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Child-Specific Exposure Factors Handbook

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Interim Report

CHILD-SPECIFIC EXPOSURE FACTORS HANDBOOK

National Center for Environmental Assessment–Washington Office
Office of Research and Development
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DISCLAIMER

This interim document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

Children are often more heavily exposed to environmental toxicants than adults. They consume more food and water and have higher inhalation rates per pound of body weight than adults. Young children play close to the ground and come into contact with contaminated soil outdoors and with contaminated dust on surfaces and carpets indoors. As another example, exposure to chemicals in breast milk affects infants and young children.

Although NCEA has published the Exposure Factors Handbook in 1997 (EPA/600/P-95/002Fa-c), that include exposure factors and related data on both adults and children, the EPA Program Offices identified the need to consolidate all children exposure data into one document. The goal of the Child-Specific Exposure Factors Handbook is to fulfill this need. The document provides a summary of the available and up-to-date statistical data on various factors assessing children exposures. These factors include drinking water consumption, soil ingestion, inhalation rates, dermal factors including skin area and soil adherence factors, consumption of fruits and vegetables, fish, meats, dairy products, homegrown foods, breast milk, activity patterns, body weight, consumer products and life expectancy.

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FOREWORD

The National Center for Environmental Assessment (NCEA) of EPA's Office of Research and Development (ORD) has five main functions: (1) providing risk assessment research, methods, and guidelines; (2) performing health and ecological assessments; (3) developing, maintaining, and transferring risk assessment information and training; (4) helping ORD set research priorities; and (5) developing and maintaining resource support systems for NCEA. The activities under each of these functions are supported by and respond to the needs of the various program offices. In relation to the first function, NCEA sponsors projects aimed at developing or refining techniques used in exposure assessments.

Exposure Factors Handbook was first published in 1989 to provide statistical data on the various factors used in assessing exposure for the general population; it was revised and published again in 1997. *Child-Specific Exposure Factors Handbook* is being prepared to focus on various factors used in assessing exposure, specifically for children ages 0–19 years. The recommended values are based solely on our interpretation of the available data. In many situations, the use of different values may be appropriate in consideration of policy, precedent, or other factors. This handbook contains numerous tables where data are presented using two and sometimes three significant figures. The use of significant figures implies that these values are known with some degree of certainty. However, in many cases, the data do not allow for this degree of precision and the user should understand this limitation and apply rounding rules as necessary to obtain a more appropriate value.

PREFACE

The National Center for Environmental Assessment (NCEA) of EPA's Office of Research and Development prepared this handbook to address factors commonly used in exposure assessments for children. Children are often more heavily exposed than adults to environmental toxicants. They consume more food and water and have higher inhalation rates per pound of body weight than do adults. Young children play close to the ground and come into contact with contaminated soil outdoors and with contaminated dust on surfaces and carpets indoors. Furthermore, exposure to chemicals in breast milk affects infants and young children.

NCEA published the latest version of *Exposure Factors Handbook* in 1997. It includes exposure factors and related data on children as well as adults. However, the EPA program offices have identified the need to prepare a document specifically for children's exposure factors. The goal of *Child-Specific Exposure Factors Handbook* is to fulfill this need.

This handbook will be continuously updated as new data become available. For example, the Agency is currently developing guidance on the use of a standard set of age groups that are needed to assess exposures in children. This guidance is expected to be completed by Fall 2002. The handbook will be revised to ensure consistency with new Agency guidance. In an effort to keep the handbook up-to-date, NCEA will incorporate new data as they become available in the published literature. Please submit comments, recommendations, suggested revisions, and corrections to moya.jacqueline@epa.gov.

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The National Center for Environmental Assessment (NCEA) of EPA's Office of Research and Development (ORD) was responsible for the publication of this handbook. The handbook was prepared by the Exposure Assessment Division of Versar, Inc., in Springfield, VA, under EPA Contract No. 68-W-99-041. Jacqueline Moya served as Work Assignment Manager, providing overall direction and technical assistance and serving as contributing author.

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2. BREAST MILK INTAKE

2.1. INTRODUCTION

Breast milk is a potential source of exposure to toxic substances for nursing infants. Lipid-soluble chemical compounds accumulate in body fat and may be transferred to breast-fed infants in the lipid portion of breast milk. Because nursing infants obtain most (if not all) of their dietary intake from breast milk, they are especially vulnerable to exposures to these compounds. Estimating the magnitude of the potential dose to infants from breast milk requires information on the milk intake rate (quantity of breast milk consumed per day) and the duration (months) over which breast-feeding occurs. Information on the fat content of breast milk is also needed for estimating dose from breast milk residue concentrations that have been indexed to lipid content.

Several studies have generated data on breast milk intake. Typically, breast milk intake has been measured over a 24-hour period by weighing the infant before and after each feeding without changing its clothing (test weighing). The sum of the difference between the measured weights over the 24-hour period is assumed to be equivalent to the amount of breast milk consumed daily. Intakes measured using this procedure are often corrected for evaporative water losses (insensible water losses) between infant weighings (NAS, 1991). Neville et al. (1988) evaluated the validity of the test weighing approach among bottle-fed infants by comparing the weights of milk taken from bottles with the differences between the infants' weights before and after feeding. When test weighing data were corrected for insensible water loss, they were not significantly different from bottle weight data. Conversions between weight and volume of breast milk consumed are made using the density of human milk (approximately 1.03 g/mL) (NAS, 1991). Recently, techniques for measuring breast milk intake using stable isotopes have been developed. However, few data based on this new technique have been published (NAS, 1991).

Studies among nursing mothers in industrialized countries have shown that intakes among infants average approximately 750 to 800 g/day (728 to 777 mL/day) during the first 4 to 5 months of life, with a range of 450 to 1200 g/day (437 to 1165 mL/day) (NAS, 1991). Similar intakes have also been reported for developing countries (NAS, 1991). Infant birth weight has been shown to influence the rate of intake (NAS, 1991). Infants who are larger at birth and/or nurse more frequently have been shown to have higher intake rates.

Key studies on breast milk intake are summarized in the following sections. Recommended intake rates are based on the results of these key studies, as described in *Exposure Factors Handbook* (U.S. EPA, 1997). Relevant data on lipid content and fat intake, breast-feeding duration, and the estimated percentage of the U.S. population that breast-feeds are also presented.

2.2. STUDIES ON BREAST MILK INTAKE

2.2.1. Pao et al., 1980

Pao et al. (1980) conducted a study of 22 healthy breast-fed infants to estimate breast milk intake rates. Infants were categorized as completely breast-fed or partially breast-fed. Breast-feeding mothers were recruited through LaLeche League groups. Except for one black infant, all the infants were from white middle-class families in southwestern Ohio. The goal of the study was to enroll infants as close to 1 month of age as possible and to obtain records near 1, 3, 6, and 9 months of age. However, not all mother/infant pairs participated at each time interval.

Data were collected for the 22 infants using the test weighing method. Records were collected for three consecutive 24-hour periods at each test interval. The weight of breast milk was converted to volume by assuming a density of 1.03 g/mL. Daily intake rates were calculated for each infant, based on the mean of the three 24-hour periods. Reported mean daily breast milk intake rates for the infants surveyed at each time interval are presented in Table 2-1. For completely breast-fed infants, the mean intake rates were 600 mL/day at 1 month of age and 833 mL/day at 3 months of age. Partially breast-fed infants had mean intake rates of 485 mL/day, 467 mL/day, 395 mL/day, and 554 mL/day at 1, 3, 6, and 9 months of age, respectively. The investigations also noted that intake rates for boys in both groups were slightly higher than those for girls.

The advantage of this study is that data for both exclusively and partially breast-fed infants were collected for multiple time periods. Also, data for individual infants were collected over 3 consecutive days, which would account for some individual variability. However, the number of infants in the study was relatively small. In addition, this study did not account for insensible water loss, which may underestimate the amount of breast milk ingested.

2.2.2. Dewey and Lönnerdal, 1983

Dewey and Lönnerdal (1983) monitored the dietary intake of 20 breast-fed infants between the ages of 1 and 6 months. Most of the infants in the study were exclusively breast-fed (five were given some formula, and several were given small amounts of solid foods after 3 months of age). According to the investigations, the mothers were all well educated and recruited through Lamaze childbirth classes in the Davis area of California. Breast milk intake volume was estimated on the basis of two 24-hour test weighings per month. Breast milk intake rates for the various age groups are presented in Table 2-2. Breast milk intake averaged 673, 782, and 896 mL/day at 1, 3, and 6 months of age, respectively.

The advantage of this study is that it evaluated breast-fed infants for a period of 6 months, two 24-hour observations per infant per month. Corrections for insensible water loss apparently were not made. Also, the number of infants in the study was relatively small.

