

# Supplementation of Fish-oil and Soy-oil during Pregnancy and Psychomotor Development of Infants

Fahmida Tofail<sup>1</sup>, Iqbal Kabir<sup>1</sup>, Jena D. Hamadani<sup>1</sup>, Fahima Chowdhury<sup>1</sup>, Sakila Yesmin<sup>1</sup>, Fardina Mehreen<sup>1</sup>, and Syed N. Huda<sup>2</sup>

<sup>1</sup>ICDDR,B: Centre for Health and Population Research, GPO Box 128, Dhaka 1000, Bangladesh and <sup>2</sup>Institute of Nutrition and Food Science, University of Dhaka, Ramna, Dhaka 1000, Bangladesh

## ABSTRACT

Supplementation of docosahexaenoic acid (DHA) in infancy improves neuro-developmental outcomes, but there is limited information about the impact of supplementing pregnant mothers with DHA on the development of their infants. In a follow-up of a randomized, double-blind controlled trial with 400 pregnant mothers, the effects of supplementation of fish-oil or soy-oil (4 g/day) during the last trimester of pregnancy on psychomotor development and behaviour of infants at 10 months of age (n=249) were assessed. The quality of psychosocial stimulation at home (HOME) and nutritional status of the subjects were also measured. There were no significant differences in the fish-oil group and soy-oil group in any of the developmental (mean±SD mental development index: 102.5±8.0 vs 101.5±7.8, psychomotor development index: 101.7±10.0 vs 100.5±10.1) or behavioural outcomes. It may, therefore, be concluded that supplementation of fish-oil during the last trimester of pregnancy does not have any added benefit over supplementation of soy-oil on the development or behaviour of infants in this population.

**Key words:** Fish-oil; Soy-oil; Psychomotor development; Infant development; Child development; Infants; Child; Bangladesh

## INTRODUCTION

Docosahexaenoic acid (DHA) is a long-chain polyunsaturated fatty acid (LCPUFA), which plays an important role in the structural development of major membrane constituent of retinal photoreceptors, neurones, and synaptic membrane. It also influences important functions, such as ion transport, receptor activity, enzyme action, and membrane fluidity, thereby improving neurogenesis and synaptogenesis (1-5). Adequate supply of DHA, therefore, needs to be ensured from maternal circulation during embryonic life and from breastmilk/infant diet in early postnatal life (6-9). DHA is formed

*denovo* by conversion of its parent essential fatty acid (EFA)— $\alpha$ -linolenic acid (LNA, 18:3n-3)—through a series of desaturation and subsequent chain-elongation reactions. Older children and adults consume the ready form of DHA from its animal source, particularly marine fish-oil, and young infants receive DHA through breastmilk (2,8,10).

In full-term infants, supplementation of DHA to infant formula results in improved mental development, comparable to breastfed infants (11-15). Pre-term low-birth-weight babies are most likely to suffer from DHA deficiency because of their lower body stores. Several studies have shown benefits of supplementation of DHA on the neuro-developmental measures in pre-term low-birth-weight infants (16-21). In the foetal brain, DHA is primarily accrued during the 'brain growth spurt', which begins in the last trimester of pregnancy and continues through the early postnatal period (22-23). A decline in maternal DHA status has also been observed in the later

Correspondence and reprint requests should be addressed to:  
Dr. Fahmida Tofail  
Assistant Scientist  
Clinical Sciences Division  
ICDDR,B: Centre for Health and Population Research  
GPO Box 128, Dhaka 1000  
Bangladesh  
Email: ftofail@icddr.org

half of pregnancy (24-26). Another study has shown that supplementation of  $\alpha$ -linolenic acid (LNA) failed to influence maternal DHA status (27), raising the question if mothers under prevailing dietary conditions are able to meet the high foetal requirements of DHA or they need additional supplementation for optimal development of foetal brain. Despite the importance of DHA, there is limited research to assess the impact of supplementation of DHA during pregnancy on development of infants. A recent study observed that more mature neonatal sleep-pattern, a measure of central nervous system (CNS) integrity, was associated with higher maternal DHA levels (28). In a randomized, double-blind controlled trial, pregnant mothers were supplemented with DHA (29) from 17-19 weeks gestation until three months after delivery. Although no difference was observed in cognitive development of infants as measured at six or nine months, a developmental benefit became apparent at the age of four years (30).

