gain or diarrheath between groups</td>
</tr>
<tr>
<td>Bakker-Zierikzee et al.</td>
<td>2005</td>
<td>GOS, 0.6 g/dL (n = 19)</td>
<td>Stool pH and E. coli count</td>
<td>Stool pH lower in prebiotic group</td>
</tr>
<tr>
<td>Bakker-Zierikzee</td>
<td>2005</td>
<td>GOS, 0.6 g/dL (n = 17)</td>
<td>Bifidobacteria as percentage of total No. of bacteria in stools</td>
<td>No differences between groups for all outcomes</td>
</tr>
<tr>
<td>Ben et al.</td>
<td>2004</td>
<td>GOS, 0.24 g/dL (n = 69)</td>
<td>Stool counts of bifidobacteria, lactobacilli, and E. coli</td>
<td>No difference in physical growth between groups; all formulas well tolerated; FOS 0.3-g/dL group had less constipation than other groups</td>
</tr>
<tr>
<td>Bettler and Euler</td>
<td>2006</td>
<td>GOS, 0.3 g/dL (n = 101); FOS, 0.15 g/dL (n = 98)</td>
<td>Stool pH, stool characteristics, serum chemistry panel</td>
<td>No difference in growth during trial period in both groups; no difference in symptoms of intolerance; stools softer and more frequent in prebiotic group; stool pH not different between groups; trend toward higher stool bifidobacteria as percentage of total bacterial count in prebiotic group; percentage of fecal clostridia at completion of trial significantly lower in prebiotic group (P = .04)</td>
</tr>
<tr>
<td>Costalos et al.</td>
<td>2008</td>
<td>GOS-lcFOS, 0.4 g/dL (n = 80)</td>
<td>Anthropometry at ages 6 and 12 wk; stool for bifidobacteria, lactobacilli, and E. coli at age 6 wk; stool characteristics at ages 6 and 10 wk</td>
<td>Growth during trial period in both groups; no difference in symptoms of intolerance; stools softer and more frequent in prebiotic group; stool pH not different between groups; trend toward higher stool bifidobacteria as percentage of total bacterial count in prebiotic group; percentage of fecal clostridia at completion of trial significantly lower in prebiotic group (P = .04)</td>
</tr>
<tr>
<td>Decsi et al.</td>
<td>2005</td>
<td>GOS, 0.4 g/dL (n = 21)</td>
<td>Fecal flora, stool characteristics, serum pH, SCFA, and E. coli at age 6 wk; stool characteristics at ages 6 and 10 wk</td>
<td>No difference in weight gain or diarrheath between groups</td>
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</table>
prebiotic supplementation. All reported that the stools were softer in the prebiotic-supplemented group.

### Stool Frequency

Costalos et al, Moro et al, and Moro et al reported on stool frequency. All reported a higher frequency of stools in prebiotic-supplemented infants. The higher frequency of stools was considered to be similar to the frequency in breastfed infants and hence was reported by the investigators as a beneficial outcome rather than as diarrhea.

### Physical Growth During the First Year of Life

Nine trials (Alliet et al, Ben et al, Better and Euler, Costalos et al, Decsi et al, Fanaro et al, Moro et al, Moro et al, and Ziegler et al) evaluated the effect of prebiotic supplementation on physical growth at various ages in the first year of life. All reported no difference in physical growth between the 2 groups. However, pooled meta-analysis of the data from 4 trials showed that infants in the prebiotic group had slightly better weight gain during the trial period than...
did controls (weighted mean difference, 1.07 g; 95% confidence interval, 0.14-1.99 g) (Figure 3).

Tolerance

Eight trials (Ben et al,24 Bettler and Euler,25 Costalos et al,26 Decsi et al,27 Fanaro et al,28 Moro et al,29,30 Moro et al,31 and Ziegler et al32) reported this outcome. All symptoms such as excessive irritability, crying, regurgitation, and tolerance in healthy formula-fed, full-term infants were detected among the 3 formula groups at 30, 60, and 90 days of age (P <.001, P = .03, and P = .004, respectively), with the supplemented-formula groups having looser stools than the control group. The 0.8-g/dL group had significantly higher stool frequency than the control and 0.4-g/dL groups at 30 days of age (P = .02 and P = .02, respectively), but all of the groups were similar at 60, 90, and 120 days of age. They found a significant increase in 3 categories of adverse events: diarrhea (0.4 g/dL vs control, 18% vs 4%; P = .008), eczema (0.4 g/dL vs control, 18% vs 7%; P = .046), and irritability (0.8 g/dL vs control, 16% vs 4%; P = .03). The risk of eczema was higher (18% vs 4%; P = .008) in the 0.4-g/dL group than in the 0.8-g/dL group. The authors concluded that infants receiving the prebiotic mixture achieved normal growth and stool characteristics more similar to those of breastfed infants in comparison with controls. They advised considering the risk of possible intolerance against the benefits of prebiotics.