2.2.3. Butte et al., 1984

Breast milk intake was studied in exclusively breast-fed infants during the first 4 months of life (Butte et al., 1984). Breast-feeding mothers were recruited through the Baylor Milk Bank Program in Texas. Forty-five mother/infant pairs participated in the study. However, data for some time periods (i.e., 1, 2, 3, or 4 months) were missing for some mothers as a result of illness or other factors. The mothers were from the middle to upper socioeconomic stratum and had a mean age of 28.0 ± 3.1 years. A total of 41 mothers were white, 2 were Hispanic, 1 was Asian, and 1 was West Indian. Infant growth progressed satisfactorily over the course of the study.

The amount of milk ingested over a 24-hour period was determined using the test weighing procedure. Test weighing occurred over a 24-hour period for most participants, but intake among several infants was studied over longer periods (48 to 96 hours) to assess individual variation in intake. Mean breast milk intake ranged from 723 g/day (702 mL/day) at 3 months to 751 g/day (729 mL/day) at 1 month, with an overall mean of 733 g/day (712 mL/day) for the entire study period (Table 2-3). Intakes were also calculated on the basis of body weight (Table 2-3). Based on the results of test weighings conducted over 48 to 96 hours, the mean variation in individual daily intake was estimated to be 7.9 ± 3.6%.

The advantage of this study is that data for a larger number of exclusively breast-fed infants were collected than were collected by Pao et al. (1980). However, data were collected over a shorter time period (i.e., 4 months compared to 6 months) and day-to-day variability was not characterized for all infants.

2.2.4. Neville et al., 1988

Neville et al. (1988) studied breast milk intake among 13 infants during their first year of life. The mothers were all multiparous, nonsmoking, Caucasian women of middle to upper socioeconomic status living in Denver, CO. All the women in the study practiced exclusive breast-feeding for at least 5 months. Solid foods were introduced at a mean age of 7 months. Daily milk intake was estimated by the test weighing method, with corrections for insensible weight loss. Data were collected daily from birth to 14 days, weekly from weeks 3 through 8, and monthly until the study period ended at 1 year after inception. The estimated breast milk intakes for this study are listed in Table 2-4. Mean breast milk intakes were 770 g/day (748 mL/day), 734 g/day (713 mL/day), 766 g/day (744 mL/day), and 403 g/day (391 mL/day) at 1, 3, 6, and 12 months of age, respectively.

Compared with the previously described studies, data were collected in this study on numerous days over a relatively long time period (12 months), and they were corrected for insensible weight loss. However, the intake rates presented in Table 2-4 are estimated, based on intake during only a 24-hour period. Consequently, these intake rates are based on short-term data that do not account for day-to-day variability among individual infants. Also, a smaller number of subjects was included than in the previous studies.

2.2.5. Dewey et al., 1991a, b

The Davis Area Research on Lactation, Infant Nutrition, and Growth (DARLING) study was conducted in 1986 to evaluate growth patterns, nutrient intake, morbidity, and activity levels in infants who were breast-fed for at least the first 12 months of life (Dewey et al., 1991a, b). Seventy-three infants aged 3 months were included in the study. At subsequent time intervals, the number of infants was somewhat lower as a result of attrition. All infants in the study were healthy and of normal gestational age and weight at birth, and they did not consume solid foods until after the first 4 months of age. The mothers were from the Davis area of California and were highly educated and of "relatively high socioeconomic status."

Breast milk intake was estimated by weighing the infants before and after each feeding and correcting for insensible water loss. Test weighings were conducted over a 4-day period every 3 months. The results of the study indicate that breast milk intake declined over the first 12 months of life. This decline was associated with the intake of solid food. Mean breast milk intake was estimated to be 812 g/day (788 mL/day) at 3 months and 448 g/day (435 mL/day) at 12 months (Table 2-5). Based on the estimated intakes at 3 months of age, variability between

individuals (coefficient of variation ([CV] = 16.3%) was higher than individual day-to-day variability ([CV] = 5.4%) for the infants in the study (Dewey et al., 1991a).

The advantages of this study are that data were collected over a relatively long time period (4 days) at each test interval, which would account for some day-to-day infant variability, and corrections for insensible water loss were made.

2.3. STUDIES ON LIPID CONTENT AND FAT INTAKE FROM BREAST MILK

Human milk contains over 200 constituents including lipids, various proteins, carbohydrates, vitamins, minerals, and trace elements as well as enzymes and hormones. The lipid content of breast milk varies according to the length of time that an infant nurses, and it increases from the beginning to the end of a single nursing session (NAS, 1991). The lipid portion accounts for approximately 4% of human breast milk (39 ± 4.0 g/L) (NAS, 1991). This value is supported by various studies that evaluated lipid content from human breast milk. Several studies also estimated the quantity of lipid consumed by breast-feeding infants. These values are appropriate for performing exposure assessments for nursing infants when the contaminant(s) have residue concentrations that are indexed to the fat portion of human breast milk.

2.3.1. Butte et al., 1984

Butte et al., (1984) analyzed the lipid content of breast milk samples taken from women who participated in a study of breast milk intake among exclusively breast-fed infants. The study was conducted with over 40 women during a 4-month period. The mean lipid content of breast milk at various infants' ages is presented in Table 2-6. The overall lipid content for the 4-month study period was 34.3 ± 6.9 mg/g (3.4%). The investigators also calculated lipid intakes from 24-hour breast milk intakes and the lipid content of the human milk samples. Lipid intake was estimated to range from 23.6 g/day (3.8 g/kg-day) to 28.0 g/day (5.9 g/kg-day).

The number of women included in this study was small, and these women were selected primarily from middle to upper socioeconomic classes. Thus, data on breast milk lipid content from this study may not be entirely representative of breast milk lipid content among the U.S. population. Also, these estimates are based on short-term data, and day-to-day variability was not characterized.

2.3.2. Maxwell and Burmaster, 1993

Maxwell and Burmaster (1993) used a hypothetical population of 5000 infants between birth and 1 year of age to simulate a distribution of daily lipid intake from breast milk. The hypothetical population represented both bottle-fed and breast-fed infants aged 1 to 365 days. A distribution of daily lipid intake was developed, based on data in Dewey et al. (1991b) on breast milk intake for infants at 3, 6, 9, and 12 months and breast milk lipid content and survey data in Ryan et al. (1991) on the percentage of breast-fed infants under the age of 12 months (i.e., approximately 22%). A model was used to simulate intake among 1113 of the 5000 infants that were expected to be breast-fed. The results of the model indicated that lipid intake among nursing infants under 12 months of age can be characterized by a normal distribution with a mean of 26.8 g/day and a standard deviation of 7.4 g/day (minimum intake was 1 g/day, maximum intake was 51.5 g/day). The model assumes that nursing infants are completely breast-fed and does not account for infants who are breast-fed longer than 1 year. Based on data collected by Dewey et al. (1991b), the investigators estimated the lipid content of breast milk to be 36.7 g/L at 3 months (35.6 mg/g or 3.6%) and 40.2 g/L (39.0 mg/g or 3.9%) at 12 months.

The advantage of this study is that it provides a "snapshot" of daily lipid intake from breast milk for breast-fed infants. However, these results are based on a simulation model, and there are uncertainties associated with the assumptions made. The estimated mean lipid intake rate represents the average daily intake for nursing infants under 12 months of age. These data are useful for performing exposure assessments when the age of the infant cannot be specified (i.e., 3 months or 6 months). Also, because intake rates are indexed to the lipid portion of the breast milk, they may be used in conjunction with residue concentrations indexed to fat content. However, the study did not generate "new" data. A reanalysis of previously reported data on breast milk intake and breast milk lipid intake were provided.

2.4. OTHER FACTORS

Other factors associated with breast milk intake include the frequency of breast-feeding sessions per day, the duration of breast-feeding per event, the duration of breast-feeding during childhood, and the magnitude and nature of the population that breast-feeds.

2.4.1. Population of Nursing Infants

According to the National Academy of Sciences (NAS), the percentage of breast-feeding women has changed dramatically over the years (NAS, 1991). The Ross Products Division of Abbott Laboratories conducted a large national mail survey in 1995 to determine patterns of

breast feeding during the first 6 months of life. The Ross Laboratory Mothers's Survey was first developed in 1955 and has since been expanded to include many more infants. Before 1991, the survey was conducted on a quarterly basis, and approximately 40,000 to 50,000 questionnaires were mailed each quarter (Ryan, 1997). Beginning 1991, the survey was conducted monthly; 35,000 were mailed each month. Over time, the response rate has been consistently in the range of 50 ± 5%. In 1989 and 1995, 196,000 and 720,000 questionnaires were mailed, respectively. Ryan (1997) reported rates of breast-feeding through 1995 and compared them with rates in 1989.