In developing countries, the impact of supplementation of DHA to pregnant mothers on the development of their infants remains largely unexplained. These mothers tend to have low hepatic and adipose tissue stores of EFA due to chronic maternal under-nutrition. We, therefore, hypothesized that supplementation of fish-oil (ready form of DHA) rather than soy-oil (precursor form of DHA), during the last trimester of pregnancy, will provide additional DHA to fulfil increased foetal requirement of DHA for developing the nervous system via placental circulation and breastmilk, which will have a positive effect on the mental and psychomotor development of infants.

## MATERIALS AND METHODS

### Study design and sampling

This study is the follow-up of an intervention study that aimed at improving pregnancy outcomes by supplementing women with DHA during the last trimester of their pregnancy. The study population was chosen from the community in Dhaka city, where illiteracy, poverty, overcrowding, poor housing, and poor hygiene are common.

In the main study, a house-to-house survey was conducted during January-March 2000, and 400 eligible pregnant women at 25 weeks of gestation (based on the first date of the last menstrual period) were enrolled and randomly assigned either to the treatment (fish-oil) or to the placebo group (soy-oil) after obtaining an informed consent. The treatment group received four fish-oil capsules (1 g in each) as a single daily dose, and the placebo group received an equal number of capsules

containing an equal volume of soy-oil. The capsules were identical in appearance, and mothers were given clear instructions about the dosage. Total daily fish-oil supplement contained 1.2 g of DHA and 1.8 g of eicosapentaenoic acid (EPA) and soy-oil supplement contained 2.25 g of linoleic acid (LA) and 0.27 g of LNA. We chose soy-oil as a control because of its common use in this country. The intervention continued from 25 weeks gestation until delivery.

As part of the main study, a detailed baseline and socioeconomic history was collected on enrollment followed by weekly visits to assess compliance to the intervention.

### Measurements

**Developmental assessment:** Developmental assessment was made at the age of 10 months ( $\pm 15$  days) using the Bayley Scales of Infant Development II (BSID-II), which included two sub-scales: mental development index (MDI) and psychomotor development index (PDI) (31). The children were brought to ICDDR,B: Centre for Health and Population Research and were tested in a quiet room in the presence of their mothers. Two female psychologists, unaware of the infant's group assignment, tested all infants. Sick infants were treated and tested after recovery. The inter-observer agreement between the testers and the trainer assessed on 30 infants before the study was high (intra-class correlation:  $r > 0.98$  for both MDI and PDI).

**Infant's behaviour:** Infant's behaviour was rated during the test using a modified five-scaled tool, designed by Wolke (32). Each of the scales had 9-point ratings and included infants' activity (very still=1 to over-active=9), emotional tone (unhappy=1 to extremely happy=9), responsiveness to examiner in the first 10 minutes (avoiding=1 to inviting=9), cooperation with the test procedure (resists all suggestions=1 to always complies=9), and vocalization (very quiet=1 to constantly vocal=9). The inter-observer reliability was  $r > 0.92$  for all five behaviour ratings.

**Quality of stimulation at home:** Quality of stimulation at home was assessed using Caldwell's Home Observation for Measurement of Environment (HOME) (33), which was modified for Bangladesh and was used in other studies by the same research team (34,35). Two female interviewers interviewed mothers at their homes in the presence of their babies. The trainer observed 30 interviews before initiation of the study, and agreements between the trainer and the interviewers were high ( $> 90\%$ ).

**Socioeconomic status:** Socioeconomic status was measured using a detailed questionnaire at enrollment. Several indices were constructed by using relevant information as follows: housing index (structure of floor, roof, and wall), crowding index (number of family members divided by number of rooms), and utility index (water, electricity, and latrine). Occupation of father (stable/unstable), occupation of mother (house-wife/working woman) and education of parents (up to grade 5 or more than grade 5) were used as dichotomous variables. An asset score was constructed by giving judged arbitrary values to family possessions, for example, possession of a radio/cassette player was given a score of '2', whereas possession of a TV was scored as '6' taking into account that the price of a TV is three times more than that of a radio/cassette player. In the same way, we scored all the possessions of the family according to the market values and then added these up to construct the asset score.