The results of our systematic review show that, in full-term neonates, prebiotic supplementation of formula milk results in higher stool colony counts of bifidobacteria. This effect was consistent across most of the trials irrespective of the heterogeneity among studies with regard to the dosage, duration of supplementation, and method.
of estimation and reporting of the results. In addition, stools in the supplemented group had higher lactobacilli counts, lower pathogenic bacteria counts, and more acidic pH and were softer and more frequent, similar to those of breastfed neonates.

Most of the trials showed a statistically significant increase in stool colony counts of bifidobacteria after prebiotic supplementation. Even studies that did not show statistically significant differences reported a trend toward higher stool colony counts of bifidobacteria in the prebiotic group. None of the studies showed a decrease in stool colony counts of bifidobacteria after prebiotic supplementation. The response to exogenous prebiotics is reported to depend on the baseline mass of healthy gut flora before the start of the supplement rather than the dose of prebiotics. However, some studies have shown a dose-dependent stimulating effect on the growth of bifidobacteria and lactobacilli in the intestine. In the absence of specific data, we can only speculate that the lack of significant benefits in some of the outcomes in the studies by Bakker-Zierikzee et al and Costalos et al (Table 3) may be related to lower counts of healthy gut flora before the commencement of supplementation.

The rationale for doses of 0.15 to 0.8 g/dL in various trials appears to be an attempt to achieve a maximum bifidogenic effect with minimal intolerance in the form of flatulence, abdominal distention, colic, etc. The European Scientific Committee on Food recommendation indicates that prebiotics can be added up to a maximum of 0.8 g per 100 mL of formula milk.

In addition to the bifidogenic effect, we assessed the physical growth of these infants because of the theoretical risk of lower weight gain after prebiotic supplementation. Animal and human trials have suggested that prebiotics may reduce hunger and food consumption, possibly mediated via gut hormones, and may be a modality for prevention and treatment of obesity. Although such effects may be beneficial in adolescents and adults, reduced weight gain can be detrimental during the immediate postnatal period. It is reassuring that all trials (n=9) that reported this outcome did not find such a detrimental effect of prebiotic supplementation. In fact, the meta-analysis of results from 4 trials showed that the prebiotic-supplemented group had slightly greater weight gain than did controls.

Excessive carbon dioxide and hydrogen gas released after fermentation of prebiotics in the colon has been shown to increase adverse effects such as flatulence, regurgitation, and vomiting. The neonates in these studies tolerated the prebiotic supplementation very well, without any increase in vomiting, irritability, or diarrhea.

When interpreting these short-term positive results, it is important to consider the possibility of publication bias wherein trials with negative results are not published. However, the funnel plots for the primary outcomes of stool pH and weight gain do not suggest such a possibility (Figure 4 and Figure 5).

Ziegler et al reported an increased incidence of atopic eczema in the prebiotic-supplemented group. However, the large RCT by Moro et al reported beneficial effects of prebiotic supplementation in reducing the incidence of atopic dermatitis and wheezing when followed up at 6 months as well as at 2 years of age. The Cochrane review that reported the meta-analysis of results of these 2 trials did not find a statistically significant difference in the incidence of eczema in the prebiotic group. The mechanism of action of prebiotics in the prevention of allergic diseases is thought to be mediated via promoting the growth of healthy bacteria in the gut early in infancy, leading to “host-microbe cross-talk” and immunomodulation. Current evidence is thus inadequate to derive any firm conclusions regarding the use of prebiotics for prevention of atopic diseases.

In summary, our results show that prebiotic supplementation of formula milk in full-term neonates is well tolerated and results in various short-term beneficial effects, including increased stool colony counts of bifidobacteria and lactobacilli, decreased counts of pathogenic enteric bacteria, more acidic stools, and softer and frequent stools, without adversely affecting weight gain. Larger population-based trials with continued long-term follow-up into adulthood are needed to find out whether these short-term benefits relate to improved general health and reduced morbidities. Until then, routine supplementation of formula milk with prebiotic oligo-
Financial Disclosure: Srinivasjois.


23. Galacto-oligosaccharides cannot be recommended. Although further investigations are needed, the results from this study indicate that galacto-oligosaccharides are safe and do not cause any negative health effects in healthy infants fed on pre- or probiotic infant formulas.


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The advantages of not going steady far outweigh the advantages of going steady in high school. Steady dating tends to stunt the development of personality.

—From the educational pamphlet “Teenage Maturity” by Daniel Lowry, 1965