The survey demonstrates recent increases in both the initiation of breast-feeding and continued breast-feeding at 6 months of age. Table 2-7 presents the proportion of breast-feeding in hospitals and at 6 months of age by selected demographic characteristics. In 1995, the incidence of breast-feeding at birth and at 6 months for all infants was approximately 60% and 22%, respectively. The largest increases in the initiation of breast-feeding between 1989 and 1995 occurred among women who (1) were Black, were < 25 years of age, were in the < $10,000 income level, had no more than grade school education, and were living in the South Atlantic region of the U.S.; (2) had infants of low birth weight; (3) were employed full time outside the home at the time they received the survey; and (4) participated in the Women, Infants, and Children (WIC) program. In 1995, as in 1989, the initiation of breast-feeding was highest among women who were > 35 years of age, in the > $25,000 income group, and college educated; women who did not participate in the WIC program; and women who were living in the Mountain and Pacific regions of the U.S.

Data on the actual length of time that infants continue to breast-feed beyond 5 or 6 months are limited (NAS, 1991). However, Maxwell and Burmaster (1993) estimated that approximately 22% of infants under 1 year of age are breast-fed. This estimate is based on a reanalysis of the survey data in Ryan et al. (1991) collected by Ross Laboratories (Maxwell and Burmaster, 1993).

2.4.2. Intake Rates Based on Nutritional Status

Information on differences in the quality and quantity of breast milk consumed on the basis of ethnic or socioeconomic characteristics of the population is limited. Lönnerdal et al. (1976) studied breast milk volume and composition (nitrogen, lactose, proteins) among underprivileged and privileged Ethiopian mothers. No significant differences were observed between the data for these two groups. Similar data were observed for well-nourished Swedish mothers. Lönnerdal et al. (1976) stated that these results indicate that breast milk quality and quantity are not affected by maternal malnutrition. However, Brown et al. (1986a, b) noted that the lactational capacity and energy concentration of marginally nourished women in Bangladesh were "modestly less than in better-nourished mothers." Breast milk intake rates for infants of marginally-nourished women in this study were 690 ± 122 g/day at 3 months, 722 ± 105 g/day at 6 months, and 719 ± 119 g/day at 9 months of age (Brown et al., 1986a). Brown et al. (1986a) observed that breast milk from women with larger measurements of arm circumference and triceps skinfold thickness had higher concentrations of fat and energy than mothers with less body fat. Positive correlations between maternal weight and milk fat concentrations were also observed. These results suggest that milk composition may be affected by maternal nutritional status.

2.5. RECOMMENDATIONS

The studies described in this section were used in selecting recommended values for breast milk intake, fat content and fat intake, and other related factors. Although different survey designs, testing periods, and populations were used in the studies to estimate intake, the mean and standard deviation estimates reported in these studies are relatively consistent. There are, however, limitations with the data. Data are not available for infants under 1 month of age. This subpopulation may be of particular concern, because a larger number of newborns are totally breast-fed. In addition, with the exception of Butte (1984), data were not presented on a body weight basis. This is particularly important because intake rates may be higher on a body-weight basis for younger infants. Also, the data used to derive the recommendations are more than 10 years old, and the sample sizes of the studies were small. Other subpopulations of concern, such as mothers highly committed to breast-feeding—sometimes for periods longer than 1 year—may not be captured by the studies presented in this chapter. Further research is needed to identify these subgroups and to get better estimates of breast milk intake rates. Table 2-8 presents the confidence rating for breast milk intake recommendations.

2.5.1. Breast Milk Intake

The breast milk intake rates for nursing infants that have been reported in the studies described in this section are summarized in Table 2-9. Based on the combined results of these studies, 742 mL/day is recommended to represent an average breast milk intake rate, and 1033 mL/day represents an upper-percentile intake rate (based on the middle range of the mean plus 2 standard deviations) for infants between the ages of 1 and 6 months of age. The average value is the mean of the average intakes at 1, 3, and 6 months from the key studies listed in Table 2-9. It is consistent with the average intake rate of 718 to 777 mL/day estimated by NAS (1991) for infants during the first 4 to 5 months of life. Intake among older infants is somewhat lower, averaging 427 mL/day for 12-month-olds (Neville et al. 1988; Dewey et al. 1991a, b). When a time-weighted average is calculated for the 12-month period, average breast milk intake is approximately 688 mL/day, and upper-percentile intake is approximately 980 mL/day. Table 2-10 summarizes these recommended intake rates.

2.5.2. Lipid Content and Lipid Intake

Recommended lipid intake rates are based on data from Butte et al. (1984) and Maxwell and Burmaster (1993). Butte et al. (1984) estimated that average lipid intake ranges from 23.6 ± 7.2 g/day (22.9 ± 7.0 mL/day) to 28.0 ± 8.5 g/day (27.2 ± 8.3 mL/day) in infants between 1 and 4 months of age. These intake rates are consistent with those reported by Maxwell and Burmaster (1993) of 26.8 ± 7.4 g/day (26.0 ± 7.2 mL/day) for infants under 1 year of age. Therefore, the recommended breast milk lipid intake rate for infants under 1 year of age is 26.0 mL/day, and the upper-percentile value is 40.4 mL/day (based on the mean plus 2 standard deviations). The recommended value for breast milk fat content is 4.0% based on data from NAS (1991), Butte et al. (1984), and Maxwell and Burmaster (1993).

Table 2-1. Daily intakes of breast milk

Age	Number of infants	Mean ± SD (mL/day)[a]	Intake Range (mL/day)
Completely breast-fed			
1 month	11	600 ± 159	426–989
3 months	2	833	645–1,000
6 months	1	682	616–786
Partially breast-fed			
1 month	4	485 ± 79	398–655
3 months	11	467 ± 100	242–698
6 months	6	395 ± 175	147–684
9 months	3	< 554	451–732

[a] Data expressed as mean ± standard deviation.

Source: Pao et al., 1980

Table 2-2. Breast milk intake for infants aged 1 to 6 months

Age (months)	Number of Infants	Intake	
		Mean ± SD (mL/day)	Range (mL/day)
1	16	673 ± 192	341–1003
2	19	756 ± 170	449–1055
3	16	782 ± 172	492–1053
4	13	810 ± 142	593–1045
5	11	805 ± 117	554–1045
6	11	896 ± 122	675–1096

Source: Dewey and Lönnerdal, 1983

Table 2-3. Breast milk intake among exclusively breast-fed infants during the first 4 months of life

Age (months)	Number of Infants	Intake (g/day)	Intake (g/kg-day)	Body Weight[a] (kg)
		Mean ± SD	Mean ± SD	
1	37	751.0 ± 130.0	159.0 ± 24.0	4.7
2	40	725.0 ± 131.0	129.0 ± 19.0	5.6
3	37	723.0 ± 114.0	117.0 ± 20.0	6.2
4	41	740.0 ± 128.0	111.0 ± 17.0	6.7

[a] Calculated by dividing breast milk intake (g/day) by breast milk intake (g/kg-day).

Source: Butte et al., 1984

Table 2-4. Breast milk intake during a 24-hour period

Age (days)	Number of Infants	Intake (g/day)	
		Mean ± SD	Range
1	7	44 ± 71	–31–149 [a]
2	10	182 ± 86	44–355
3	11	371 ± 153	209–688
4	11	451 ± 176	164–694
5	12	498 ± 129	323–736
6	10	508 ± 167	315–861
7	8	573 ± 167	406–842
8	9	581 ± 159	410–923
9	10	580 ± 76	470–720
10	10	589 ± 132	366–866
11	8	615 ± 168	398–934
14	10	653 ± 154	416–922
21	10	651 ± 84	554–786
28	13	770 ± 179	495–1144
35	12	668 ± 117	465–930
42	12	711 ± 111	554–896
49	10	709 ± 115	559–922
56	13	694 ± 98	556–859
90	12	734 ± 114	613–942
120	13	711 ± 100	570–847
150	13	838 ± 134	688–1173
180	13	766 ± 121	508–936
210	12	721 ± 154	486–963
240	10	622 ± 210	288–1002
270	12	618 ± 220	223–871
300	11	551 ± 234	129–894
330	9	554 ± 240	120–860
360	9	403 ± 250	65–770

[a] Negative value due to insensible water loss correction.