**Anthropometry:** Anthropometry was performed within 72 hours of birth and then monthly up to six months using standard techniques (36) and also at the time of Bayley test. Z-scores for weight-for-age (WAZ), height-for-age (HAZ), and weight-for-height (WHZ) were then calculated using NCHS reference data (36). Ponderal index (PI) was calculated using the formula:  $PI = (\text{birth-weight in g} / \text{length cm}^3) * 100$ .

### Ethics

The research and ethical review committees of ICDDR,B approved the study, and informed written consents were obtained from all mothers prior to their enrollment in the study.

### Statistics

Data were entered and analyzed using SPSS for Windows (version 10; SPSS Inc., Chicago). Distribution of each variable was checked for normality, and where necessary appropriate transformations were made. Bivariate correlations between developmental variables and socioeconomic measures were assessed.

To examine the treatment effect, series of multiple linear regression analyses were performed where each of the developmental variables was treated as a dependent variable. In the first block, we entered age and sex. In the second block, we offered socioeconomic and biological variables that were significantly different between the groups and between the lost and the tested sample (family income, education of father, age of mother, body mass index (BMI) of mother, pedal oedema, systolic blood pressure, pregnancy weeks at enrollment, and number of children). In the third block, we offered the birth-

related variables, which were significantly different between the lost and the tested sample and between the groups (gestational age, birth-weight, birth-length, head size, resuscitation of child at delivery, problem of mother during delivery). In addition, we offered those variables, which were significantly associated with outcome variables (crowding, housing, and home environment). In the final block, we entered the treatment group.

## RESULTS

### Attrition

Of the 400 enrolled pregnant women, 76 were lost before delivery due to out-migration (fish-oil: 19 vs soy-oil: 16) and refusal to take capsules (22 vs 19). Therefore, 324 mothers were available at delivery. Only 301 liveborn singletons completed the original study because further losses occurred after delivery due to stillbirth (8 vs 6), early neonatal death (4 vs 5), subsequent out-migration (19 vs 26), and infant death (3 vs 4) in the fish-oil and soy-oil groups respectively. From this birth cohort, we could locate 249 infants for measurement of their development at 10 months of age.

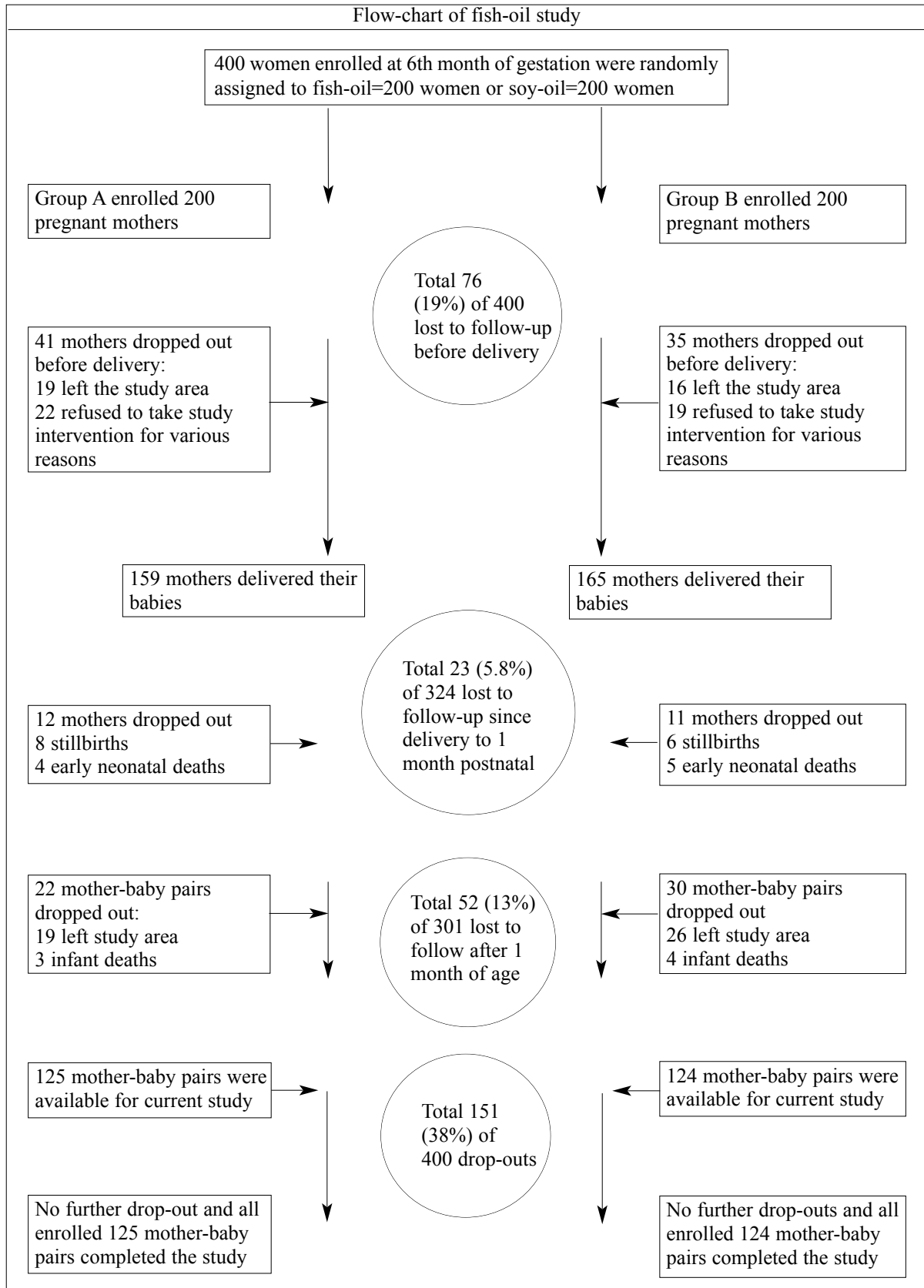
We compared the characteristics of mothers and infants who were lost at different stages with the tested infants and their mothers (Flow-chart). The lost and tested infants and their mothers differed significantly on a number of variables. Before delivery, the mothers in the lost group had higher systolic blood pressure and gestational age at enrollment, more pedal oedema, and lower family income than the tested group. The lost infants had significantly lower birth-weight and birth-length and required more resuscitation time after birth than the tested infants.