Source: Neville et al., 1988

Table 2-5. Breast milk intake estimated by the Darling Study

Age (months)	Number of Infants	Intake
		Mean ± SD
3	73	812 ± 133
9	60	769 ± 171
9	50	646 ± 217
12	42	448 ± 251

Source: Dewey et al., 1991b

Table 2-6. Lipid content of human milk and estimated lipid intake among exclusively breast-fed infants

Age (months)	Number of Observations	Lipid Content (mg/g)	Lipid Content % [a]	Lipid Intake (g/day) Mean ± SD	Lipid Intake (g/kg-day) Mean ± SD
		Mean ± SD			
1	37	36.2 ± 7.5	3.6	28.0 ± 8.5	5.9 ± 1.7
2	40	34.4 ± 6.8	3.4	25.2 ± 7.1	4.4 ± 1.2
3	37	32.2 ± 7.8	3.2	23.6 ± 7.2	3.8 ± 1.2
4	41	34.8 ± 10.8	3.5	25.6 ± 8.6	3.8 ± 1.3

[a] Percents calculated from lipid content reported in mg/g.

Source: Butte et al., 1984

Table 2-7. Percentage of mothers breast-feeding newborn infants in the hospital and infants at 5 or 6 months of age in the United States in 1989[a], by ethnic background and selected demographic variables[b]

Characteristic	Percentage of mothers breast-feeding					
	In hospital			At 6 months		
	1989	1995	Change	1989	1995	Change
All Infants	52.2	59.7	14.4	18.1	21.6	19.3
White	58.5	64.3	9.9	21.0	24.1	14.8
Black	23.0	37.0	60.9	6.4	11.2	75.0
Hispanic	48.4	61.0	26.0	13.9	19.6	41.0
Maternal age (years)						
< 20	30.2	42.8	41.7	5.6	9.1	62.5
20–24	4.2	52.6	16.4	11.5	14.6	27.0
25–29	58.8	63.1	7.3	21.1	22.9	8.5
30–34	65.5	68.1	4.0	29.3	29.0	(1.0)[b]
35+	66.5	70.0	5.3	34.0	33.8	(0.6)[b]
Total family income						
< $10,000	31.8	41.8	31.4	8.2	11.4	39.0
$10,000 – $14,999	47.1	51.7	9.8	13.9	15.4	10.8
$15,000 – $24,999	54.7	58.8	7.5	18.9	19.8	4.8
≥ $25,000	66.3	70.7	6.6	25.5	28.5	11.8
Maternal education						
Grade school	31.7	43.8	38.2	11.5	17.1	48.7
High school	42.5	49.7	16.9	12.4	15.0	21.0
College	70.7	74.4	5.2	28.8	31.2	8.3
Maternal employment						
Employed full time	50.8	60.7	19.5	8.9	14.3	60.7
Employed part time	59.4	63.5	6.9	21.1	23.4	10.9
Not employed	51.0	58.0	13.7	21.6	25.0	15.7
Birth weight						
Low (≤2,500 g)	36.2	47.7	31.8	9.8	12.6	28.6
Normal	53.5	60.5	13.1	18.8	22.3	18.6
Parity						
Primiparous	52.6	61.6	17.1	15.1	19.5	29.1
Multiparous	51.7	57.8	11.8	21.1	23.6	11.8
WIC participation						
Participant	34.2	46.6	36.3	8.4	12.7	51.2
Nonparticipant	62.9	71.0	12.9	23.8	29.2	22.7

Table 2-7. Percentage of mothers breast-feeding newborn infants in the hospital and infants at 5 or 6 months of age in the United States in 1989[a], by ethnic background and selected demographic variables[b] (continued)

Characteristic	Percentage of mothers breast-feeding					
	In hospital			At 6 months		
	1989	1995	Change	1989	1995	Change
U.S. census region						
New England	52.2	61.2	17.2	18.6	22.2	19.4
Middle Atlantic	47.4	53.8	13.5	16.8	19.6	16.7
East North Central	47.6	54.6	14.7	16.7	18.9	13.2
West North Central	55.9	61.9	10.7	18.4	21.4	16.3
South Atlantic	43.8	54.8	25.1	13.7	18.6	35.8
East South Central	37.9	44.1	16.4	11.5	13.0	13.0
West South Central	46.0	54.4	18.3	13.6	17.0	25.0
Mountain	70.2	75.1	7.0	28.3	30.3	7.1
Pacific	70.3	75.1	6.8	26.6	30.9	16.2

[a] The percent change was calculated using the following formula: % breast fed in 1984 – % breast fed in 1989 / % breast fed in 1984.

[b] Figures in parentheses indicate a decrease in the rate of breast-feeding from 1989 to 1995.

WIC = Women, Infants, and Children supplemental food program.

Source: Ryan, 1997

Table 2-8. Confidence in breast milk intake recommendations

Considerations	Rationale	Rating
Study Elements		
Level of peer review	All key studies are from peer-reviewed literature.	High
Accessibility	Papers are widely available from peer review journals.	High
Reproducibility	Methodology used was clearly presented.	High
Focus on factor of interest	The focus of the studies was on estimating breast milk intake.	High
Data pertinent to U.S.	Subpopulations of the U.S. were the focus of all the key studies.	High
Primary data	All the studies were based on primary data.	High
Currency	Studies were conducted between 1980–1997.	Medium-High
Adequacy of data collection period	Infants were not studied long enough to fully characterize day-to-day variability. With the exception of Neville et al. (1988), the measurements were made for frequency (e.g., once a month) and the data may not represent the potential first year of lactation (both for less than 1 month of age and for longitudinal measurements of more than 6 months).	Medium
Validity of approach	Methodology uses changes in body weight as a surrogate for total ingestion. This is the best methodology there is to estimate breast milk ingestion. Mothers were instructed in the use of infant scales to minimize measurement errors. Three out of the five studies corrected data for insensible water loss.	Low
Study size	The sample sizes used in the key studies were fairly small (range 13–73).	Low
Representativeness of the population	Population are representative of the general mother-infant pair population.	High
Characterization of variability	Not very well characterized. Infants under 1 month not captured, mothers committed to breast-feeding over 1 year not captured.	Low

Table 2-8. Confidence in breast milk intake recommendations (continued)

Considerations	Rationale	Rating
Lack of bias in study design (high rating is desirable)	Bias in the studies was not characterized. Two out of five studies corrected for insensible water loss.	Low
Measurement error	All mothers were well-educated and trained in the use of the scale, which helped minimize measurement error. Not correcting for insensible water loss may underestimate intake. Mothers selected for the studies were volunteers; therefore, response rate does not apply. Population studied may introduce some bias in the results (see above).	Medium
Other Elements		
Number of studies	There are five key studies.	Medium
Agreement between researchers	There is good agreement among researchers.	High
Overall Rating	Studies were well-designed. Results were consistent. Sample size was fairly low. Variability cannot be characterized due to limitations in data collection period.	**Medium**

Table 2-9. Breast milk intake rates derived from key studies

Age (months)	Mean intake (mL/day)	Number of Children	Upper Percentile (mL/day)[a]	Reference
1	600	11	918	Pao et al., 1980
	729	37	981	Butte et al., 1984
	747	13	1095	Neville et al., 1988
	673	16	1057	Dewey and Lönnerdal, 1983
	weighted avg = 702		1007[b]	
3	833	2	—	Pao et al., 1980
	702	37	923	Butte et al., 1984
	712	12	934	Neville et al., 1988
	782	16	1126	Dewey and Lönnerdal, 1983
	788	73	1046	Dewey et al., 1991b
	weighted avg = 759		1025[b]	
6	682	1	—	Pao et al., 1980
	744	13	978	Neville et al., 1988
	896	11	1140	Dewey and Lönnerdal, 1983
	747	60	1079	Dewey et al., 1991b
	weighted avg = 765		1059[b]	
9	600	12	1027	Neville et al., 1988
	627	50	1049	Dewey et al., 1991b
	avg = 622		1038	
12	391	9	877	Neville et al., 1988
	435	42	923	Dewey et al., 1991a, b
	weighted avg = 427		900	
12-month time weighted average				
688			Range 900–1059 (middle of the range 980)	

[a] Upper percentile is reported (mean plus 2 standard deviations), except as noted.
[b] Middle of the range.

Table 2-10. Summary of recommended breast milk and lipid intake rates

Age	Mean intake (mL/day)	Upper percentile (mL/day)
Breast Milk		
1-6 months	742	1033.0
12-month-average	688	980.0
Lipids[a]		
< 1 Year	26	40.4

[a] The recommended value for the lipid content of breastmilk is 4%.