### Difference between the groups

The groups were similar in parental schooling, paternal occupation, breastfeeding and socioeconomic status, except that mothers in the fish-oil group were younger ( $p < 0.02$ ) and had fewer children ( $p < 0.008$ ) (Table 1). MDI, PDI, behaviour ratings, and HOME were also similar in the two groups (Table 2). There were also no significant group differences in any anthropometric measurements at birth or at 10 months (Tables 1 and 2).

### Association with developmental variables

Bivariate correlations were determined between outcome variables and biological and social background variables. Both MDI and PDI significantly correlated with the HOME, asset, housing index, family income, maternal



Characteristics	Fish-oil group (n=125)	Soy-oil group (n=124)	p value*
<b>Maternal biological characteristics at enrollment</b>			
Age (years) of mothers	22.1 (4.2)	23.4 (4.5)	0.02
Body mass index	20.3 (3.1)	20.4 (3.1)	0.8
Mid-upper arm circumference (cm)	23.6 (2.7)	23.8 (2.7)	0.6
Pregnancy duration (weeks) at enrollment	24.9 (1.2)	24.9 (1.1)	0.9
Women with >2 children (%)	16.8	31.5	<0.01
Compliance (mean capsule intake-days)	84.7 (10.3)	86.5 (7.4)	0.1
Compliance (% took capsule $\geq$ 90 days)	68	71.8	0.3
<b>Socioeconomic factors</b>			
Crowding index	3.9 (1.6)	4.2 (1.5)	0.09
Utility index	8.3 (0.8)	8.3 (0.9)	0.5
Housing index	3.5 (0.8)	3.5 (0.9)	0.7
Asset index	24.4 (1.4)	24.3 (1.3)	1.0
Family income (Taka/month) <sup>†</sup>	5,890 (2.1)	5,484 (2.0)	0.4
<b>Parental characteristics</b>			
Mothers with >5 years of schooling (%)	36.8	32.3	0.5
Working mothers (%)	16.0	12.1	0.5
Fathers with stable job, %	65.6	65.3	1.0
Fathers with >5 years schooling (%)	64.0	54.0	0.1
<b>Factors relating to child at and after birth</b>			
Male (%)	50.0	50.4	1.0
Gestational age (weeks)	38.7 (2.6)	39.2 (2.5)	0.2
Preterm birth (%)	24.0	21.8	0.4
Birth-weight (kg)	2.7 (0.4)	2.7 (0.4)	0.5
Birth-length (cm)	47.6 (2.1)	48.1 (2.0)	0.1
Birth-head circumference (cm)	32.3 (1.8)	32.4 (1.7)	0.7
Ponderal index	2.5 (0.2)	2.4 (0.2)	0.2
Duration of exclusive breastfeeding (months)	4.0 (1.6)	4.0 (1.8)	0.9
Age (days) of testing	300.7 (4.3)	300.7 (4.3)	1.0
*Independent sample <i>t</i> -test or $\chi^2$ -test			
<sup>†</sup> 1US\$=Taka 59.00			
Values are mean (SD) or %			