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United States
Environmental Protection
Agency

Child-Specific Exposure Factors Handbook

EPA-600-P-00-002B
September 2002
Interim Report

CHILD-SPECIFIC EXPOSURE FACTORS HANDBOOK

National Center for Environmental Assessment–Washington Office
Office of Research and Development
U.S. Environmental Protection Agency
Washington, D.C. 20460

DISCLAIMER

This interim document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

Children are often more heavily exposed to environmental toxicants than adults. They consume more food and water and have higher inhalation rates per pound of body weight than adults. Young children play close to the ground and come into contact with contaminated soil outdoors and with contaminated dust on surfaces and carpets indoors. As another example, exposure to chemicals in breast milk affects infants and young children.

Although NCEA has published the Exposure Factors Handbook in 1997 (EPA/600/P-95/002Fa-c), that include exposure factors and related data on both adults and children, the EPA Program Offices identified the need to consolidate all children exposure data into one document. The goal of the Child-Specific Exposure Factors Handbook is to fulfill this need. The document provides a summary of the available and up-to-date statistical data on various factors assessing children exposures. These factors include drinking water consumption, soil ingestion, inhalation rates, dermal factors including skin area and soil adherence factors, consumption of fruits and vegetables, fish, meats, dairy products, homegrown foods, breast milk, activity patterns, body weight, consumer products and life expectancy.

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U.S. Environmental Protection Agency (EPA). (2002) Child-specific exposure factors handbook. National Center for Environmental Assessment, Washington, DC; EPA/600/P-00/002B. Available from: National Information Service, Springfield, VA; PB2003-101678 and <http://www.epa.gov/ncea>.

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FOREWORD

The National Center for Environmental Assessment (NCEA) of EPA's Office of Research and Development (ORD) has five main functions: (1) providing risk assessment research, methods, and guidelines; (2) performing health and ecological assessments; (3) developing, maintaining, and transferring risk assessment information and training; (4) helping ORD set research priorities; and (5) developing and maintaining resource support systems for NCEA. The activities under each of these functions are supported by and respond to the needs of the various program offices. In relation to the first function, NCEA sponsors projects aimed at developing or refining techniques used in exposure assessments.

Exposure Factors Handbook was first published in 1989 to provide statistical data on the various factors used in assessing exposure for the general population; it was revised and published again in 1997. *Child-Specific Exposure Factors Handbook* is being prepared to focus on various factors used in assessing exposure, specifically for children ages 0–19 years. The recommended values are based solely on our interpretation of the available data. In many situations, the use of different values may be appropriate in consideration of policy, precedent, or other factors. This handbook contains numerous tables where data are presented using two and sometimes three significant figures. The use of significant figures implies that these values are known with some degree of certainty. However, in many cases, the data do not allow for this degree of precision and the user should understand this limitation and apply rounding rules as necessary to obtain a more appropriate value.

PREFACE

The National Center for Environmental Assessment (NCEA) of EPA's Office of Research and Development prepared this handbook to address factors commonly used in exposure assessments for children. Children are often more heavily exposed than adults to environmental toxicants. They consume more food and water and have higher inhalation rates per pound of body weight than do adults. Young children play close to the ground and come into contact with contaminated soil outdoors and with contaminated dust on surfaces and carpets indoors. Furthermore, exposure to chemicals in breast milk affects infants and young children.

NCEA published the latest version of *Exposure Factors Handbook* in 1997. It includes exposure factors and related data on children as well as adults. However, the EPA program offices have identified the need to prepare a document specifically for children's exposure factors. The goal of *Child-Specific Exposure Factors Handbook* is to fulfill this need.

This handbook will be continuously updated as new data become available. For example, the Agency is currently developing guidance on the use of a standard set of age groups that are needed to assess exposures in children. This guidance is expected to be completed by Fall 2002. The handbook will be revised to ensure consistency with new Agency guidance. In an effort to keep the handbook up-to-date, NCEA will incorporate new data as they become available in the published literature. Please submit comments, recommendations, suggested revisions, and corrections to moya.jacqueline@epa.gov.

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The National Center for Environmental Assessment (NCEA) of EPA's Office of Research and Development (ORD) was responsible for the publication of this handbook. The handbook was prepared by the Exposure Assessment Division of Versar, Inc., in Springfield, VA, under EPA Contract No. 68-W-99-041. Jacqueline Moya served as Work Assignment Manager, providing overall direction and technical assistance and serving as contributing author.

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In addition, ORD's National Exposure Research Laboratory made an important contribution to this handbook by conducting additional analyses of mouthing behavior data from the Davis (1995) study. Data analyses were conducted by Nicole Tulve.

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2. BREAST MILK INTAKE

2.1. INTRODUCTION

Breast milk is a potential source of exposure to toxic substances for nursing infants. Lipid-soluble chemical compounds accumulate in body fat and may be transferred to breast-fed infants in the lipid portion of breast milk. Because nursing infants obtain most (if not all) of their dietary intake from breast milk, they are especially vulnerable to exposures to these compounds. Estimating the magnitude of the potential dose to infants from breast milk requires information on the milk intake rate (quantity of breast milk consumed per day) and the duration (months) over which breast-feeding occurs. Information on the fat content of breast milk is also needed for estimating dose from breast milk residue concentrations that have been indexed to lipid content.

Several studies have generated data on breast milk intake. Typically, breast milk intake has been measured over a 24-hour period by weighing the infant before and after each feeding without changing its clothing (test weighing). The sum of the difference between the measured weights over the 24-hour period is assumed to be equivalent to the amount of breast milk consumed daily. Intakes measured using this procedure are often corrected for evaporative water losses (insensible water losses) between infant weighings (NAS, 1991). Neville et al. (1988) evaluated the validity of the test weighing approach among bottle-fed infants by comparing the weights of milk taken from bottles with the differences between the infants' weights before and after feeding. When test weighing data were corrected for insensible water loss, they were not significantly different from bottle weight data. Conversions between weight and volume of breast milk consumed are made using the density of human milk (approximately 1.03 g/mL) (NAS, 1991). Recently, techniques for measuring breast milk intake using stable isotopes have been developed. However, few data based on this new technique have been published (NAS, 1991).

Studies among nursing mothers in industrialized countries have shown that intakes among infants average approximately 750 to 800 g/day (728 to 777 mL/day) during the first 4 to 5 months of life, with a range of 450 to 1200 g/day (437 to 1165 mL/day) (NAS, 1991). Similar intakes have also been reported for developing countries (NAS, 1991). Infant birth weight has been shown to influence the rate of intake (NAS, 1991). Infants who are larger at birth and/or nurse more frequently have been shown to have higher intake rates.

Key studies on breast milk intake are summarized in the following sections. Recommended intake rates are based on the results of these key studies, as described in *Exposure Factors Handbook* (U.S. EPA, 1997). Relevant data on lipid content and fat intake, breast-feeding duration, and the estimated percentage of the U.S. population that breast-feeds are also presented.

2.2. STUDIES ON BREAST MILK INTAKE

2.2.1. Pao et al., 1980

Pao et al. (1980) conducted a study of 22 healthy breast-fed infants to estimate breast milk intake rates. Infants were categorized as completely breast-fed or partially breast-fed. Breast-feeding mothers were recruited through LaLeche League groups. Except for one black infant, all the infants were from white middle-class families in southwestern Ohio. The goal of the study was to enroll infants as close to 1 month of age as possible and to obtain records near 1, 3, 6, and 9 months of age. However, not all mother/infant pairs participated at each time interval.

Data were collected for the 22 infants using the test weighing method. Records were collected for three consecutive 24-hour periods at each test interval. The weight of breast milk was converted to volume by assuming a density of 1.03 g/mL. Daily intake rates were calculated for each infant, based on the mean of the three 24-hour periods. Reported mean daily breast milk intake rates for the infants surveyed at each time interval are presented in Table 2-1. For completely breast-fed infants, the mean intake rates were 600 mL/day at 1 month of age and 833 mL/day at 3 months of age. Partially breast-fed infants had mean intake rates of 485 mL/day, 467 mL/day, 395 mL/day, and 554 mL/day at 1, 3, 6, and 9 months of age, respectively. The investigations also noted that intake rates for boys in both groups were slightly higher than those for girls.

The advantage of this study is that data for both exclusively and partially breast-fed infants were collected for multiple time periods. Also, data for individual infants were collected over 3 consecutive days, which would account for some individual variability. However, the number of infants in the study was relatively small. In addition, this study did not account for insensible water loss, which may underestimate the amount of breast milk ingested.

2.2.2. Dewey and Lönnerdal, 1983

Dewey and Lönnerdal (1983) monitored the dietary intake of 20 breast-fed infants between the ages of 1 and 6 months. Most of the infants in the study were exclusively breast-fed (five were given some formula, and several were given small amounts of solid foods after 3 months of age). According to the investigations, the mothers were all well educated and recruited through Lamaze childbirth classes in the Davis area of California. Breast milk intake volume was estimated on the basis of two 24-hour test weighings per month. Breast milk intake rates for the various age groups are presented in Table 2-2. Breast milk intake averaged 673, 782, and 896 mL/day at 1, 3, and 6 months of age, respectively.

The advantage of this study is that it evaluated breast-fed infants for a period of 6 months, two 24-hour observations per infant per month. Corrections for insensible water loss apparently were not made. Also, the number of infants in the study was relatively small.

2.2.3. Butte et al., 1984

Breast milk intake was studied in exclusively breast-fed infants during the first 4 months of life (Butte et al., 1984). Breast-feeding mothers were recruited through the Baylor Milk Bank Program in Texas. Forty-five mother/infant pairs participated in the study. However, data for some time periods (i.e., 1, 2, 3, or 4 months) were missing for some mothers as a result of illness or other factors. The mothers were from the middle to upper socioeconomic stratum and had a mean age of 28.0 ± 3.1 years. A total of 41 mothers were white, 2 were Hispanic, 1 was Asian, and 1 was West Indian. Infant growth progressed satisfactorily over the course of the study.

The amount of milk ingested over a 24-hour period was determined using the test weighing procedure. Test weighing occurred over a 24-hour period for most participants, but intake among several infants was studied over longer periods (48 to 96 hours) to assess individual variation in intake. Mean breast milk intake ranged from 723 g/day (702 mL/day) at 3 months to 751 g/day (729 mL/day) at 1 month, with an overall mean of 733 g/day (712 mL/day) for the entire study period (Table 2-3). Intakes were also calculated on the basis of body weight (Table 2-3). Based on the results of test weighings conducted over 48 to 96 hours, the mean variation in individual daily intake was estimated to be 7.9 ± 3.6%.

The advantage of this study is that data for a larger number of exclusively breast-fed infants were collected than were collected by Pao et al. (1980). However, data were collected over a shorter time period (i.e., 4 months compared to 6 months) and day-to-day variability was not characterized for all infants.

2.2.4. Neville et al., 1988

Neville et al. (1988) studied breast milk intake among 13 infants during their first year of life. The mothers were all multiparous, nonsmoking, Caucasian women of middle to upper socioeconomic status living in Denver, CO. All the women in the study practiced exclusive breast-feeding for at least 5 months. Solid foods were introduced at a mean age of 7 months. Daily milk intake was estimated by the test weighing method, with corrections for insensible weight loss. Data were collected daily from birth to 14 days, weekly from weeks 3 through 8, and monthly until the study period ended at 1 year after inception. The estimated breast milk intakes for this study are listed in Table 2-4. Mean breast milk intakes were 770 g/day (748 mL/day), 734 g/day (713 mL/day), 766 g/day (744 mL/day), and 403 g/day (391 mL/day) at 1, 3, 6, and 12 months of age, respectively.

Compared with the previously described studies, data were collected in this study on numerous days over a relatively long time period (12 months), and they were corrected for insensible weight loss. However, the intake rates presented in Table 2-4 are estimated, based on intake during only a 24-hour period. Consequently, these intake rates are based on short-term data that do not account for day-to-day variability among individual infants. Also, a smaller number of subjects was included than in the previous studies.

2.2.5. Dewey et al., 1991a, b

The Davis Area Research on Lactation, Infant Nutrition, and Growth (DARLING) study was conducted in 1986 to evaluate growth patterns, nutrient intake, morbidity, and activity levels in infants who were breast-fed for at least the first 12 months of life (Dewey et al., 1991a, b). Seventy-three infants aged 3 months were included in the study. At subsequent time intervals, the number of infants was somewhat lower as a result of attrition. All infants in the study were healthy and of normal gestational age and weight at birth, and they did not consume solid foods until after the first 4 months of age. The mothers were from the Davis area of California and were highly educated and of "relatively high socioeconomic status."

Breast milk intake was estimated by weighing the infants before and after each feeding and correcting for insensible water loss. Test weighings were conducted over a 4-day period every 3 months. The results of the study indicate that breast milk intake declined over the first 12 months of life. This decline was associated with the intake of solid food. Mean breast milk intake was estimated to be 812 g/day (788 mL/day) at 3 months and 448 g/day (435 mL/day) at 12 months (Table 2-5). Based on the estimated intakes at 3 months of age, variability between

individuals (coefficient of variation ([CV] = 16.3%) was higher than individual day-to-day variability ([CV] = 5.4%) for the infants in the study (Dewey et al., 1991a).

The advantages of this study are that data were collected over a relatively long time period (4 days) at each test interval, which would account for some day-to-day infant variability, and corrections for insensible water loss were made.

2.3. STUDIES ON LIPID CONTENT AND FAT INTAKE FROM BREAST MILK

Human milk contains over 200 constituents including lipids, various proteins, carbohydrates, vitamins, minerals, and trace elements as well as enzymes and hormones. The lipid content of breast milk varies according to the length of time that an infant nurses, and it increases from the beginning to the end of a single nursing session (NAS, 1991). The lipid portion accounts for approximately 4% of human breast milk (39 ± 4.0 g/L) (NAS, 1991). This value is supported by various studies that evaluated lipid content from human breast milk. Several studies also estimated the quantity of lipid consumed by breast-feeding infants. These values are appropriate for performing exposure assessments for nursing infants when the contaminant(s) have residue concentrations that are indexed to the fat portion of human breast milk.

2.3.1. Butte et al., 1984

Butte et al., (1984) analyzed the lipid content of breast milk samples taken from women who participated in a study of breast milk intake among exclusively breast-fed infants. The study was conducted with over 40 women during a 4-month period. The mean lipid content of breast milk at various infants' ages is presented in Table 2-6. The overall lipid content for the 4-month study period was 34.3 ± 6.9 mg/g (3.4%). The investigators also calculated lipid intakes from 24-hour breast milk intakes and the lipid content of the human milk samples. Lipid intake was estimated to range from 23.6 g/day (3.8 g/kg-day) to 28.0 g/day (5.9 g/kg-day).

The number of women included in this study was small, and these women were selected primarily from middle to upper socioeconomic classes. Thus, data on breast milk lipid content from this study may not be entirely representative of breast milk lipid content among the U.S. population. Also, these estimates are based on short-term data, and day-to-day variability was not characterized.

2.3.2. Maxwell and Burmaster, 1993

Maxwell and Burmaster (1993) used a hypothetical population of 5000 infants between birth and 1 year of age to simulate a distribution of daily lipid intake from breast milk. The hypothetical population represented both bottle-fed and breast-fed infants aged 1 to 365 days. A distribution of daily lipid intake was developed, based on data in Dewey et al. (1991b) on breast milk intake for infants at 3, 6, 9, and 12 months and breast milk lipid content and survey data in Ryan et al. (1991) on the percentage of breast-fed infants under the age of 12 months (i.e., approximately 22%). A model was used to simulate intake among 1113 of the 5000 infants that were expected to be breast-fed. The results of the model indicated that lipid intake among nursing infants under 12 months of age can be characterized by a normal distribution with a mean of 26.8 g/day and a standard deviation of 7.4 g/day (minimum intake was 1 g/day, maximum intake was 51.5 g/day). The model assumes that nursing infants are completely breast-fed and does not account for infants who are breast-fed longer than 1 year. Based on data collected by Dewey et al. (1991b), the investigators estimated the lipid content of breast milk to be 36.7 g/L at 3 months (35.6 mg/g or 3.6%) and 40.2 g/L (39.0 mg/g or 3.9%) at 12 months.

The advantage of this study is that it provides a "snapshot" of daily lipid intake from breast milk for breast-fed infants. However, these results are based on a simulation model, and there are uncertainties associated with the assumptions made. The estimated mean lipid intake rate represents the average daily intake for nursing infants under 12 months of age. These data are useful for performing exposure assessments when the age of the infant cannot be specified (i.e., 3 months or 6 months). Also, because intake rates are indexed to the lipid portion of the breast milk, they may be used in conjunction with residue concentrations indexed to fat content. However, the study did not generate "new" data. A reanalysis of previously reported data on breast milk intake and breast milk lipid intake were provided.

2.4. OTHER FACTORS

Other factors associated with breast milk intake include the frequency of breast-feeding sessions per day, the duration of breast-feeding per event, the duration of breast-feeding during childhood, and the magnitude and nature of the population that breast-feeds.