Variable	Fish-oil group (n=125)	Soy-oil group (n=124)	95 % CI of difference between means
Mental developmental index	102.5 (8.0)	101.5 (7.8)	-0.98, 3.0
Psychomotor developmental index	101.7 (10.9)	100.5 (10.1)	-1.3, 3.8
Approach	6.3 (1.3)	6.4 (1.3)	-0.41, 0.23
Activity	5.7 (1.4)	5.8 (1.4)	-0.45, 0.25
Cooperation	5.7 (1.6)	5.7 (1.5)	-0.37, 0.39
Emotional tone	5.6 (1.6)	5.7 (1.5)	-0.50, 0.26
Vocalization	5.0 (1.7)	5.1 (1.7)	-0.47, 0.39
Head circumference (cm)	43.0 (1.4)	43.2 (1.4)	-0.47, 0.22
Weight-for-height z-score	-0.6 (0.9)	-0.6 (0.8)	-0.23, 0.21
Weight-for-age z-score	-1.5 (1.1)	-1.5 (1.0)	-0.27, 0.24
Height-for-age z-score	-1.3 (1.0)	-1.3 (0.9)	-0.24, 0.22
HOME	89.4 (9.9)	90.8 (9.3)	-3.8, 1.0
Values are mean (SD)			
CI=Confidence interval; HOME=Home observation for measurement of environment			

BMI, parental education, and anthropometric measurements at birth and at 10 months. MDI and PDI negatively correlated with crowding index. Age and sex of infants significantly correlated with MDI, and utility index significantly correlated with PDI.

#### Treatment effect

There were no differences in multiple regression analysis, controlling for the possible confounders. The effect size ( $\pm$ SE) for MDI and PDI was  $-1.1 \pm 1.0$  (95% CI  $-2.9, 0.7$ ), and  $-2.1 \pm 1.1$  ( $-4.3, 0.1$ ) respectively. Age, HOME, and birth-weight were significant predictors of MDI, while sex, gestational age, BMI of mother, presence of utilities at home, birth-length, and HOME significantly predicted PDI.

### DISCUSSION

Supplementation of fish-oil during the last trimester of pregnancy did not show any added benefit over soy-oil on the development of infants. Despite a substantial loss at 10-month follow-up, the calculated power of the study with the achieved sample size was  $>80\%$ . Therefore, there was sufficient power to detect any significant differences. The women satisfactorily complied to the study, and almost 70% took capsules more than 90 days. We had trained the testers intensively and had achieved good inter-observer reliabilities before and during the tests.

There are several possibilities for lacking a benefit in the study. We had suffered a loss of 38% from the original randomized sample, and there were significant differences in the lost and tested subjects in both the groups. The lost infants were from poorer families, had lower birth-size, and required more resuscitation at birth, and their mothers had more clinical problems during pregnancy. They were definitely more at risk, and had they remained in the study, it is likely that they would have benefited more from the intervention.

The supplementation in our study was started at 25 weeks of gestation and was continued until delivery. The other study that showed improvement with supplementation of DHA at four years of age (30) started supplementation at 17-19 weeks of pregnancy and continued so until three months after delivery. It is possible that the duration and timing of our supplementation was not sufficient to demonstrate a significant effect of supplementation of fish-oil in this population. Moreover, the same study did not show any effect at six or nine months of age. It is possible that the developmental domains that require DHA for their maturation are not fully functional or expressed at an early age and are only manifested later

in life. Improvements from supplementation of DHA on the development of these children may become apparent at a later age.