2.4.1. Population of Nursing Infants

According to the National Academy of Sciences (NAS), the percentage of breast-feeding women has changed dramatically over the years (NAS, 1991). The Ross Products Division of Abbott Laboratories conducted a large national mail survey in 1995 to determine patterns of

breast feeding during the first 6 months of life. The Ross Laboratory Mothers's Survey was first developed in 1955 and has since been expanded to include many more infants. Before 1991, the survey was conducted on a quarterly basis, and approximately 40,000 to 50,000 questionnaires were mailed each quarter (Ryan, 1997). Beginning 1991, the survey was conducted monthly; 35,000 were mailed each month. Over time, the response rate has been consistently in the range of 50 ± 5%. In 1989 and 1995, 196,000 and 720,000 questionnaires were mailed, respectively. Ryan (1997) reported rates of breast-feeding through 1995 and compared them with rates in 1989.

The survey demonstrates recent increases in both the initiation of breast-feeding and continued breast-feeding at 6 months of age. Table 2-7 presents the proportion of breast-feeding in hospitals and at 6 months of age by selected demographic characteristics. In 1995, the incidence of breast-feeding at birth and at 6 months for all infants was approximately 60% and 22%, respectively. The largest increases in the initiation of breast-feeding between 1989 and 1995 occurred among women who (1) were Black, were < 25 years of age, were in the < $10,000 income level, had no more than grade school education, and were living in the South Atlantic region of the U.S.; (2) had infants of low birth weight; (3) were employed full time outside the home at the time they received the survey; and (4) participated in the Women, Infants, and Children (WIC) program. In 1995, as in 1989, the initiation of breast-feeding was highest among women who were > 35 years of age, in the > $25,000 income group, and college educated; women who did not participate in the WIC program; and women who were living in the Mountain and Pacific regions of the U.S.

Data on the actual length of time that infants continue to breast-feed beyond 5 or 6 months are limited (NAS, 1991). However, Maxwell and Burmaster (1993) estimated that approximately 22% of infants under 1 year of age are breast-fed. This estimate is based on a reanalysis of the survey data in Ryan et al. (1991) collected by Ross Laboratories (Maxwell and Burmaster, 1993).

2.4.2. Intake Rates Based on Nutritional Status

Information on differences in the quality and quantity of breast milk consumed on the basis of ethnic or socioeconomic characteristics of the population is limited. Lönnerdal et al. (1976) studied breast milk volume and composition (nitrogen, lactose, proteins) among underprivileged and privileged Ethiopian mothers. No significant differences were observed between the data for these two groups. Similar data were observed for well-nourished Swedish mothers. Lönnerdal et al. (1976) stated that these results indicate that breast milk quality and quantity are not affected by maternal malnutrition. However, Brown et al. (1986a, b) noted that the lactational capacity and energy concentration of marginally nourished women in Bangladesh were "modestly less than in better-nourished mothers." Breast milk intake rates for infants of marginally-nourished women in this study were 690 ± 122 g/day at 3 months, 722 ± 105 g/day at 6 months, and 719 ± 119 g/day at 9 months of age (Brown et al., 1986a). Brown et al. (1986a) observed that breast milk from women with larger measurements of arm circumference and triceps skinfold thickness had higher concentrations of fat and energy than mothers with less body fat. Positive correlations between maternal weight and milk fat concentrations were also observed. These results suggest that milk composition may be affected by maternal nutritional status.

2.5. RECOMMENDATIONS

The studies described in this section were used in selecting recommended values for breast milk intake, fat content and fat intake, and other related factors. Although different survey designs, testing periods, and populations were used in the studies to estimate intake, the mean and standard deviation estimates reported in these studies are relatively consistent. There are, however, limitations with the data. Data are not available for infants under 1 month of age. This subpopulation may be of particular concern, because a larger number of newborns are totally breast-fed. In addition, with the exception of Butte (1984), data were not presented on a body weight basis. This is particularly important because intake rates may be higher on a body-weight basis for younger infants. Also, the data used to derive the recommendations are more than 10 years old, and the sample sizes of the studies were small. Other subpopulations of concern, such as mothers highly committed to breast-feeding—sometimes for periods longer than 1 year—may not be captured by the studies presented in this chapter. Further research is needed to identify these subgroups and to get better estimates of breast milk intake rates. Table 2-8 presents the confidence rating for breast milk intake recommendations.

2.5.1. Breast Milk Intake

The breast milk intake rates for nursing infants that have been reported in the studies described in this section are summarized in Table 2-9. Based on the combined results of these studies, 742 mL/day is recommended to represent an average breast milk intake rate, and 1033 mL/day represents an upper-percentile intake rate (based on the middle range of the mean plus 2 standard deviations) for infants between the ages of 1 and 6 months of age. The average value is the mean of the average intakes at 1, 3, and 6 months from the key studies listed in Table 2-9. It is consistent with the average intake rate of 718 to 777 mL/day estimated by NAS (1991) for infants during the first 4 to 5 months of life. Intake among older infants is somewhat lower, averaging 427 mL/day for 12-month-olds (Neville et al. 1988; Dewey et al. 1991a, b). When a time-weighted average is calculated for the 12-month period, average breast milk intake is approximately 688 mL/day, and upper-percentile intake is approximately 980 mL/day. Table 2-10 summarizes these recommended intake rates.

2.5.2. Lipid Content and Lipid Intake

Recommended lipid intake rates are based on data from Butte et al. (1984) and Maxwell and Burmaster (1993). Butte et al. (1984) estimated that average lipid intake ranges from 23.6 ± 7.2 g/day (22.9 ± 7.0 mL/day) to 28.0 ± 8.5 g/day (27.2 ± 8.3 mL/day) in infants between 1 and 4 months of age. These intake rates are consistent with those reported by Maxwell and Burmaster (1993) of 26.8 ± 7.4 g/day (26.0 ± 7.2 mL/day) for infants under 1 year of age. Therefore, the recommended breast milk lipid intake rate for infants under 1 year of age is 26.0 mL/day, and the upper-percentile value is 40.4 mL/day (based on the mean plus 2 standard deviations). The recommended value for breast milk fat content is 4.0% based on data from NAS (1991), Butte et al. (1984), and Maxwell and Burmaster (1993).

Table 2-1. Daily intakes of breast milk

Age	Number of infants	Mean ± SD (mL/day)[a]	Intake Range (mL/day)
Completely breast-fed			
1 month	11	600 ± 159	426–989
3 months	2	833	645–1,000
6 months	1	682	616–786
Partially breast-fed			
1 month	4	485 ± 79	398–655
3 months	11	467 ± 100	242–698
6 months	6	395 ± 175	147–684
9 months	3	< 554	451–732

[a] Data expressed as mean ± standard deviation.

Source: Pao et al., 1980

Table 2-2. Breast milk intake for infants aged 1 to 6 months

Age (months)	Number of Infants	Intake	
		Mean ± SD (mL/day)	Range (mL/day)
1	16	673 ± 192	341–1003
2	19	756 ± 170	449–1055
3	16	782 ± 172	492–1053
4	13	810 ± 142	593–1045
5	11	805 ± 117	554–1045
6	11	896 ± 122	675–1096

Source: Dewey and Lönnerdal, 1983

Table 2-3. Breast milk intake among exclusively breast-fed infants during the first 4 months of life

Age (months)	Number of Infants	Intake (g/day)	Intake (g/kg-day)	Body Weight[a] (kg)
		Mean ± SD	Mean ± SD	
1	37	751.0 ± 130.0	159.0 ± 24.0	4.7
2	40	725.0 ± 131.0	129.0 ± 19.0	5.6
3	37	723.0 ± 114.0	117.0 ± 20.0	6.2
4	41	740.0 ± 128.0	111.0 ± 17.0	6.7

[a] Calculated by dividing breast milk intake (g/day) by breast milk intake (g/kg-day).

Source: Butte et al., 1984

Table 2-4. Breast milk intake during a 24-hour period

Age (days)	Number of Infants	Intake (g/day)	
		Mean ± SD	Range
1	7	44 ± 71	–31–149 [a]
2	10	182 ± 86	44–355
3	11	371 ± 153	209–688
4	11	451 ± 176	164–694
5	12	498 ± 129	323–736
6	10	508 ± 167	315–861
7	8	573 ± 167	406–842
8	9	581 ± 159	410–923
9	10	580 ± 76	470–720
10	10	589 ± 132	366–866
11	8	615 ± 168	398–934
14	10	653 ± 154	416–922
21	10	651 ± 84	554–786
28	13	770 ± 179	495–1144
35	12	668 ± 117	465–930
42	12	711 ± 111	554–896
49	10	709 ± 115	559–922
56	13	694 ± 98	556–859
90	12	734 ± 114	613–942
120	13	711 ± 100	570–847
150	13	838 ± 134	688–1173
180	13	766 ± 121	508–936
210	12	721 ± 154	486–963
240	10	622 ± 210	288–1002
270	12	618 ± 220	223–871
300	11	551 ± 234	129–894
330	9	554 ± 240	120–860
360	9	403 ± 250	65–770

[a] Negative value due to insensible water loss correction.

Source: Neville et al., 1988

Table 2-5. Breast milk intake estimated by the Darling Study

Age (months)	Number of Infants	Intake
		Mean ± SD
3	73	812 ± 133
9	60	769 ± 171
9	50	646 ± 217
12	42	448 ± 251

Source: Dewey et al., 1991b

Table 2-6. Lipid content of human milk and estimated lipid intake among exclusively breast-fed infants

Age (months)	Number of Observations	Lipid Content (mg/g)	Lipid Content % [a]	Lipid Intake (g/day) Mean ± SD	Lipid Intake (g/kg-day) Mean ± SD
		Mean ± SD			
1	37	36.2 ± 7.5	3.6	28.0 ± 8.5	5.9 ± 1.7
2	40	34.4 ± 6.8	3.4	25.2 ± 7.1	4.4 ± 1.2
3	37	32.2 ± 7.8	3.2	23.6 ± 7.2	3.8 ± 1.2
4	41	34.8 ± 10.8	3.5	25.6 ± 8.6	3.8 ± 1.3

[a] Percents calculated from lipid content reported in mg/g.

Source: Butte et al., 1984

Table 2-7. Percentage of mothers breast-feeding newborn infants in the hospital and infants at 5 or 6 months of age in the United States in 1989[a], by ethnic background and selected demographic variables[b]

Characteristic	Percentage of mothers breast-feeding					
	In hospital			At 6 months		
	1989	1995	Change	1989	1995	Change
All Infants	52.2	59.7	14.4	18.1	21.6	19.3
White	58.5	64.3	9.9	21.0	24.1	14.8
Black	23.0	37.0	60.9	6.4	11.2	75.0
Hispanic	48.4	61.0	26.0	13.9	19.6	41.0
Maternal age (years)						
< 20	30.2	42.8	41.7	5.6	9.1	62.5
20–24	4.2	52.6	16.4	11.5	14.6	27.0
25–29	58.8	63.1	7.3	21.1	22.9	8.5
30–34	65.5	68.1	4.0	29.3	29.0	(1.0)[b]
35+	66.5	70.0	5.3	34.0	33.8	(0.6)[b]
Total family income						
< $10,000	31.8	41.8	31.4	8.2	11.4	39.0
$10,000 – $14,999	47.1	51.7	9.8	13.9	15.4	10.8
$15,000 – $24,999	54.7	58.8	7.5	18.9	19.8	4.8
≥ $25,000	66.3	70.7	6.6	25.5	28.5	11.8
Maternal education						
Grade school	31.7	43.8	38.2	11.5	17.1	48.7
High school	42.5	49.7	16.9	12.4	15.0	21.0
College	70.7	74.4	5.2	28.8	31.2	8.3
Maternal employment						
Employed full time	50.8	60.7	19.5	8.9	14.3	60.7
Employed part time	59.4	63.5	6.9	21.1	23.4	10.9
Not employed	51.0	58.0	13.7	21.6	25.0	15.7
Birth weight						
Low (≤2,500 g)	36.2	47.7	31.8	9.8	12.6	28.6
Normal	53.5	60.5	13.1	18.8	22.3	18.6
Parity						
Primiparous	52.6	61.6	17.1	15.1	19.5	29.1
Multiparous	51.7	57.8	11.8	21.1	23.6	11.8
WIC participation						
Participant	34.2	46.6	36.3	8.4	12.7	51.2
Nonparticipant	62.9	71.0	12.9	23.8	29.2	22.7

Table 2-7. Percentage of mothers breast-feeding newborn infants in the hospital and infants at 5 or 6 months of age in the United States in 1989[a], by ethnic background and selected demographic variables[b] (continued)

Characteristic	Percentage of mothers breast-feeding					
	In hospital			At 6 months		
	1989	1995	Change	1989	1995	Change
U.S. census region						
New England	52.2	61.2	17.2	18.6	22.2	19.4
Middle Atlantic	47.4	53.8	13.5	16.8	19.6	16.7
East North Central	47.6	54.6	14.7	16.7	18.9	13.2
West North Central	55.9	61.9	10.7	18.4	21.4	16.3
South Atlantic	43.8	54.8	25.1	13.7	18.6	35.8
East South Central	37.9	44.1	16.4	11.5	13.0	13.0
West South Central	46.0	54.4	18.3	13.6	17.0	25.0
Mountain	70.2	75.1	7.0	28.3	30.3	7.1
Pacific	70.3	75.1	6.8	26.6	30.9	16.2

[a] The percent change was calculated using the following formula: % breast fed in 1984 – % breast fed in 1989 / % breast fed in 1984.

[b] Figures in parentheses indicate a decrease in the rate of breast-feeding from 1989 to 1995.

WIC = Women, Infants, and Children supplemental food program.

Source: Ryan, 1997

Table 2-8. Confidence in breast milk intake recommendations

Considerations	Rationale	Rating
Study Elements		
Level of peer review	All key studies are from peer-reviewed literature.	High
Accessibility	Papers are widely available from peer review journals.	High
Reproducibility	Methodology used was clearly presented.	High
Focus on factor of interest	The focus of the studies was on estimating breast milk intake.	High
Data pertinent to U.S.	Subpopulations of the U.S. were the focus of all the key studies.	High
Primary data	All the studies were based on primary data.	High
Currency	Studies were conducted between 1980–1997.	Medium-High
Adequacy of data collection period	Infants were not studied long enough to fully characterize day-to-day variability. With the exception of Neville et al. (1988), the measurements were made for frequency (e.g., once a month) and the data may not represent the potential first year of lactation (both for less than 1 month of age and for longitudinal measurements of more than 6 months).	Medium
Validity of approach	Methodology uses changes in body weight as a surrogate for total ingestion. This is the best methodology there is to estimate breast milk ingestion. Mothers were instructed in the use of infant scales to minimize measurement errors. Three out of the five studies corrected data for insensible water loss.	Low
Study size	The sample sizes used in the key studies were fairly small (range 13–73).	Low
Representativeness of the population	Population are representative of the general mother-infant pair population.	High
Characterization of variability	Not very well characterized. Infants under 1 month not captured, mothers committed to breast-feeding over 1 year not captured.	Low

Table 2-8. Confidence in breast milk intake recommendations (continued)

Considerations	Rationale	Rating
Lack of bias in study design (high rating is desirable)	Bias in the studies was not characterized. Two out of five studies corrected for insensible water loss.	Low
Measurement error	All mothers were well-educated and trained in the use of the scale, which helped minimize measurement error. Not correcting for insensible water loss may underestimate intake. Mothers selected for the studies were volunteers; therefore, response rate does not apply. Population studied may introduce some bias in the results (see above).	Medium
Other Elements		
Number of studies	There are five key studies.	Medium
Agreement between researchers	There is good agreement among researchers.	High
Overall Rating	Studies were well-designed. Results were consistent. Sample size was fairly low. Variability cannot be characterized due to limitations in data collection period.	**Medium**

Table 2-9. Breast milk intake rates derived from key studies

Age (months)	Mean intake (mL/day)	Number of Children	Upper Percentile (mL/day)[a]	Reference
1	600	11	918	Pao et al., 1980
	729	37	981	Butte et al., 1984
	747	13	1095	Neville et al., 1988
	673	16	1057	Dewey and Lönnerdal, 1983
	weighted avg = 702		1007[b]	
3	833	2	—	Pao et al., 1980
	702	37	923	Butte et al., 1984
	712	12	934	Neville et al., 1988
	782	16	1126	Dewey and Lönnerdal, 1983
	788	73	1046	Dewey et al., 1991b
	weighted avg = 759		1025[b]	
6	682	1	—	Pao et al., 1980
	744	13	978	Neville et al., 1988
	896	11	1140	Dewey and Lönnerdal, 1983
	747	60	1079	Dewey et al., 1991b
	weighted avg = 765		1059[b]	
9	600	12	1027	Neville et al., 1988
	627	50	1049	Dewey et al., 1991b
	avg = 622		1038	
12	391	9	877	Neville et al., 1988
	435	42	923	Dewey et al., 1991a, b
	weighted avg = 427		900	
12-month time weighted average				
688			Range 900–1059 (middle of the range 980)	

[a] Upper percentile is reported (mean plus 2 standard deviations), except as noted.
[b] Middle of the range.

Table 2-10. Summary of recommended breast milk and lipid intake rates

Age	Mean intake (mL/day)	Upper percentile (mL/day)
Breast Milk		
1–6 months	742	1033.0
12-month-average	688	980.0
Lipids[a]		
< 1 Year	26	40.4

[a] The recommended value for the lipid content of breastmilk is 4%.

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