The other factor that may have contributed to the lack of any benefit demonstrated from supplementation of fish-oil is that DHA is available in breastmilk in abundance, and it is usually found that children who are exclusively breastfed have high levels of DHA (10). In our study, 82% of the children were predominantly breastfed and, therefore, have received sufficient amount of DHA from breastmilk.

In our study, we used the Bayley test to assess the development of children. The Bayley test has not been standardized for Bangladesh, and there has been no study of validity here. The test has, however, been used in many developing countries, including Bangladesh, and in many of our studies. It has been the instrument of choice for much nutrition and child-development research at this age and has often been sensitive to changes following interventions. The Bayley is the only test we know of for this age-group that has been used in research in Bangladesh, where sensible and predictable correlations were found between the scores and socio-economic conditions, education of parents, stimulation in the home, and nutritional status of children. As it is not a standardized test in this population, it may not have been sensitive to minor differences expected to occur between the two intervention groups.

In our study, we used soy-oil as control since it is usually consumed by people in this community. Soy-oil contains no DHA but  $\alpha$ -linolenic acid, which is a precursor of DHA and can also influence fatty acid pattern in umbilical plasma phospholipid.

About 28% of mothers of this population suffered from maternal under-nutrition, taking pregnancy BMI cut-off of 19.8, and were likely to have low hepatic and adipose tissue reserves. Studies in adequately-nourished mothers have noted a gross fall in maternal DHA status during the last trimester of pregnancy (24,25), suggestive of rapid accretion of DHA by foetal tissues during this period. In a rat model, it has also been observed that accretion of DHA was most profound compared to other fatty acids, particularly in the last three prenatal days (37). This suggests a possible role of supplementation of DHA during the last weeks of pregnancy on the development of infants. During pregnancy, higher maternal intake of DHA results in increased transfer of DHA to the foetus via the placenta (29,38), and there is an indication of preferential placental transfer of maternal plasma DHA over  $\alpha$ -linolenic acid (39). Studies in in-

infants observed better developmental impacts of supplementation of DHA (through breastmilk or supplemented formula) than supplementation of  $\alpha$ -linolenic acid during the crucial period of rapid development of the brain (40-43).

We are aware of only one study in which supplementation of DHA during pregnancy failed to show any benefit on infants at six or nine months of age as assessed by the Fagan test (29), but a significant benefit on IQ at four years of age was observed (30); however, loss from the study was considerable.

In our study, we did not follow up the infants for future developmental assessment because they were from a migrating population. Moreover, as we did not measure serum or RBC DHA levels in these infants, we were unable to correlate biochemical improvements with functional outcomes.

It may be concluded that supplementation of fish-oil during the last trimester of pregnancy may not have any added benefit over supplementation of soy-oil on the development or behaviour of infants in this population when assessed by the Bayley Scale of Infant Development. Further studies with a true placebo and, if possible, with more sensitive tests are recommended to ascertain the role of antenatal supplementation of fish-oil on the development of children. As development of the foetal brain begins as early as the third week after conception (44), supplementation throughout pregnancy may also be considered for subsequent child development. Follow-up of these subjects in childhood is important to determine if the effects appear at a later time.

#### ACKNOWLEDGEMENTS

This research was supported by the World Bank (grant no. 00251). ICDDR,B acknowledges with gratitude the commitment of the World Bank to the Centre's research efforts. The authors are grateful to the mothers and children who participated in the study; without their help this research could not have been possible. The authors thank Dr. Md. Abdus Salam, Dr. Hasan Ashraf, and Dr. Anna Moore for reviewing the manuscript and giving their valuable suggestions.

#### REFERENCES

- Valenzuela A, Nieto MS. Docosahexaenoic acid (DHA) in fetal development and in infant nutrition. *Rev Med Chil* 2001;129:1203-11.
- Kurlak LO, Stephenson TJ. Plausible explanations for effects of long chain polyunsaturated fatty acids (LCPUFA) on neonates. *Arch Dis Child Fetal Neonatal Ed* 1999;80:F148-F54.
- Martinez M. Tissue levels of polyunsaturated fatty acids during early human development. *J Pediatr* 1992;120:S129-38.
- Simopoulos AP. Omega-3 fatty acid in health and disease and in growth and development. *Am J Clin Nutr* 1991;54:438-63.
- Neuringer M. Infant vision and retinal function in studies of dietary long-chain polyunsaturated fatty acids: methods, results, and implications. *Am J Clin Nutr* 2000;71(Suppl 1):256S-67.
- Clandinin MT, Chappell JE, Leong S, Heim T, Swyer PR, Chance GW. Fatty acid accretion in the development of the human spinal cord. *Early Hum Dev* 1981;5:1-6.
- Clandinin MT, Chappell JE, Leong S, Heim T, Swyer PR, Chance GW. Fatty acid utilization in perinatal de novo synthesis of tissues. *Early Hum Dev* 1981;5:355-66.
- Clandinin MT, Chappell JE, Leong S, Heim T, Swyer PR, Chance GW. Intrauterine fatty acid accretion rates in human brain: implications for fatty acid requirements. *Early Hum Dev* 1980;4:121-9.
- Montgomery C, Speake BK, Cameron A, Sattar N, Weaver LT. Maternal docosahexaenoic acid supplementation and fetal accretion. *Br J Nutr* 2003;90:135-45.
- Sastry PS. Lipids of nervous tissue, composition and metabolism. *Prog Lipid Res* 1985;24:69-176.
- Makrides M, Neumann M, Simmer K, Pater J, Gibson R. Are long chain polyunsaturated fatty acids essential nutrients in infancy? *Lancet* 1995;345:1463-8.
- Birch EE, Hoffman DR, Uauy RD, Birch DG, and Prestidge C. Visual acuity and the essentiality of docosahexaenoic acid in the diet of term infants. *Pediatr Res* 1998;44:201-9.
- Birch EE, Garfield S, Hoffman DR, Uauy RD, Birch DG. A randomized controlled trial of early dietary supply of long-chain polyunsaturated fatty acids and mental development in term infants. *Dev Med Child Neurol* 2000;42:174-81.
- Birch EE, Hoffman DR, Castaneda YS, Fawcett SL, Birch DG, Uauy RD. A randomized controlled trial of long-chain polyunsaturated fatty acid supplementation of formula in term infants after weaning at 6 wk of age. *Am J Clin Nutr* 2002;75:570-80.

15. Willatts P, Forsyth JS, DiModugno MK, Varma S, Colvin M. Effect of long chain polyunsaturated fatty acids in infant formula on problem solving at 10 months of age. *Lancet* 1998;352:688-91.
16. Carlson SE, Werkman SH, Rhodes PG, Tolley EA. Visual acuity development in healthy preterm infants: effect of marine oil supplementation. *Am J Clin Nutr* 1993;58:35-42.
17. Carlson SE, Werkman SH, Peeples JM, Wilson WM. Long chain fatty acids and early visual and cognitive development of preterm infants. *Eur J Clin Nutr* 1994;48(Suppl 2):S27-30.
18. Bjerve KS, Thoresen L, Bonna K, Vik T, Johnsen H, Brubakk AM. Clinical studies with alpha lolenic acid and long chain n-3 fatty acids. *Nutrition* 1992;8:130-2.
19. Lucas A, Morley R, Cole TJ, Lister G, Leeson-Payne C. Breast milk and subsequent intelligence quotient in children born preterm. *Lancet* 1992;339:261-4.
20. Uauy RD, Birch DG, Birch EE, Tyson JE, Hoffman DR. Effect of dietary omega-3 fatty acids on retinal function of very-low-birth-weight neonates. *Pediatr Res* 1990;28:485-92.
21. Werkman SH, Carlson SE. A randomized trial of visual attention of preterm infants fed docosahexaenoic acid until nine months. *Lipids* 1996;31:91-7.
22. Wainwright P. Nutrition and behaviour: the role of n-3 fatty acids in cognitive function (invited commentary). *Br J Nutr* 2000;83:337-9.
23. Innis SM. Essential fatty acids in growth and development. *Prog Lipid Res* 1991;30:39-103.
24. Otto SJ, Houwelingen AC, Antal M, Manninen A, Godfrey K, Lopez-Jaramillo P *et al.* Maternal and neonatal essential fatty acid status of phospholipids: an international comparative study. *Eur J Clin Nutr* 1997;51:232-42.
25. Al MD, van Houwelingen AC, Kester AD, Hassart TH, de Jong AD, Hornstra G. Maternal essential fatty acid patterns during normal pregnancy and their relationship to the neonatal essential fatty acid status. *Br J Nutr* 1995;74:55-68.
26. Hornstra G. Essential fatty acids in mothers and their neonates. *Am J Clin Nutr* 2000;71(5 Suppl):1262S-9S.
27. de Groot RH, Adam J, Jolles JJ, Hornstra G. Selective attention deficits during human pregnancy. *Neurosci Lett* 1993;340:21-4.
28. Cheruku SR, Montgomery-Downs HE, Farkas SL, Thoman EB, Lammi-Keefe CJ. Higher maternal plasma docosahexanoic acid during pregnancy is associated with more mature neonatal sleep-state patterning. *Am J Clin Nutr* 2002;76:608-13.
29. Helland IB, Saugstad OD, Smith L, Saarem K, Solvoll K, Ganes T *et al.* Similar effects on infants of n-3 and n-6 fatty acids supplementation to pregnant and lactating women. *Pediatrics* 2001;108:E82. ([www.pediatrics.org/cgi/content/full/108/5/e82](http://www.pediatrics.org/cgi/content/full/108/5/e82), accessed on 2005).
30. Helland IB, Smith L, Saarem K, Saugstad OD, Drevon CA. Maternal supplement with very-long-chain n-3 fatty acids during pregnancy and lactation augments children's IQ at 4 years of age. *Pediatrics* 2003;111:e39-e44. ([www.pediatrics.org/cgi/content/full/111/1/e39](http://www.pediatrics.org/cgi/content/full/111/1/e39), accessed on 2005).
31. Bayley N. Bayley scales of infant development. 3d ed. San Antonio, TX: Psychological Corporation, 1993. 360 p.
32. Wolke D, Skuse D, Mathisen V. Behavioral style in failure to thrive infants: a preliminary communication. *J Pediatr Psychol* 1990;15:237-54.
33. Caldwell BM. Descriptive evaluation of child development and of developmental settings. *Pediatrics* 1967;40:46-52.
34. Hamadani JD, Fuchs GJ, Osendarp SJ, Khatun F, Huda SN, Grantham-McGregor SM. Randomized controlled trial of the effect of zinc supplementation on the mental development of Bangladeshi infants. *Am J Clin Nutr* 2001;74:381-6.
35. Hamadani JD, Fuchs GJ, Osendarp SJ, Huda SN, Grantham-McGregor SM. Zinc supplementation during pregnancy and effects on mental development and behaviour of infants: a follow-up study. *Lancet* 2002;360:290-4.
36. World Health Organization. Measuring change in nutritional status. Guideline for assessing nutritional impact of supplementary feeding programme for vulnerable groups. Geneva: World Health Organization, 1983:7-61.
37. Schefermeier M, Yavin E. n-3 deficient and docosahexanoic acid enriched diets during critical periods of the developing prenatal rat brain. *J Lipid Res* 2002;43:124-31.
38. Connor WE, Lowensohn R, Hatcher L. Increased docosahexaenoic acid levels in human newborn infants by administration of sardines and fish oil during pregnancy. *Lipids* 1996;31(Suppl):S183-7.



39. Dutta-Roy AK. Transport mechanisms for long-chain polyunsaturated fatty acids in the human placenta. *Am J Clin Nutr* 2000;71(Suppl):S315-S22.
40. Anderson WJ, Johnstone BM, Remley DT. Breast-feeding and cognitive development: a meta-analysis. *Am J Clin Nutr* 1999;70:525-35.
41. Marini A, Vegni C, Gangi S, Benedetti V, Agosti M. Influence of different types of post-discharge feeding on somatic growth, cognitive development and their correlation in very low birthweight preterm infants. *Acta Paediatr* 2003;441:18-33.
42. Gibson RA, Makrides M. n-3 polyunsaturated fatty acid requirements of term infants. *Am J Clin Nutr* 2000;71:251S-5S.
43. O'Connor DL, Hall R, Adamkin D, Auestad N, Castillo M, Connor WE *et al.* Growth and development in preterm infants fed long-chain polyunsaturated fatty acids: a prospective, randomized control trial. *Pediatrics* 2001;108:359-71.
44. Johnson MH. *Developmental cognitive neuroscience*. 2d ed. Malden, MA: Blackwell Publishing, 2005. 230 p.